Understanding Dengue Transmission:
Application of an Ecohealth Approach in Dhaka, Bangladesh

By
Parnali Dhar Chowdhury

A Thesis Submitted to the Faculty of Graduate Studies of
The University of Manitoba
In Partial Fulfilment of the Requirements for the Degree of

Doctor of Philosophy

Clayton H. Riddell Faculty of Environment, Earth and Resources
Natural Resources Institute
University of Manitoba
Winnipeg, Manitoba
R3T 2M6

ABSTRACT

Affected by unprecedented urban growth, overcrowding, poverty, and health inequalities, Bangladesh has remained hyperendemic for dengue since 2000. Considering the complexities involved with dengue transmission, I argued that understanding transmission requires encapsulating different disciplinary knowledge as well as non-academic knowledge. I have applied an Ecohealth approach to investigate dengue transmission dynamics in Dhaka, Bangladesh.

Using the Delphi method, all 90 Wards of Dhaka were classified into 'high', 'medium', and 'low' Socio-Economic Status (SES) zones. A total of 1,200 households were randomly selected which represented the SES zones. During 2011-2012, these sampled households were repeatedly inspected for *Aedes* mosquitoes and to collect blood samples from residing members. This transdisciplinary investigation focused on: i) the rates of human exposure to dengue virus (DENV) by identifying individuals with IgM and IgG antibodies in the serosurvey samples; ii) abundance of dengue vector mosquitoes (*Aedes aegypti*) in the same households; iii) risk perception, and Knowledge, Attitude and Practice (KAP) regarding dengue among community members and experts.

KAP survey results indicated that 93.7% of the community members knew that mosquitoes act as the primary vector of its transmission; 87.3% were unaware that *Aedes* mosquitoes prefer to lay their eggs in water containers. The entomological survey results showed that 26.7% of all surveyed houses in the city were infested with *Aedes aegypti* mosquitoes. The ornamental functional categories of containers were most significant containers in producing maximum number of *Aedes* pupae; this was found to be a significant risk factor for seroprevalence and seroconversion. The examination of IgG seroprevalence revealed that seropositivity was strongly correlated with increased age and number of indoor potted plants. The serosurvey findings showed that seroprevalence was high (79.9%), revealing that most dwellers had been exposed DENV. However, there was no significant association between *Aedes* positive houses and houses with seroconverted persons, indicating that people were being infected in distant areas outside their houses.

A persistently high rate of dengue infection in Dhaka is being influenced by the lack of knowledge and awareness of the eco-bio-social factors. Improvement in intersectoral coordination to formulate and implement dengue epidemic prevention and control interventions is necessary.

ACKNOWLEDGEMENTS

I take this opportunity to gratefully acknowledge the support and cooperation of many individuals and institutions during the course of my doctoral study. My biggest thanks must go to the research participants of the city of Dhaka, Bangladesh who let me enter into their homes, gave their blood, allowed me to snoop around their house and yards for mosquitoes, and taught me so much about so many things. They added a wider perspective to the study by sharing information and knowledge regarding mosquito breeding and abundance, dengue disease, and risk perception of dengue.

My advisor Dr. C. Emdad Haque (Professor, Natural Resources Institute-NRI) has been very supportive throughout the process. Starting from the conceptualization of the research proposal to finalization of the thesis, he has remained a constant source of guidance and encouragement. Thank you, Dr. Haque, for your unflagging support and flexibility during both good and difficult times - and offering your wisdom and experience. My sincere thanks to Dr. Michael A. Drebot (Director, Science Technology and Core Services and Chief of Viral Zoonosis, Zoonotic Diseases and Special Pathogen-ZDSP) of National Microbiology Laboratory (NML) of Public Health Agency of Canada, Winnipeg, for his unconditional mentorship, academic and professional help, and keeping faith on me that with nominal experience of laboratory experience in zoonotic diseases, I would be able to perform successfully any kind of serological diagnostic works for my thesis research. My special gratitude and thanks go to Dr. Robbin Lindsay (Research Scientist, Field Studies and ZDSP of NML), who not only provided leadership in conducting multi-year entomological surveys in very challenging conditions in Bangladesh but also gave me enormous inspiration to carrying out the thesis research all the way. Throughout my journey, I was extremely fortunate to receive immense support from Dr. Stephane Mclachlan (Professor, Department of Environemnt and Geography) as one of my thesis research advisory committee members during my masters as well as doctoral research process, and to obtain his broad and insightful perspectives on social and ecological parts of the thesis. I am very thankful to you, Dr. Mclachlan for your kind support and encouragement.

I would like to offer my sincere gratitude to all my colleagues in the viral zoonoses and special pathogen section of NML for their support, guidance, and advice. Special thanks to Antonia Dibernardo - a wonderful personality with the philosophy of helping others always - taught me to take things ‘easy’ during difficult times. I am also grateful to Antonia for performing some critical serological diagnostic tests with me and providing me mentorship during my lab work. I would also like to thank sincerely Kai Makowski for being my lab instructor and proving me unconditional supports to the process of completion of some serological works. As well, I would like to acknowledge Nicole Barairo and Kimberly Holloway for helping me in laboratory diagnostic tests. I would also like to thank the following NML staff at ZDSP section: Maya Andonova, Kristina Dimitrova, and Dorothy McColl.

Heart-felt thanks to Dr. G.U. Ahsan (North South University) and Dr. Andres Sanchez (International Development Research Centre, Ottawa), Dr. Shakhawat Hossian (University of

Winnipeg) for their constructive, thoughtful, and valuable inputs and comments on my research. Special thank to Dr. Shakhawat Hossian for providing me the statistical inputs and feedbacks. I appreciate Population Services Training Center- an NGO in Dhaka - for their kind assistance in introducing me to different communities, and government entomological technicians of Ministry of Health in Bangladesh for completion of the entomological surveys over a three season during 2011-2013. I am very thankful to icddr,b (Dr. Abdullah Brooks and Dr. Kishor Paul) in Dhaka for their unconditional support and commitment in completion of city-wide serological surveys during three seasons (2012-2013). My heartfelt thanks go to all the faculty members, students, support and administrative staffs of the Department of Public Health, North-South University, Bangladesh, for their assistance and support during my field work in Dhaka.

The Natural Resources Institute, University of Manitoba is an excellent place to engage in interdisciplinary scholarly research. I had the best support from the faculty and staff members during my tenure at the institute. The students at the institute are amazing and I could not have expected to be in a better company than this. I am proud to be a part of the Natural Resources Institute. I would like to thank the following NRI administrative staff: Tamara Keedwell, Dalia Naguib, and Shannon Wiebe. I would also like to extend my sincere thanks to Jason Northage (IT specialist, C.H.R.faculty of Environment, Earth, and Resources) for his technical support. Mohammed Hasan Mahmud (NRI) assisted me in drawing some figures and maps skillfully and he also developed the software structure to manage huge dataset of the project from which it was easier for me to manage and analyze my part of the project data.

My work has been supported by the Ecohealth Program of the International Development Research Centre, Ottawa, Canada; the Graduate Scholarship from Manitoba Health Research Council, Canada; and a Doctoral Research Award by International Development Research Centre, Ottawa. I would also like to thank Dr. Emdad Haque (NRI) and Dr. Michael Drebot (Zoonotic Diseases and Special Pathogens, NML) for their financial supports. I gratefully acknowledge all these financial supports without which this work would not have been possible. I would also like to thank Faculty of Graduate Studies, University of Manitoba Graduate Students Association, C.H.R. Faculty of Earth, Environment, and Resources, and NRI travel grants for providing me with necessary resources to disseminate successfully my results within and outside Canada.

I have benefited from numerous discussions with colleagues at the Ecohealth Program personnel of the International Development Research Centre, Ottawa, University of Wisoconsin-Madison, and University of Northern British Columbia during my participation in CoPeh-Can and One health course.

I am grateful to my family who sacrificed a lot for me. Thank you to all my family members for being very understanding and fully supportive of the fact that I was unable to stay by their side even at the moment they needed me the most. Finally, my parents, Poly Dhar Chowdhury and Rana Dhar Chowdhury deserve the best of my gratitude for always being there and praying for my success.

Parnali Dhar Chowdhury, Winnipeg, Manitoba, March 2015

Dedicated to-

All my teachers, those who hold the supreme art *“to awaken joy in creative expression and knowledge”* (Albert Einstein) among their pupils and being I was one of such fortunate ones……

TABLE OF CONTENTS

CHAPTER FOUR
SOCIOECONOMIC AND ECOLOGICAL FACTORS INFLUENCING *AEDES AEGYPTI* ABUNDANCE

CHAPTER FIVE
SEROEPIDEMIOLOGY AND SOCIOECONOMIC RISK FACTORS

CHAPTER SIX
SPATIAL EVALUATION OF DENGUE VECTOR ABUNDANCE AND ITS ASSOCIATION WITH SEROCONVERSION

CHAPTER SEVEN

ROLE OF KNOWLEDGE, RISK PERCEPTION AND ATTITUDES, AND PRACTICES IN DENGUE TRANSMISSION

CHAPTER EIGHT
TOWARDS UNDERSTANDING DENGUE TRANSMISSION: INTEGRATION FOR TRANSDISCIPLINARY KNOWLEDGE DEVELOPMENT

CHAPTER NINE
SYNTHESIS AND CONCLUSIONS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

GLOSSARY OF TERMS

Biomedical Approach: A conceptual notion of illness that is grounded on positivist (systemic scientific) philosophical orientation and excludes psychological and social factors. It therefore includes only biologic factors in an attempt to understand a person's medical illness or disorder.

Breateau Index: For entomologic surveillance Breatau Index is a larval index which has been based on number of positive containers per 100 houses (Sanchez et al., 2006).

Container Index: For entomologic surveillance Container Index is a larval index which has been based on percentage of containers positive for *Aedes* larvae (Sanchez et al., 2006).

Complex Systems Thinking: It assumes that human life exists within a context of systems that are complex-that is, systems characterized by self-organization and emergent properties and in which the whole is greater than the sum of the parts (Robinson, 2009).

Dengue Fever: Dengue fever is most commonly an acute febrile illness defined by the presence of fever and two or more of the following, retro-orbital or ocular pain, headache, rash, myalgia, arthralgia, leukopenia, or hemorrhagic manifestations but not meeting the case definition of dengue hemorrhagic fever. Anorexia, nausea, abdominal pain, and persistent vomiting may also occur but are not case-defining criteria for dengue fever (CDC, 2009).

Dengue Hemorrhagic Fever: With fever lasting from 2-7 days, dengue hemorrhagic fever is characterized by thrombocytopenia ($\leq$100,000 cells per mm^3) and with the evidence of plasma leakage shown by hemoconcentration (an increase in hematocrit $\geq$20% above average for age or a decrease in hematocrit $\geq$20% of baseline following fluid replacement therapy), or pleural effusion, or hypoproteinemia (CDC, 2009).

Dengue Shock Syndrome: Dengue shock syndrome is characterized by rapid and weak pulse and narrow pulse pressure (<20mm Hg), or age-specific hypotension and cold, clammy skin and restlessness (CDC, 2009).

Eco-bio-social Determinants: Ecological, biological and social factors determine dengue vector densities and contribute to viral transmission (Arunachalam et al., 2010).

Ecohealth Approach: An integrative, systemic, participatory approach to understanding and promoting health and wellbeing in the context of social andecological interactions. It applies an ecosystem approach to health (Waltner-Toews, 2009).

House Index: For entomologic surveillance House Index is a larval index which has been based on percentage of house positive for *Aedes* larvae (Sanchez et al., 2006).

Human *Agency*: In sociological sense, it refers to the ability of human individuals who proactively undertake actions, beyond the domain of nature. Thus, the emphasis is placed upon the free will of humans as an active agent (Giddens, 2013).

IgG/IgM ELISA: Qualitative detection of Immunoglobulin G (IgG) or Immunoglobulin M (IgM) antibodies in serum for the presumptive clinical laboratory diagnosis of dengue virus infection in patients with clinical symptoms consistent with dengue fever or dengue hemorrhaghic fever.

Key Informant Interviews: Qualitative in-depth interviews to collect information from a wide range of selected people-including community leaders, professionals, or residents-who have first hand knowledge about the community (Lavrakas, 2008).

Mental Model: General concept used to describe a cognitive mechanism for representing and making inferences about a system or problem. It is illustrated by drawing influence diagrams showing the causal linkages between elements (Borgman, 1984).

Plaque Reduction Neutralization Test (PRNT): This serological assay is used to distinguish between related arboviruses by determining the presence of neutralizing antibody in infected human serum. Determination of recent infection by demonstration of four-fold increase in neutralizing antibody level between an acute and convalescent sera (Viral Zoonoses and Special Pathogen of National Microbiology Laboratoty in house protocol, 2010).

Polymerase Chain Reaction (PCR): PCR is a technology in molecular biology used to amplify a single copy or a few copies of a piece of DNA across several orders of magnitude, gathering thousands to millions of copies of a particular DNA sequence (GeneReviews Illustrated Glossary, 2013).

Self-Organizing Holarchic Open system: In the context of complex systems thinking, the dynamics of ecosystems and human systems are predominated by both positive and negative feedback processes operating over a range of spatial and temporal scales (Kay et al., 1999).

Social-ecological Systems: Social-ecological systems consider a holistic approach by integrating natural systems and human systems together, and thereby humans are regarded as constituent part of nature (Berkes and Folke, 1998).

Transdisciplinarity: Transdisciplinarity in knowledge and practice is rooted in the Latin prefix 'trans' which denotes transgressing the boundaries defined by traditional disciplinary modes of enquiry. It is usually reflected in them as more than the sum of disciplinary components and the approaches are not the 'mixing of disciplines' (i.e. interdisciplinary approach) but are the 'fusion of disciplines' (Charron, 2012).

CHAPTER ONE

INTRODUCTION

1.1 Introduction to the Problem

Globally, vector-borne diseases are becoming an increasingly significant public health problem, with several 'old' diseases seeing a resurgence in recent years (Ellis and Wilcox, 2009). Most prominent among these had been Dengue. Both dengue fever (DF) and dengue hemorrhagic fever (DHF) are characterized by a very complex epidemiology, resulting from the underlying biotic and abiotic determinants in the human-environmental system (also known as the social-ecological system, or SES). Though dengue is regarded as among the most serious infectious diseases, it has resurfaced due to the failure of traditional reductionist approaches to understanding its transmission process and controlling its vectors (e.g. *Aedes aegypti* and *Aedes albopictus* mosquitos) through sector-oriented interventions. Challenging these reductionist notions[1] are critical theories that advocate 'complex system thinking' with regards to disease processes, focusing on the interactions between various elements of human-environment system.

In the context of 'Post-Normal Science', which is grounded in 'complex systems thinking', the human-environment system is the portrayal of a Self-Organizing Holarchic Open (SOHO) system whose dynamics are predominated by both positive and negative feedback processes (Kay et al., 2000). Therefore, an accurate model of disease emergence should encompass both socio-economic and bio-physical parameters, and the interactions of the virus-vector-host nexus operating over a range of spatial and temporal scales.

[1] Reductionism is a philosophical view which holds that entities of a given kind are collections or combinations ofsimpler or more basic entities, or that expressions denoting such entities are definable in terms of expressions denoting the more basic entities.

Research on the impacts of ecological and environmental factors on dengue transmission and resurgence have shown that the dengue virus (DENV), vector, host populations and ecosystem interact within the complex SES (Despommier et al., 2006; Koopman and Longini, 1994). However, because these studies generally treated vector abundance, virus circulation, and dengue transmission as separate factors, with little regard to their interactions within the SES, they did not succeed in producing an accurate, complex epidemiological model of dengue transmission.

My thesis research is based on the notion that dengue disease transmission requires the development of a holistic epistemology that can assess the driving eco-bio-social factors and their interaction with human action (Ooi and Gubler, 2009; Spigel et al., 2005; Wilcox and Colwell, 2005). The expectation that new vaccines and anti-viral drugs would single-handedly prevent dengue outbreaks has thus far been frustrated by the increasing complexity of dengue's epidemiology. My study attempts to apply a holistic, transdisciplinary "Ecohealth Approach" to identifying key factors in dengue transmission, such as the role of human action in determining the course of outbreaks.

The Ecohealth approach views human beings as an integral part of ecosystems and argues that 'systems thinking' is necessary for understanding both human and ecosystem health (Lebel, 2003; Dakubo, 2010). This approach recognizes that human health is influenced and conditioned by a nested hierarchy of eco-bio-social factors ranging from the individual to the planetary level.

My study focuses on the multi-level driving factors of dengue transmission in Bangladesh, a rapidly-developing country in the tropics. Like many low-income, developing countries, Bangladesh faces serious challenges in the face of emerging infectious diseases, extreme poverty, and environmental degradation. By studying the dynamics of disease transmission in such an environment, a better understanding of the eco-bio-social complexity of infectious outbreaks - and better methods for countering them in a resource-constrained society - can be obtained (Arthur & McNicoll, 1978).

In this dissertation, my thesis is that obtaining an accurate model of dengue transmission may not be possible using a purely reductionist approach. It is also necessary to consider the complex interactions between various key factors, including the effects of human choices and actions.

I believe the key to understanding dengue epidemiology lies not only in the individual eco-bio-social factors driving transmission, but in the complex interactions between these factors; and that integrating these factors with human perception, action, and institutions provides the best approach to controlling dengue outbreaks in an effective, participatory manner.

1.2 Purpose of the Study

The overall purpose of the study is a) to determine the eco-bio-social factors responsible for dengue transmission; and b) to enhance our conceptual understanding of dengue transmission in a developing country setting by employing a transdisciplinary, holistic epistemological framework.

1.3 Research Objectives

The specific research objectives are to:

1) Identify socioeconomic and ecological factors influencing dengue vector abundance in the city of Dhaka.

2) Examine the seroprevalence of dengue virus and socio economic risk factors.

3) Evaluate spatial dimensions of dengue vector abundance and its association with seroconversion.

4) Assess the role of knowledge, risk perceptions and attitudes, and practices in dengue transmission.

1.4 Worldwide Distribution of Dengue

There are three commonly-cited candidates for the first recorded dengue outbreak. The first recorded case of a disease matching dengue's profile was recorded in China in 610 A.C. (Gubler, 1998), while the first likely outbreak occurred in the French West Indies in 1635 (Gubler, 1998). The most commonly cited origin for dengue, however, was in Philadelphia in the summer of 1779 (Gubler and Clark, 1995; Holmes and Twiddy, 2003). There is disagreement as to the specific origin of the dengue virus, which is thought to be either Africa or Asia. This confusion originates from the discovery of non-human primate carriers of DENV in sylvatic environments on both continents; the direction of the expansion it is unclear (Holmes and Twiddy, 2003).

There were at least four recorded dengue-like epidemics in the Americas during early 19th century (Pinheiro and Nelson, 1996). Asia saw similar instances of non-fatal epidemics at 10-40 year intervals (Gubler, 1998). Widespread movements of troops and refugees during and after World War II introduced vectors and viruses into many new areas, and this trend has continued (Calisher, 2005). By the end of 20th century, annual epidemics of dengue were occurring in any parts of Central and South America (Rodriguez-Roche et al., 2005) and throughout the Pacific Islands (Effler et al., 2005) and South East Asia, with occasional outbreaks in North Australia and Africa. The negative impact of World War II on the South East Asian environment was likely the key event that triggered the emergence of the modern, virulent strain of dengue.

Hyperendemicity and expanded DENV epidemics in the region were the prelude to the first confirmed worldwide epidemics of DHF, which later became established as an emerging global disease. The first outbreak of virulent DHF is thought to have occurred in Manila, Philippines in 1953–1954 (Gubler, 1998); however, according to Halstead (1990), non-confirmed DHF epidemics had already previously appeared in Australia in 1897 and Greece in 1928. Following the 1953 Manila epidemic, DHF spread throughout Asia, starting in the Southeast and gradually spreading northwards.

The first DHF outbreak in the Americas was reported in Cuba in 1981. 10,300 cases were registered, of which 158 were fatal. The second large epidemic took place in Venezuela in 1989, with 2,665 reported cases. According to the WHO Denguenet, from 1960 onwards Cuba and Venezuela were the two countries with the greatest number of reported dengue cases (WHO, 2009). In 1998, the largest epidemics in history occurred throughout Asia and the Americas, with more than 1.2 million cases of DF/DHF reported to the WHO.

At the beginning of twenty-first century, dengue has become the most important emerging arboviral disease in humans (Gubler, 2002). Between 2000 and 2007, at least eight previously dengue-free areas have experienced outbreaks, including Hong Kong, Macau, Nepal, Bhutan, Madagascar, Hawaii, Galapagos, and Easter Island (Wilder-Smith and Schwartz, 2005). Multiple dengue viruses have been endemic in South-east Asia for years (Halstead, 2007). Manila, Philippines recorded the first dengue outbreak in 1953, with a second outbreak two years later in 1956 (Gubler, 1997; Ooi and Gubler, 2009). Bangkok saw an epidemic in 1958 although sporadic cases of DHF were identified in Thailand throughout the 1950s (Halstead, 1990). Multiple factors have contributed to this increased prevalence, including increases in vector density, co-circulation of multiple dengue serotypes, and the aforementioned endemicity of DHF in multiple countries (Guzman & Kouri, 2002).

1.5 The Dengue Problem in Bangladesh: Field Context of the City of Dhaka

Bangladesh is a tropical country in south central Asia, with a population of 150 million crowded in an area of 143,000 sq. km. Its closest neighbors are India, Nepal, Myanmar and Thailand (Streatfield & Karar, 2008). Except for a handful of isolated cases, Dengue remained generally unrecognized in Bangladesh until the 1990s (Yunus et al., 2001). The first official cases of dengue fever, popularly known as 'Dacca fever' (Aziz et al., 1967) in Bangladesh, were recorded in the mid 1960s and the mid-1990s. Dengue infection was confirmed by the 1996-97 Integrated Control of Vector-Borne Disease (ICOVED) Project of the Directorate-General of Health Services, in collaboration with WHO (Yunus et al., 2001). As well as confirming the present of dengue in the country, this study also identified the risk of a future potential outbreak. Nonetheless, the population at large, the health professionals and the disease control programs of the government remained generally unfamiliar with as well as deficient in gathering knowledge of dengue in any of the associated aspects including diagnosis, management, prevention and control.

Starting in June 2000, cases of dengue hemorrhagic fever began filling urban hospitals and clinics, mostly in the cities of Dhaka, Chittagong and Khulna. Cases were reported from 17 other cities as well (Yunus et al., 2001). The outbreak ended in December of that year with a total of 5, 551 reported cases, 93(1.6%) fatal. Of all cases, 4, 385 were DF (78.9%) and 1, 166 were DHF (21.1%). Inadequate training, lack of specialized dengue case management knowledge among physicians, and absence of national guidelines for clinical management of dengue resulted in a high mortality rate. The proportion of DHF was lower in the city of Dhaka and the mortality rate was lower in both Dhaka and Chittagong. It was hypothesized by Yunus et al. (2001) that this discrepancy was related to the availability of better case management facilities in Dhaka compared to other cities.

As reported by Banu et al. (2012), DF incidence in Bangladesh fluctuated from 2000 to 2010, with major outbreaks in 2000 and 2002. The Directorate General of Health Services (DGHS) registered 23,872 cases of dengue fever and DHF - 233 fatal - between 2000 and 2009 (Banu et al., 2012). Due to limited access to clinics and hospitals, stemming primarily from poverty, overcrowding, economic instability, traffic congestion and other infrastructural deficiencies, dengue cases are widely believed to be underreported all across Bangladesh. From 2000-2009, the monthly incidence of DF ranged from 0 to 3,281, with the highest number of cases being reported in August 2002. An overall decreasing trend has been observed since 2002. Banu et al. (2001) asserted that although individual DF cases are reported almost constantly throughout the year, a 1-year inter-epidemic period between major outbreaks could be observed. The results of a cluster analysis of the space-time distribution of DF for the periods of 2000-2002, 2003-2005, and 2006-2009 by these investigators revealed that the district of Dhaka (urban and rural inclusive) was the 'most likely cluster', with Khulna and Chittagong being 'secondary clusters' (Banu et al., 2001; p. 1088). Rahman et al. (2002) speculated that increased adherence to national dengue guidelines and increased public awareness following the 2002 outbreak contributed to the subsequent decline in dengue transmission.

However, in the absence of scientifically-designed surveillance systems in Bangladesh (Mahmood and Mahmood, 2011), institutional responses to the DF and DHF epidemics of 2000 and 2002 relied on information available via mass media and local public health concerns expressed by elected officials (such as City Mayors and Ward Councilors) and public health personnel. Epidemic prevention and control measures therefore mainly took the form of post-facto interventions made in response to public and political pressure.

Due to Dhaka's 7% demographic growth rate, the prevalence of all dengue virus serotypes of dengue virus, and the abundance of *Aedes* mosquitoes throughout Bangladesh, both the overall risk of dengue epidemics and the seasonal incidence of dengue during each monsoon have remained high. This trend is clearly mirrored by the 2-3 year cycle of dengue resurgence in Dhaka during 2000-2010 period. However, Dengue cases were diagnosed every year in recent years. For examples, from 2005 to 2009, there were 3,130 admissions for dengue fever to the 11 hospitals located in the City of Dhaka (Haque et al., 2012; Hashizume et al., 2007).

As there is no effective vaccine or specific treatment for dengue (besides supportive care), reducing or eliminating larval habitats of the disease's principal vectors (e.g. *Aedes aegypti* mosquitoes) has become the primary tool in Dhaka City Corporation's dengue reduction efforts (Aldstadt et al., 2011). This approach triggered the development of vertically structured (i.e. top-down) governmental programs geared towards larval control in domestic water storage containers as well as the wide-scale use of insecticides. However, increasing rates of insecticide resistance in mosquitoes, homeowner resistance towards the treatment of their drinking water, and difficulties in attaining sufficient insecticide coverage has resulted in a general failure of vector and dengue disease control programs (Guzman et al., 2010), as evidenced by the reemergence of dengue in Dhaka during 2000-2010.

The 2000 dengue epidemic in Bangladesh raised a number of questions, such as i) why regular outbreaks were not observed in Bangladesh as they have been in neighboring Myanmar (Thu et al., 2004) and Thailand (Nisalak et al., 2003)? ii) Was the outbreak in 2000 caused by the appearance of a new local strain of DENV, or the introduction of strains from outside Bangladesh (Poddar et al., 2006)? Answering these questions has been consistently hampered by a lack of reliable data, resulting from inadequate surveillance systems and the nominal involvement of local communities in dengue prevention and control.

Dengue management issues have received some public policy attention in Bangladesh in recent years (Akhther et al., 2009); nonetheless, little attention has yet been paid to understanding dengue transmission processes in the country. Government policy has remained focused on patient care rather than prevention and control of dengue vectors. Prevention and control of dengue, especially through vector control or tackling ecological, biological and social factors, have generally been ignored. During the 2000 outbreak, fumigation programs were only finally launched by the authorities in response to public and media outcry. Consequently, the potential for persistently high dengue incidences rates, as well as large-scale epidemics, remains high.

1.6 Overview of Dengue Disease and Transmission

1.6.1 Dengue virus

Flaviviridae has three genera: Hepacivirus, Pestivirus and Flavivirus, the latter of which Dengue virus (DENV) is a member. There are more than 70 species of Flavivirus, including West Nile Virus (WNV), Saint Louis Virus (SLE), Yellow Fever (YFV), Murray Valley Encephalitis, Kunjin virus and Japanese Encephalitis (JEV) (Lamb et al., 2001; Mukhopadhyay et al., 2005).

There are four closely-related but antigenically distinct DENV serotypes (DENV1-4), all with similar clinical manifestations. Each serotype indices lifetime immunity against homologous DENV, and temporary/partial immunity against heterologous DENV (WHO, 1997; Lamb et al., 2001; Kuno, 1997). The virion is spherical, about 50 nm in diameter with a positive-sense, single-stranded RNA genome approximately 10,700 nucleotides in length. It comprises three structural protein genes encoding the nucleocapsid and core protein (C), a membrane associated protein (M), an envelope protein (E), and seven nonstructural protein genes: NS1, NS2A, NS2B, NS3, NS4A, NS4B and NS5. Using molecular clock techniques, it is suggested that the present DENV strain emerged about 1,000 years ago. Most phylogenies demonstrate that DENV 4 is the most divergent serotype, followed by DENV2, DENV 3 and DENV 1 (Twiddy et al., 2003).

1.6.2 Dengue vector

Aedes mosquitoes, the primary DENV vector for humans, belong to the subgenus Stegomyia. *Aedes aegypti* (or *Ae. aegypti*) is considered to be the principal dengue vector, and *Aedes albopictus (or Ae. albopictus*) the secondary (Kuno 1997; Nagao et al., 2003). However, *Ae*.

aegypti has demonstrated greater viral transmission efficiency as it has adapted to live within human communities, sharing resting areas and using water stored by humans to host their larvae. This is in contrast to *Ae. albopictus*, which although a more aggressive vector, usually maintains larval development sites farther away from human settlements. It is believed that *Ae. aegypti* originated in the tropical forests of Africa and likely spread around the globe aboard trading ships during the seventeenth to nineteenth centuries (Gubler and Kuno, 1997). There are also forest-dwelling *Aedes* mosquitoes in Africa and Southeast Asia, responsible for a sylvatic cycle of DENV involving mainly nonhuman primates.

Understanding the life cycle of *Aedes* mosquitoes is important as they change dramatically in shape, capabilities, and habitat throughout. Female mosquitoes lay their eggs on damp surfaces in water-holding containers. Larva emerge from the eggs and pass through four instars, the duration of each of which depends on temperature, rainfall, food availability and larval density (Koyadun, 2010). At room temperature (22° C), the whole life cycle of *Ae. aegypti* mosquitoes takes approximately 8-10 days. After emergence, mature mosquitoes mate, and female mosquitoes seek out a blood meal with which to incubate their developing eggs. Only the adult female mosquitoes can transmit DENV, as they are the only sex which feeds on human blood. If they bite a dengue-infected person, the virus is acquired and, following an extrinsic incubation period of 8-12 days, is capable of being transmitted by the mosquito (Koyadun, 2010). Female *Ae. aegypti* may take blood meals from other warm-blooded animals, but but they are highly anthropophilic and will discontinue feeding at the slightest disturbance. The tendency to feed exclusively on humans and to readily take blood meals from multiple individuals makes *Ae. aegypti* mosquitoes highly efficient vectors for dengue.

1.6.3 The human host and disease transmission

The most important transmission process from the perspective of public health in tropical countries is the urban-endemic cycle, which involves three main components: virus, vector, and host (humans). The transmission of DENV to humans occurs in a full cycle that requires the completion of two incubation periods. The intracutaneous deposition of DENV in a human host via the bite of infected mosquito is followed by an Intrinsic Incubation Period of approximately 4-7 days (Gubler, 1998) during which the virus multiplies and reaches high levels in the human blood. Following this period, the host may fall ill (i.e., develop dengue haemorrhagic fever or DHF) or, in rare cases, remain asymptomatic.

The second part of the cycle begins when uninfected mosquito bites a viremic individual. The ingestion of the infected blood meal is followed by an Extrinsic Incubation Period of approximately 10 days (Kuno, 1995) during which the virus multiplies and reaches the mosquito's salivary gland. Once the mosquito is infected, it remains infectious for life (up to 70 days (Morse, 1995) and can subsequently transmit the virus to other uninfected persons (WHO, 1997; Gubler, 1998). In addition, experimental studies have demonstrated that mosquito-to-mosquito transmission by vertical transovarial infection is possible, but this is not an effective mechanism. Mourya et al. (2001) found DENV in *Ae. aegypti* eggs and the vertical transmission rate were higher in those eggs with more time to hatch.

1.6.4 Clinical manifestation

The clinical characteristics of dengue disease differ among individuals, with some infected individuals remaining completely asymptomatic.

According to WHO, a typical clinical case of DF manifests as a frontal headache, retroocular pain, muscle pain, joint pain, and rash. Other signs and symptoms are also often present, such as lymphadenopathy, petechiae, nausea, hepatomegaly, and various hemorrhages. A probable case of DF is defined as one which exhibits i) fever and two or more of the following symptoms: headache, retro-orbital pain, myalgias, arthralgias, rash, hemorrhagic manifestation; and ii) supportive serology (HI, IgG, IgM tests). DF is confirmed by i) isolation of DENV from serum or autopsy sample; ii) demonstration of fourfold change in reciprocal IgG or IgM antibody titers in paired serum samples; iii) demonstration of DENV antigen in autopsy tissue, serum or cerebro-spinal fluid samples via immunohistochemistry, immunofluorescence or ELISA; or iv) detection of virus genome sequence in autopsy tissue, serum or cerebro-spinal fluid samples by RT-PCR. Confirmed DHF cases must also meet the following criteria: fever, hemorrhagic tendencies (including positive tourniquet test), thrombocytopenia (1,00,000 per mm^3 or less) and plasma leakage (hematocrit >20% and signs of plasma leakage such as pleural effusion, ascites and hypoproteinemia) (PAHO, 1994; WHO, 1997). DHF with shock is also known as Dengue Shock Syndrome or DSS (PAHO, 1994).

1.6.5 Pathogenesis of dengue and dengue hemorrhagic fever

The pathogenesis of dengue is a product of human host factors as well as the microbial factors inherent to DENV. For the host, extrinsic factors such as immune status and intrinsic factors such as age, sex, race, innate immune system and individual or species- level genetics are involved. DENV appears unique among human pathogens in that an indivdual host’s immune status can vary the disease’s manifestation over an extremely wide range, from the severe symptoms of DHF and DSS to complete asymptomatic presentation (Halstead, 2008). The study of DENV pathogenesis has been impaired by the lack of animal models that reproduce the clinical and pathologic characteristics of dengue in humans. Consequently, research on dengue pathogenesis has mainly relied on epidemiological, clinical and pathological studies on naturally infected persons.

Two main theories have been advanced to explain the wide range of severity exhibited by dengue (McBride et al., 2000; Gubler, 1998). According to the Antibody Dependent Enhanced (ADE) theories, pre-existing antibodies to a specific dengue serotype bind to different serotypes, producing non-neutralized antibody–virus complexes. These complexes bind to macrophages, which lead to activation of T cells from previous presentations to Major Histocompatibility Complex molecules (MHC). Cytokine production then becomes a consequence of T cells activation: Interferon-γ, Tumor Necrosis Factor (TNF), IL1, IL6, IL8 (Yang et al., 2001; Fernandez et al., 2004; Huang et al., 2000). Among other effects, this process produces changes in capillary walls, leading to hemorrhage and serum leakage with potentially fatal consequences.

According to the second theory, more severe dengue symptoms are simply caused by more virulent strains of dengue virus (Rico-Hesse, 2010; Rico-Hesse et al., 1997). Epidemiological studies have demonstrated the relationship between severity of epidemics and the previous serological conditions of the affected population. The sequence of infection with DENV-1 virus followed by DENV-2 has been demonstrated to correlate with high rates of DHF (WHO, 2009). However, differences in the severity and number of DHF cases have been demonstrated between the Asian and American strains of DENV-2, the latter being less virulent (Rico-Hesse, 2010).

1.7 Factors for Dengue Transmission: Multiple Scales Perspectives

1.7.1 Global and regional factors

Certain specific social, demographic, and ecological factors which function at various scales, including global and regional, have been identified as major contributors to the dramatic emergence of DF/DHF as a major public health problem in recent years (Morse, 1995; Rodhain, 1989). Among these, human population exposure to DENV, re-infestation of *Ae. aegypti*, and lack of effective mosquito control are considered the most pressing (Winch et al., 2002). Human exposure factors, including host immune status and risk of exposure to DENV-infected *Aedes* mosquitoes, appear to be important determinants in DHF rates because individuals who suffer a secondary infection with a heterologous serotype are at higher risk for DHF and DSS. The lack of effective mosquito control in many countries has resulted in an increase in mosquito populations living in close association with humans. Kyle and Harris (2008) hypothesized that the spread of dengue viruses and their mosquito vectors was accelerated by the movement of troops during World War II, and the associated large-scale disturbances to regional ecosystems and human settlements in Southeast Asia and the Western Pacific (Lloyd et al., 1992). Southeast Asia has remained hyperendemic for all four DENV serotypes throughout the post-war period. Kyle and Harris further asserted that increases in human population, uncontrolled urbanization, and international travel are major factors in explaining the spread and persistence of dengue in the twentieth and early twenty-first centuries (Lloyd et al., 1992). Movement of humans and commodities due to globalization since the 1990s - as well as the ubiquity of jet airplane travel - have provided the ideal mechanism for worldwide dissemination of pathogens and their vectors (Gubler, 2011). Gubler (2011) identified one classic example of this. In 1970, dengue was only hyperendemic in Southeast Asian countries; by 2007, it had become hyperendemic across the whole of Asia due to urbanization, lack of mosquito control, and widespread transportation of people and goods.

1.7.2 Urban institutional factors

As stated above, since the early 1990s the globalization of the world economy and society has lead to the continuous explosion of unplanned urban centres in developing countries, many of which suffer from substandard housing and inadequate water and waste-management systems. Such environments furnish prime breeding grounds for vectors such as mosquitos, which can spread dengue virus. Simultaneously, these regions have experienced uncontrolled population growth, increasing the number of potential hosts living in close proximity to vectors (Kyle & Harris, 2008). Consequently, understanding the impact of urban development, planning, and management factors - such as water management, waste management, housing provision, drainage and sewerage infrastructure - upon the spread of the dengue virus and the *Ae. aegypti* mosquitos constitutes an important focus of my thesis.

It is worth noting that the minimum population size required to sustain dengue transmission is estimated to range between 10,000 and 1,000,000 (Kuno, 1997), and early epidemics of dengue in Southeast Asia were linked to towns with populations over 10,000 (Smith, 1956). The role of the urban social-ecological environment in dengue transmission dynamics has been examined by a number of research efforts. In one such study, a mathematical model examining the spatiotemporal incidence of DHF over a 15-year period in Thailand estimated that epidemics of DHF originate in the capital city of Bangkok every 3 years and spread outward to the rest of the country at a rate of 148 km per month (Cummings et al., 2004). In the tropical and subtropical regions where *Ae. aegypti* mosquitoes are prevalent, urban growth was not accompanied by well-organized water and waste management programs because the sheer volume of people migrating from the countryside had outpaced public investment in urban development. Lack of good governance and poor coordination among government institutions were also major contributing factors (Knudsen and Sloof, 1992).

1.7.3 Human choices and behavioral factors

As explained above, the key factors driving dengue transmission function at various temporal and spatial scales, ranging from the individual to the local and global, and from days to decades. In this section, I will introduce and discuss the primarily individual cognitive, perceptual, and behavioral factors relevant to dengue transmission. The literature on human and societal factors is extensive, and the most significant studies are discussed in Chapter 2. All such factors, however, can broadly be categorized into three main groups: i) self-risk perception effects ii) effects of livelihood-related economic activities; and iii) factors associated with social structure and power distribution (e.g., gender inequality, marginalization of the poor). Only the former two factors are directly relevant to this thesis research.

Human health risks from dengue and diseases stem from deliberate decisions by individuals as well as from exogenous environmental or institutional sources (McMichael et al., 2003). In the process of making decisions, individuals attempt to comprehend the risks and benefits related to alternative courses of action. In such cognitive processes, peoples' subjective perception of risks plays a critical role (Morgan et al., 1992). The significance of investigating self-risk perception of people about dengue lies in the need to develop effective communications strategies and other interventions to drive changes in human awareness and behaviour concerning disease (Phuanukoonnon et al., 2006).

Among the main human behavioral factors associated with dengue transmission at the personal and household level are water management and storage (Caprara et al., 2009), solid waste disposal and management (Arunachalam et al., 2010), bed net and house screening use (Koopman et al., 1991; Rodriguez-Figueroa et al., 1995). At the regional, national, and international levels, the major factors are human mobility and migration (Gubler, 1997), and commodity exchange. A detailed review of these factors is provided in Chapter 2. Kyle and Harris (2008), in discussing the dynamics of these factors, succinctly summarized the following: in many developing countries, where the availability of piped water is intermittent or non-existing, the both indoor and outdoor water storage containers used city residents create prime breeding grounds for *Ae. aegypti* larvae (Rodhain and Rosen, 1997). In addition, the buildup of discarded, non-biodegradable plastic products such as car tyres leads to the accumulation of stagnant rainwater, creating further breeding sites. On a larger scale, commercial shipping has been linked to the spread of *Ae. aegypti* and *Ae. albopictus* between previously disparate regions (Hawley et al., 1987). Similarly, air travel has increased the dissemination of dengue viruses via the rapid mass transport of millions of viremic individuals around the world (Gubler, 1997).

In addition to individual perceptions and behavior, selected social structural variables - namely power relations, social injustice, and inequity - have also been recognized as significant factors in generating conditions for vector development and dengue exposure (Suarez et al., 2009). In a study of two Columbian towns, Suarez et al. (2009), observed that dengue was highly associated with the poor population, who were spatially segregated to live in low-valued areas near the confluence of the Magdalena and Bogota rivers. The study further revealed that people from lower social strata faced considerably more risk of ‘having dengue vector forms’ (p. S110). A common characteristic of these areas was the lack of in-house water tanks, the locals instead using open metal or plastic containers which furnished fertile breeding grounds for *Ae. aegypti* mosquitoes. Such conditions were also found by Caprara et al. (2009) in Fortaleza, Brazil, where the irregular nature of the water supply forced poorer residents to store water in open containers such as cisters, barrels and pots. In contrast, wealthier residents, while still not connected to the public water systems, were nonetheless able to afford well and pumps and were therefore less affected by the irregularity of water supply.

1.8 Significance of Research

This thesis explores an ‘Ecohealth approach’ to disease research and prevention, supported by a strong and continuous transdisciplinary effort to provide an integrative, holistic conceptual framework for understanding dengue in poor, environmentally degraded settings like Bangladesh. The main principles of the Ecohealth approach -namely social-ecological systems thinking, transdisciplinary research, and stakeholder participation - have been considered in order to identify the causal and non-causal determinants and interactions in disease transmission and the role of humans as hosts and active agents. The main contribution of this research is to establish the need for more integrated, transdisciplinary, system-based approach to understanding and controlling disease transmission. The specific contributions of this thesis are:

- Understanding the risk factors affecting dengue seropositivity in the city of Dhaka, Bangladesh, and other developing country mega-cities.
- Determining the main social and ecological factors affecting dengue vector abundance at the household level and the role of land-cover/landuse in the spatial distribution of vectors and seroconverted cases (recently infected individuals).
- Mapping perceptual configurations of local community members regarding dengue vector and disease transmission, and methods of dengue prevention and control of dengue.
- Examining the policy implications of the findings with regards to developing strategies and interventions for preventing and controlling dengue.

1.9 Organization of the Thesis

The thesis is organized into nine chapters - each incorporating a list of references - followed by fifteen appendices. Each chapter features its own distinct format based on its content and role in the overall thesis. For example, Chapters 1 and 2 provide theoretical orientation and Chapter 3 provides methodological orientation to the thesis, while Chapters 4, 5, 6, 7 combine theoretical concepts with research findings. Chapters 4, 5, 6 and 7 correspond to the four main research objectives, respectively. Finally, Chapter 8 provides an overall discussion and integration of research findings while Chapter 9 evaluates the research outcomes and their relevance to academic, policy, and applied work. The following provides a more detailed overview of each chapter’s contents.

Chapter 1 summarizes the theoretical context for this research, its purpose and objectives, and the conceptual orientation of its analysis. Chapter 2 reviews the current literature and examines this study's place within it. The philosophical and methodological approaches that have guided this study's field research methods are outlined in Chapter 3. Chapter 4 examines the dengue vector (*Ae. aegypti*) as well as the ecological factors regulating its relative abundance in open water containers. Chapter 5 explores the socioeconomic risk factors concerning dengue seroprevalence and seroincidence in the city of Dhaka, Bangladesh. Chapter 6 examines spatial the spacial distribution of dengue vector and its association with recent seroconversion. Chapter 7 elaborates on the critical role of local knowledge, risk perception, attitudes, and practices in dengue transmission. Chapter 8 deals with the overall integration of each of the previous four chapters, while Chapter 9 concludes the thesis by revisiting the research objectives, presenting key findings and conclusions, and discussing future potential research opportunities.

Parts	**Scope and Contents**
Part One	
Chapter 1	Statement of the problem; purpose of the study; research objectives; dengue problem in Bangladesh; The field context; significance of the present study
Chapter 2	Review of the literature and current state of knowledge concerning health, dengue; various research approaches; position of present research in the current literature
Chapter 3	Methodology; research approach of the present study; research process
Part Two	
Chapter 4	Socio-economic and ecological factors influencing *Aedes aegypti* abundance and distribution; role of different socio-economic status (SES) of urban zones in *Ae. aegypti* distribution; role of container types and functional categories in immature *Aedes* production
Chapter 5	Socio-economic risk factors regarding previous and recent exposure to dengue virus; age dependent aspects of seroprevalence and seroconversion
Chapter 6	Spatial evaluation of *Aedes aegypti* abundance and its association with seroconversion; landscape, landuse and landcover factors affecting *Aedes* habitat; influence of microenvironment on spatial distribution of *Aedes*
Chapter 7	Role of risk perception and knowledge, attitudes, practices in dengue transmission; public and expert Mental Model of dengue; knowledge gaps and juxtaposition
Part Three	
Chapter 8	A discussion on integration for transdisciplinary knowledge development on dengue transmission; formulation of a transdisciplinary framework
Part Four	
Chapter 9	Synthesis of major findings;contributions of the present research;limitations of the research; future research directions and policy recommendations

Figure 1.1: A schematic diagram of thesis organization

References

Akther M S, Islam I, Hasan M U. (2009). Evaluation of municipal services in selected wards of Dhaka city corporation:Citizen's perspective. *Therotical and Empirical Researches in Urban Environment, Special Number 1S*, 133-145.

Aldstadt, J., Koenraadt, C. J., Fansiri, T., Kijchalao, U., Richardson, J., Jones, J. W., & Scott, T. W. (2011). Ecological modeling of Aedes aegypti (L.) pupal production in rural Kamphaeng Phet, Thailand. *PLoS Neglected Tropical Diseases, 5*(1), e940.

Arthur, W. B., McNicoll, G. (1978). An analytical survey of population and development in Bangladesh. *Population and Development Review*, *4*(1), 23-80.

Arunachalam, N., Tana, S., Espino, F., Kittayapong, P., Abeyewickrem, W., Wai, K. T., . . . Petzold, M. (2010). Eco-bio-social determinants of dengue vector breeding: a multicountry study in urban and periurban Asia. *Bulletin of the World Health Organization, 88*(3), 173-184.

Aziz, M. A., Gorham, J. R., Gregg M B. (1967). "Dhaka fever"-an outbreak of dengue. *Pakistan Medical Journal of Research, 6,* 83-92.

Banu, S., Hu, W., Hurst, C., Guo, Y., Islam, M. Z., & Tong, S. (2012). Space-time clusters of dengue fever in Bangladesh. *Tropical Medicine & International Health, 17*(9), 1086-1091.

Calisher, C. H. (2005). Persistent emergence of dengue. *Emerging Infectious Disease, 11*, 738-739.

Caprara, A., Lima, J. W. O., Marinho, A. C. P. (2009). Irregular Water Supply, household usage and dengue: a bio-social study in the Brazilian Northeast. *Cad. Saude Publica, 25*(Sup 1), S125-S136.

CDCP. (1993). *Guidelines for arbovirus surveillance in the United States.* Fort Collins, Colorado: US Department of Health ans Human Services, Public Health Service.

Cummings, D. A., Irizarry, R. A., Huang, N. E., Endy, T. P., Nisalak, A., Ungchusak, K., & Burke, D. S. (2004). Travelling waves in the occurrence of dengue haemorrhagic fever in Thailand. *Nature, 427*(6972), 344-347.

Dakubo C Y. (2010). *Ecosystems and Human Health: A Critical Approach to Ecohealth Research and Practice*. New York: Springer.

Despommier, D., Brett, R., Wilcox,B.A. (2006). The role of ecotones in emerging infectious disease. *Ecohealth, 3*(4), 281-289.

Effler, P. V., Pang, L., Kitsutani, P., Vorndam, V., Nakata, M., Ayers, T., . . . Rigau-Perez, J. G. (2005). Dengue fever, Hawaii, 2001–2002. *Emerg Infect Dis, 11*(5), 742-749.

Ellis, B. R., & Wilcox, B. A. (2009). The ecological dimensions of vector-borne disease research and control. *Cadernos De Saude Publica, 25*, S155-S167.

Fernandez, M., Gendzekhadze, K., Rivas, P.,Layrisse, Z. (2004). TNF- 308 An Allele, a possible severity risk factor of hemorrhagic manifestation in dengue fever patients. *Tissue Antigens*, *64*, 469-472.

Gubler, D. (1998). Resurgent Vector-Borne Disease as a Global Health Problem. *Emerging Infectious Disease, 4*(3), 442-450.

Gubler, D.J., Kuno, G. (1997). *Dengue and dengue hemorrhagic fever*. Wallingford, Oxon, UK; New York: CAB International.

Gubler, D. J. (1997). Dengue and dengue hemorrhagic fever. *Seminars in Pediatric Infectious Diseases*, *8*(1) 3-9.

Gubler, D. J. (2002). Epidemic dengue/dengue hemorrhagic fever as a public health, social and economic problem in the 21st century. *Trends in Microbiology*, *10*(2), 100-103.

Gubler, D. J. (2011). Dengue, Urbanization and Globalization: The Unholy Trinity of the 21(st) Century. *Tropical Medicine and Health*, *39*(4 Suppl), 3-11.

Gubler, D. J., & Clark, G. G. (1995). Dengue/dengue hemorrhagic fever: the emergence of a global health problem. *Emerg Infect Dis, 1*(2), 55-57.

Guzmán, M. G., & Kouri, G. (2002). Dengue: an update. *The Lancet Infectious Diseases, 2*(1), 33-42.

Guzmán, M. G., & Vazquez, S. (2010). The complexity of antibody-dependent enhancement of dengue virus infection. *Viruses, 2*(12), 2649-2662.

Halstead, S. B. (1977). Dengue viruses and mononuclear phagocytes. *The Journal of Experimental Medicine*, *146*, 201-205.

Halstead, S. B. (2007). Dengue. *The Lancet*, *370*(9599), 1644-1652.

Halstead, S. B. (2008). Dengue virus-mosquito interactions. *Annu.Rev.Entomol., 53*, 273-291.

Halstead, S. B. (1990). Global epidemiology of dengue hemorrhagic fever. *The Southeast Asian Journal of Tropical Medicine and Public Health*, *21*(4), 636-641.

Haque, M. A., Yamamoto, S. S., Malik, A. A., & Sauerborn, R. (2012). Households' perception of climate change and human health risks: A community perspective. *Environmental Health, 11*(1), 12.

Hashizume, M., Armstrong, B., Hajat, S., Wagatsuma, Y., Faruque, A. S., Hayashi, T., & Sack, D. A. (2007). Association between climate variability and hospital visits for non-cholera diarrhoea in Bangladesh: effects and vulnerable groups. *International Journal of Epidemiology, 36*(5), 1030-1037.

Hawley, W. A., Reiter, P., Copeland, R. S., Pumpuni, C. B., & Craig, G. B., Jr. (1987). Aedes albopictus in North America: probable introduction in used tires from northern Asia. *Science (New York, N.Y.), 236*(4805), 1114-1116.

Holmes, E. C., & Twiddy, S. S. (2003). The origin, emergence and evolutionary genetics of dengue virus. *Infection, Genetics and Evolution, 3*(1), 19-28.

Hossain, M. A., Khatun, M.,Arjumand, F. et al. (2003). Serologica evidence of dengue infection before onset of epidemic, Bangladesh. *Emerging Infectious Disease, 9*(11), 1411-1414.

Huang, Y., Lei, H., Liu, H., Liu, C.,Yeh, T. (2000). Dengue virus infects human endothelial cells and induces IL-6 and IL-8 production. *American Journal of Tropical Medicine and Hygiene, 63*(1,2), 71-75.

Joshi, V., Mourya, D.,Sharma, R. (2002). Persistence of dengue 3 virus through transovarial transmission passage in successive generation of *Ae. aegypti* mosquitoes. *American Journal of Tropical Medicine and Hygiene, 67*(2), 158-161.

Kay, J. J. (Ed.). (2000). *Ecosystems as self-organizing holarchic open systems: narratives and the second law of thermodynamics* CRC press.

Knipe D, Howley P, Griffin D, Lamb R, Martin M, Roizman B,Straus S. (2001). *Fields Virology*. Philadelphia: Lippincott Williams & Wilkins.

Knudsen, A. B., & Slooff, R. (1992). Vector-borne disease problems in rapid urbanization: new approaches to vector control. *Bulletin of the World Health Organization, 70*(1), 1-6.

Koopman, J S, Prevots, D R, Van Martin,M A et al. (1991). Determinants and predictors of dengue infection in Mexico. *American Journal of Epidemiology, 133*, 1168-1178.

Koopman, J. S., Longini,I.M. (1994). The ecological effects of individual exposures and nonlinear disease dynamics in populations. *American Journal of Tropical Medicine and Hygiene, 84*(5), 836-842.

Koyadun, S. (2010). *An Eco-Bio-Social Approach To Assess Dengue Transmission Dynamics in Thailand.* Mahidol University). *Doctor of Philosophy.*

Kuno, G. (1995). Review of factors modulating dengue transmission. *Epidemiology Review, 17*, 321-335.

Kuno G (Ed.). (1997). *Factor influencing the transmission of dengue viruses*. New York: CAB International.

Kyle, J. L., & Harris, E. (2008). Global spread and persistence of dengue. *Annu.Rev.Microbiol., 62,* 71-92.

Lamb, R. A., Krug, R., & Knipe, D. (2001). Fields virology.

Lebel, J. (2003). *Health: an Ecosystem Approach*. Ottawa: International Development Research Centre.

Lloyd, L. S., Winch, P., Ortega-Canto, J., & Kendall, C. (1992). Results of a community-based Aedes aegypti control program in Merida, Yucatan, Mexico. *Am J Trop Med Hyg, 46*(6), 635-642.

Mahmood, B. A. I., & Mahmood, S. A. I. (2011). Emergence of Dengue in Bangladesh a major international public health concern in recent years. *Journal of Environmental Research and Management, 2*, 035-041.

McBride W J, B. H. (2000). Dengue viral infections; pathogenesis and epidemiology. *Microbes and Infections, 2*, 1041-1050.

McMichael, A. J., Campbell-Lendrum, D. H., Ebi, K., Githeko, A., Scheraga, J., & Woodward, A. (2003). *Climate change and human health: risks and responses.* World Health Organization.

Morgan, M. G., Fischhoff, B., Bostrom, A., Lave, L. B., & Atman, C. J. (1992). Communicating risk to the public.

Morse, S. (1995). Factors in the emergency of infectious diseases. *Emerging Infectious Disease, 1*(1), 7-15.

Mourya, D.T., Gokhale, Basu A, Barde, P.V., Sapkal, G.N, Padbidri, V.S.,Gore, M.M. (2001). Horizontal and vertical transmission of dengue virus type 2 in highly and lowly susceptible strains of *Ae. aegypti* mosquitoes. *Acta Virol., 45*(2), 67-71.

Mukhopadhyay, S., Kuhn, R.,Rossmann, M. (2005). A structural perspective of *flavivirus* life cycle. *Nature Reviews Microbiology, 3*, 13-22.

Nagao, Y., Thavara, U., Chitnumsup, P., Apiwat Tawatsin, A., Chansang, C.,Campbell-Lendrum, D. (2003). Climatic and social risk factors for Aedes infestation in rural Thailand. *Tropical Medicine and International Health, 8*, 650-659.

Nisalak A, Endy T,Nimmannitya S et al. (2003). Serotype specific dengue virus circulation and dengue disease in Bangkok, Thailand from 1973-1999. *American Journal of Tropical Medicine and Hygiene, 68*, 191-202.

Ooi, E. E., Gubler,D.J. (2009). Global spread of epidemic dengue: the influence of environmental change. *Future Virology, 4*(6), 571-580.

PAHO. (1994). *Dengue and dengue hemorrhagic fever in the Americas: Guidelines for prevention and control.* (No. 548).

Phuanukoonnon, S., Brough, M., & Bryan, J. H. (2006). Folk knowledge about dengue mosquitoes and contributions of health belief model in dengue control promotion in Northeast Thailand. *Acta Tropica, 99*(1), 6-14. doi:10.1016/j.actatropica.2006.05.012

Pinheiro, F. d. P., & Nelson, M. (1996). Epidemiological and entomological surveillance of Dengue in the Américas. *Epidemiological and entomological surveillance of Dengue in the Américas*. Pan Américan Health Organization.

Poddar, G., Breiman, R. F., Azim, T.,Thu, H. M. et al. (2006). Short Report: Origin of dengue type 3 viruses associated with the dengue outbreak in Dhaka, Bangladesh, in 2000 and 2001. *American Journal of Tropical Medicine and Hygiene, 74*(2), 263-265.

Rahman, M., Rahman, K., Siddque, A., Shoma, S., Kamal, A., Ali, K., . . . Breiman, R. F. (2002). First outbreak of dengue hemorrhagic fever, Bangladesh. *Emerging Infectious Diseases, 8*(7), 738-740.

Rico-Hesse, R., Harrison, L. M., Salas, R. A., Tovar, D., Nisalak, A., Ramos, C., . . . Rosa, A. T. d. (1997). Origins of dengue type 2 viruses associated with increased pathogenicity in the Americas. *Virology, 230*(2), 244-251.

Rico-Hesse, R. (Ed.). (2010). *Dengue Virus Virulence and Transmission Determinants*. Verlag Berlin Heidelberg: Springer.

Rodhain, F., & Rosen, L. (1997). Mosquito vectors and dengue virus-vector relationships. *Dengue and Dengue Hemorrhagic Fever,* 45-60.

Rodhain, F., Gonzalez, J. P., Mercier, E., Helynck, B., Larouze, B., & Hannoun, C. (1989). Arbovirus infections and viral haemorrhagic fevers in Uganda: a serological survey in Karamoja district, 1984. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 83*(6), 851-854.

Rodriguez-Figueroa, L., Rigau-Perez, J G., Suarez, E. L.,et.al. (1995). Risk factors for dengue infection during an outbreak in Yanes, Puerto Rico in 1991. *American Journal of Epidemiology, 52*, 496-502.

Smith, C. E. (1956). The history of dengue in tropical Asia and its probable relationship to the mosquito Aedes aegypti. *The Journal of Tropical Medicine and Hygiene, 59*(10), 243-251.

Spiegel, J. M., Ibarra, M., Kouri, G.,et al. (2007). An integrated ecosystem approach for sustainable prevention and control of dengue in central Havana. *International Journal of Occupational and Environmental Health, 13*(2), 188-194.

Spigel J, Bennett S,Hattersley L et al. (2005). Barriers and bridges to prevention and control of dengue: The need for a social-ecological approach. *Ecohealth, 2*, 273-290.

Streatfield, P. K., & Karar, Z. A. (2008). Population challenges for Bangladesh in the coming decades. *Journal of Health, Population, and Nutrition, 26*(3), 261-272.

Suárez, R., González, C., Carrasquilla, G., & Quintero, J. (2009). An ecosystem perspective in the socio-cultural evaluation of dengue in two Colombian towns. *Cadernos De Saúde Pública, 25*, S104-S114.

Thu, H. M., Lowry, K., Myint, T. T. et al. (2004). Myanmar dengue outbreak associate with displacement of serotypes 2, 3, and 4 by dengue 1. *Emerging Infectious Disease*, *10*, 593-597.

Twiddy, S. S., Holmes, E. C.,Rambaut, A. (2003). Inferring the rate and time-scale of dengue virus evolution. *Molucular Biology Evol., 20*, 122-129.

Wang, E., Ni, H., Xu, R., Barrett, A. D., Watowich, S. J.,Gubler, D. J. (2000). Evolutionary relationships of endemic/epidemic and sylvatic dengue viruses. *Journal of Virology*, *74*(7), 3227-3234.

WHO. (1997). *Dengue hemorrhagic fever, diagnosis, treatment and control*. Geneva: World Health Organization.

WHO. (2009). DengueNet, Available at: http://www.who.int/denguenet.

Wilcox, B. A., Colwell,R.R. (2005). Emerging and re-emerging infectious diseases: Biocomplexity as an interdisciplinary paradigm. *Ecohealth*, *2*(4), 244-257.

Wilder-Smith, A., & Schwartz, E. (2005). Dengue in travelers. *New England Journal of Medicine, 353*(9), 924-932.

Winch, P. J., Leontsini, E., Rigau-Pérez, J. G., Ruiz-Pérez, M., Clark, G. G., & Gubler, D. J. (2002). Community-based dengue prevention programs in Puerto Rico: impact on knowledge, behavior, and residential mosquito infestation. *American Journal of Tropical Medicine and Hygiene*, *67*(4), 363-370.

Yang, K. D., Yeh, W. T., Yang, M. Y., Chen, R. F.,Shaio, M. F. (2001). Antibody dependent enhancement of heterotypic dengue infections involved in suppression of IFN gamma production. *Journal of Medical Virology*, *63*(2), 150-157.

Yunus, E. B., Bangali, A. M., Mahmood, M. A. H., Rahman, M. M., Chowdhury, A., & Talukder, K. (2001). Dengue outbreak 2000 in Bangladesh: from speculation to reality and exercises. *Dengue Bulletin*, *25*, 15-20.

CHAPTER TWO
REVIEW OF LITERATURE

The issues surrounding dengue transmission are complex, and addressing them requires a broader perspective concerning human health and the ecosystem. In this chapter, I first provide a critical review the relevant literature from the perspective of human health and its interactive association with social-ecological systems. Second, I review the discourse in the shift in conceptual approaches in human health studies – from the conventional biomedical approaches to Ecohealthapproaches. Following these background discussions, I focus on three specific areas of dengue disease transmission literature: i) dengue vector and virus dynamics; ii) socio-economic and ecological factors in dengue transmission in urban context; and iii) risk perception and behavior among city dwellers.

2.1 Linkage between Human Health and the Ecosystem in the Context of Dengue

The concept of disease has evolved over time through incremental development of knowledge about its role in human health. The ecosystem approach to human health is designed to shift public health thinking from the traditional, unidimentional biomedical approach towards a new transdisciplinary and integrated approach. It is premised on the notion that human beings cannot be healthy in an unhealthy ecosystem. In the following sections, the literature on the role of socio-ecological systems and their pertinent elements in disease transmission, particularly dengue is critically assessed.

2.1.1 Key concepts of human health

The World Health Organization (WHO) defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 1948). This definition has long been criticized as being overly idealistic, and was finally updated by the European region of WHO to frame the extent to which an individual or group is able to realize aspirations and satisfy needs, and to change and cope with the environment. In 1978, the Alma Ata declaration on primary health care emphasized the social dimensions of health and the importance of community participation in health promotion initiatives (WHO, 1978). This declaration encouraged people to take ownership of their health. In 1986, the Ottawa Charter viewed health as a resource for everyday life, not the objective of living (WHO, 1986). Therefore, health is seen as instrumental, a means rather than an end alongside other basic needs such as peace, shelter, education, basic nutrition, income, a stable environment, sustainable resources, and social justice and equity.

Achieving health therefore becomes a shared responsibility between society and the individual (Lincoln, 1992). This conceptualization of health incorporates the broad social and ecological conceptualization of health and use of an ecosystem as an analytical construct that helps illustrate the dynamic interplay between various factors. This conceptualization of health differs from the linear, individualistic ethic that ascribes poor health status to individual characteristics, such as lifestyle choices, behaviors and habits, without addressing structural forces that prevent the achievement of optimal health.

Literature suggests that while the WHO has provided a number of formal definitions of health, it is important to understand that health is a social construct and has no pre-determined meaning (Dakubo, 2010). From a postmodern perspective then, health has no stable or fixed meanings; it is always in flux, and has to defined or interpreted based on contexts (Fox, 1991; 1994).

2.1.2 Key concepts of ecosystem and integrated social-ecological systems

The concept of 'ecosystem' refers to the interaction of a set of living organisms, including humans, and their non-living environments (Millennium Ecosystem Assessment, 2005). Tansley first introduced the concept 'ecosystem' in 1935 (Tansley, 1935). Tansley described the ecosystem as "not only the organism-complex, but also the whole complex of physical factors forming what we call the environment" (Tansley, 1935; p. 299). Tansley noted that ecosystems vary in size and structure. Odum defined ecosystems as the interaction between living and the nonliving components of a system (Odum, 1953); therefore, ecosystems are characterized by a high level of interdependence and interaction between living things and non-living components within a defined space in the environment. Within the health and environment literature, the terms 'ecosystem' and 'environment' are often used interchangeably (Dakubo, 2010).

The term 'environment' usually refers to the external or inherent physical conditions that influence the growth and development of organisms, and which exist beyond humans rather than encompassing them (Labonte, 1991). The 'system' in the ecosystem refers to the set of elements that interact with each other within a defined boundary. Ecosystems have complex structures and are sometimes described from the perspective of nested, interlocking hierarchies of geographic units embedded within the biosphere (Kay et al., 1999). Each geographic unit is both a complete entity in itself and part of a larger entity. Each level of the ecosystem hierarchy interlocks and influences each other in ways that can negatively and positively influence human health through feedback loops (Waltner-Toews, 2001).

Several investigators conceived and elaborated upon ecosystem themes using different terminology. For example, ecological and social scientists working on ecosystem and natural resources management challenges refer to ‘‘social–ecological systems’’ (Berkes & Folke, 1998; Berkes et al., 2003) or ‘‘human and natural systems’’ (Gunderson & Holling, 2002). The ‘‘socio-ecological systems’’ has been used to describe the same-systems perspective, amplifying coupled human–natural systems and complexity theory, in the context of health and emerging infectious diseases (Waltner-Toews, 2001). The hyphenated or contracted terms emphasise the interaction of humans and nature as a complex system, and arguably embrace what is fundamentally the same paradigm (Wilcox and Colwell, 2005).

2.1.3 Dengue disease and integrated social-ecological systems

Several studies have discussed the intrinsic link between ecosystem health and human disease, especially in the case of vector-mediated disease (Epstein, 1995; Chivian, 2001; Forget & Lebel, 2001; VanLeeuwen et al., 1999; Waltner-Toews, 2001). These authors have noted that ecosystem health is influenced by human activities and that human health depends on proper ecosystem functioning. It has been suggested that disease incidence within a human population can be used as bioindicator or ‘yardstick’ of the health of the local ecosystem (Cook et al., 2004; Rapport, 1999). Cook et al. (2004) suggested that human disease incidence is in fact one of the most useful and practical bioindicators of the health of an ecosystem. A “social-ecological systems” perspective, in which humans and their surroundings are seen as so-called “coupled human-natural systems,” is one new way of thinking that has provem helpful in explaining patterns of disease emergence in relation to human interactions with its surrounding natural systems (Wilcox & Colwell, 2005; Wilcox & Gubler, 2005).

After Wilcox et al. (2008), Figure 2.1 presents a graphical representation of this perspective, illustrating the linkage of human systems on a regional scale with natural systems, such as ecological communities and ultimately host–parasite complexes, on successively smaller ecological scales. Changes at the level of the regional environment, such as population growth, cascade down through these successively smaller scales to facilitate the emergence or re-emergence of infectious diseases. This coupled system thus "sends" the diseases in the opposite direction, up through the system to potentially impact public health on a regional or even global scale (Wilcox et al., 2008).

The relatively recent discovery of the connection between dengue as an emerging vector-borne disease, the ecosystem, and human-natural interactions has dramatically broadened the scope of understanding concerning dengue disease transmission process. According to Wilcox and Colwell (2005), dengue is a classic reemerging infectious disease from which considerable knowledge can be gained using social-ecological systems perspectives. In case of DENV, human-made ecological disruption is an important cause for the emergence of more virulent genotypes, as there is no evidence for rapid natural evolution and selection for DENV. The older, less virulent DENV is mainly transmitted by an enzootic cycle and does not cause outbreaks in human populations, but due to constant reduction of natural forests, the natural DENV cycle has emerged as an urban epidemic cycle (Rico-Hesse, 2010).

The principal vector, *Aedes aegypti*, has made evolutionary adjustments to coexist within the human sphere (Monath, 1994). This mosquito originated in Africa and adapted to use rainwater-filled tree holes as larval development sides. However, unprecedented forest destruction for human habitat extension and agricultural intensification have made *Ae. aegypti* a highly domesticated animal which increasingly uses artificial water-storage containers for breeding, uses human habitations to shelter from predators and harsh weather, and gets easy blood meals within a short flight range from humans (Monath, 1994). Unchecked human population growth in the tropics, dramatic redistribution of the human population into urban areas, and the expansion of global trade have also influenced the epidemiology of dengue and the distribution and abundance of its primary vector.

An interesting illustration of how social-ecological system dynamics play an important role in dengue vector ecology is provided by the introduction and spread of another dengue vector, *Aedes albopictus* in America from Asia in the 1980s (Monath, 1994). This species was separately introduced in Houston, Texas (USA) and Rio de Janeiro (Brazil) from different regions of Asia (Forattini, 1986). Commerce in used truck tires imported from Asia for the purpose of recapping was the main vehicle for mosquito egg and larve introduction into these regions (Reiter, 1987). The *Ae. albopictus* invasion spread rapidly, extending the range of this species to the eastern United States. Alongside this global trade expansion, social changes and efforts to control emerging/ reemerging infectious diseases have also contributed to the severity of the dengue disease problem (Wilcox & Gubler, 2005). Insufficient urban piped water supplies, necessitating the storage of water for drinking and washing, and poor sanitation in developing countries results in the accumulation of huge amounts of discarded containers that collect rainwater, which have in turn have been responsible for an enormous expansion in dengue vector populations.

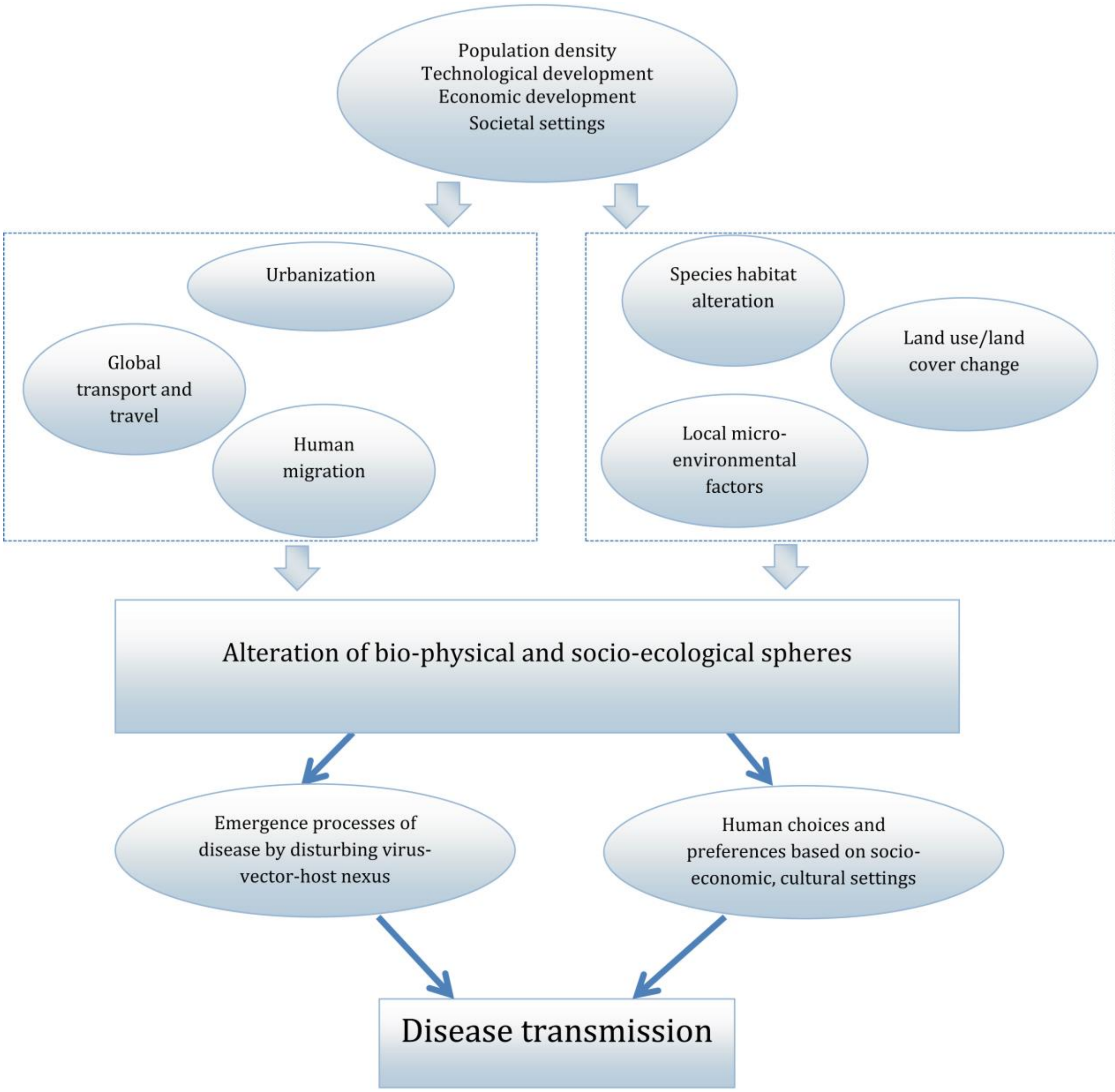


Figure 2.1: Causal relationship of regional scale environmental drivers on disease emergence represented as an integrated social-ecological systems (after: Wilcox et. al., 2008)

2.2 Shifts in Conceptual Approaches in Human Health Studies

2.2.1 Conventional biomedical approach

The conventional biomedical approach in public health is characterized by three phases: the sanitary phase (1840s -1870s), the preventive phase (1870s-1930s), and the therapeutic phase (1930s-1970s). The biomedical model of health is associated with all these three phases, with each era defined according to dominant forms of medical knowledge (Brown and Duncan, 2002). Occurring between 1840s and 1870s, diseases were attributed to contaminated environments (Pedersen, 1996). The primary focus at that time to prevent disease was on monitoring the transfer of dangerous substances from the physical environment into the human body and those being excreted from the human body into the environment (Dubos, 1968). This sanitary paradigm paved the way for the introduction of fields like hygiene, public works and sanitary engineering (Dakubo, 2010).

The era from the 1870s-1930s was dominated by medical and public health sciences due to the emergence of Robert Koch's germ theory, John Snow's work on cholera, and Louis Pasteur's work on silkworm epidemics caused by living micro-oorganisms (Susser & Susser, 1996). The focus on specific agents led to a reductionist model of disease causation and a unidirectional laboratory perspective of identifying and experimentally transmitting disease-causing microorganisms (Evans, 1976). After this phase, victory over infectious diseases ended due to the emergence of chronic diseases like peptic ulcers, lung cancer, and heart diseases following World War II. Studies in early 1970s illustrated the association between certain lifestyles such as alcoholism, and smoking with non-infectious diseases.

The biomedical approaches that emphasize therapy, treatment of infectious diseases, cause-effect mechanisms and behavior and lifestyle modifications, do not usually take into account the social context in which health decision and actions occur (Minkler, 1994). Critics argued that the undue stress of the biomedical approaches on the individual blames the victim, and has narrow focus on social vulnerability. A disproptionate amount of disease burden falls on poor, rural residents and other at the bottom of socio-economic ladder is partially linked to the conceptualization and practice of such biomedical approaches (Schulz et al., 2002).

2.2.2 Contemporary "Ecohealth" approach

With growing criticism of the individualistic focus of biomedical approaches to health and their failure to respond to the complex and structural determinants of poor health, a contemporary public health approach for disease prevention and control has emerged in the mid-1970s (Dakubo, 2010). The new paradigm shifted its focus from the individual to a multi-causal, socio-economic approach to health, taking into account the interaction of social, environmental, psychosocial and other factors in producing ill health.

The Lalonde Report was one of the first documents to emphasize the important role of environmental factors in shaping human health beyond the conventional biomedical model (Lalonde, 1974). After this, the United States Department of Health, Education and Welfare published Healthy People (United States Surgeon General Report, 1996) discussing the role of both individual behaviors and environmental factors in influencing health. Emulating this concept, the Ottawa Charter for Health Promotion (WHO, 1986) broadened the concept of community involvement and equal participation by both gender in health promotion strategies. This was the first time ecological thinking has been officially endorsed following the contemporary Ecohealth approach.

The objective of this new paradigm was to re-orient public health from an individualistic focus to a more social, ecological approach by integrating social, environmental, cultural, and community aspects of health (Green et al., 1996). Ecological approaches to health tend to seek equilibrium among individual-level factors and broader social and ecological factors. Models of human health from an ecosystem perspective make use of systems-thinking that recognizes human health as being influenced and conditioned by factors at various levels and scales including those related to the individual, family, community, surrounding biophysical and socio-economic environments, and national and global policies (Dakubo, 2010). This nested nature of health determinants recognizes that the complexity and multiplicity of factors influencing human health cannot be sufficiently resolved through a unidirectional or piece-meal approach.

2.3 Ecohealth Research Approach

2.3.1 Ecohealth research approach to human and environmental health

To conduct research on issues at the interface of environment and health, the Ecohealth approach serves as a useful framework for planning healthy communities or assisting communities to investigate and respond to an environmental health problem. The primary entry point could be from a community perspective where a community might be facing a particular health concern that has a strong environmental component but is uncertain as to the causal linkages between environmental conditions and health conditions. The literature has suggested two other entry points for Ecohealth research: i) the identification of an environmental problem which is suspected to adversely impact human health; and/or ii) a well-documented health concern that is suspected to be associated with environmental degradation (Forget & Lebel, 2001). In both scenarios, it is important to integrate multiple perspectives from many disciplines to address the complexity what is not amenable to conventional reductionist science (Nielsen, 2001). Transdisciplinarity transcends conventional single and multidisciplinal approaches but does not replace them. It is a means to bridge the functional gap between the natural sciences and the social sciences or humanities (Wilson, 1998).

There are five key elements central to conducting an ecohealth research: (1) the integration of transdisciplinary, indigenous and stakeholder perspectives, (2) the use of participatory and inclusive procedures, (3) sensitivity to social diversities and their respective experiences and responses to environmental health problems, (4) studying environment and health problems from a historical perspective, and (5) making use of critical perspectives to illuminate the political and social dimensions of human-environment relationships (Dakubo, 2010). As one of the primary goals of Ecohealth research is to create opportunities for all relevant stakeholders to participate in evaluating an environmental health problem and to gain sufficient insight to implement the appropriate interventions, community based participatory research (CBPR) is particularly suitable for conducting Ecohealth research. In the public health domain, CBPR is an investigative approach that actively involves all stakeholders - including community members, various institutional representatives and researchers - in all phases of the research process to evaluate and respond to particular health concerns including disease prevention and control (Israel et al., 2003; Laverack & Labonte, 2000). In their study, Israel et al. (2003) suggested that the goal of CBPR-based Ecohealth research is to bring together the unique perspectives, experience and knowledge systems about a particular problem and integrate the knowledge with action to improve community members' health and well-being. Overall, CBPR fits well into the Ecohealth research framework as Ecohealth calls for the integration of perspectives from various disciplines with those of relevant stakeholders.

2.3.2 Ecohealth application in understating emerging infectious diseases

The Ecohealth perspectives of infectious disease transmission bring about a holistic, transdisciplinary explanation via its broad, multi-scale scope for capturing interconnectedness among ecological, biological and societal phenomena. Investigating the root causes of infectious disease emergence directs us towards adoption of complexity theory, including systems thinking, and to consider the view that humans and nature be seen as both intricately interwoven and simultaneously distinct components of the "coupled human-natural systems." Evidence of the difficulty in explaining the transmission of infectious diseases including dengue lies in the long list of human pathogens that have emerged and remerged during the last three decades. They included malaria, tuberculosis, avian influenza, leptospirosis, Nipah virus, Marburg virus, HIV/AIDS, Henipavirus, and West Nile Virus. The interconnections among social and ecological systems at varying scales, ranging from villages to the globe, need to be assessed in the wider contexts of social-ecological systems from which infectious diseases emerge. The societal factors such as, income inequalities and governance, social power dynamics, and policy implementations are also captured in attempts to comprehend infectious disease transmission from the Ecohealth perspectives.

One can draw upon the significance and scope for contributions by the Ecohealth approach in understanding Emerging Infectious Disease (EID) transmission in different parts of the world. Here some examples of how Ecohealh-oriented research helped to create new knowledge of EID transmission as well as their transfer to the local communities for affecting resource management practices as well as behavior change are worth assessing. One such good example is the recent advancement in understanding malaria transmission in Uganda and Tanzania using this Approach , where malaria mostly a ‘rural disease’ as agriculture is the backbone of household economy, and poverty and illiteracy are very common (Okello-Onen et al., 2012). Farming systems influence malaria by changing the prevailing ecological conditions for mosquito vectors or by altering the contact between the human population and the vector mosquito (Ijumba and Lindsay, 2001). As a result, human-vector-parasite contact patterns are altered, and the spread of malaria is facilitated. Ecohealth-oriented research projects implemented in Tanzania and Uganda attempted to delineate the links between agricultural and natural-resource management practices and malaria, as well as to unravel various elements of malaria epidemiology and its socio-economic impacts (Okello-Onen et al., 2012). To advance knowledge of transmission process, the research initially conducted empirical entomological, malariometric, and sociological surveys to encompass local ecological characteristics and community perspectives. In addition, community diagnosis workshops were conducted involving directly the farming communities and other stakeholders from policymakers, local politicians, malaria experts, and other stakeholders. The local communities received feedback on the research results and they made invaluable contributions to knowledge translation and the identification of potential options for malaria management in Tanzania.

By applying the Ecohealth concept, the Uganda study revealed that the breeding of anophiline mosquitoes was influenced by floating vegetation and shade levels around water bodies (Okello-Onen et al., 2012). When floating vegetation (*Azolla filiculoides* or ‘water fern') covered more than 90% of the pond surface, anophelines were almost completely eliminated in these areas and no mosquito breeding sites could be detected. Planting of trees created a thick canopy that shaded the ponds and reduced water temperature, and in turn, generated unsuitable conditions for anophilines breeding. In Tanzania, the findings showed that mosquito productivity was associated with land use and water management in rice farming; and thereby the prevalence of malaria and other parasitic diseases were linked with such economic activities. The above stated Ecohealth-oriented research projects, by providing evidence-based explanations, established links between agricultural practices, livelihood patterns, and malaria risk; the local communities were thus able to identify potential malaria control interventions that could be implemented.

Another example of applying Ecohealth approach in understanding transmission and controlling the EID is Chagas disease risk in Guatemala (Bustamante et al., 2009). Vector distribution and Chagas risk in Guatemala have been found closely related to poor socioeconomic conditions, certain cultural characteristics, adobe housing construction and poor hygienic conditions. Recognizing that it would not be possible to address the problem of Chagas disease without involving local community members in the management of their environment and natural reosurces, an Ecohealth framework-based research attempted to address *Triatoma dimidiata* insect infestation problem in rural Guatemala. Different disciplinary knowledge stemming medical entomology, anthropology, microbiology, architecture, and civil engineering were put together to understand the different facets of the problem. In addition, local-community self-development approach was undertaken with the help of local leaders and stakeholders to motivate the communities to enhance the priority of addressing the Chagas disease problem. Such efforts, in turn, transformed the Chagas-control project to a community development initiative where greenhouse of both native and fruit trees were established and housing improvement activities, including reforestation, were strengthened among the population.

Transdisciplinary approaches – one of the major pillars of the Ecohealth framework – to leptospirosis had applicability and relevance to understanding the mechanisms by which infectious diseases emerge and reemerge. Leptospirosis - an important waterborne disease affecting hundreds of millions of people worldwide – is transmitted within a socio-ecological context where human population come into contact with water contaminated by urine from a wide variety of both wild and domesticated animals. The transmission of leptospirosis is anthropogenically driven by a variety of human cultural factors, combined with unique biological factors. Leptospirosis can therefore be seen as a multidisciplinary problem within biomedical, ecological, environmental, social, political, and cultural contexts (Lewis, 2005).

From the Ecohealth perspectives, research to delineate transmission of leptospirosis in Iquitos, Peru considered the complex anthropogenic environmental factors that influenced infectious disease emergence, the socio-political factors that determined how humans interacted with their environments, and combined these with quantification of leptospires in the environment, i.e., surface waters. In Iquitos, Peru, where governmental subsidies led to the extensions of housing, pig farming, and new settlements to support people involved in deforestation activities to reclaim rainforest for human use, without adequate provision for sanitation, led to environmental contamination by pig urine. It was revealed that risk exposures were generated not only because these animals were the vectors for transmitting leptospires to the environment, but activities that led to land clearance inevitably also had the scope to create other unanticipated consequences, such as facilitating tropical viral emergence and reemergence, as has occurred with sylvatic yellow fever, alphaviruses, arenaviruses, etc.(Weaver et al., 2000; Moncayo et al., 2001). By assessing local knowledge and risk perception among farmers, the Iquitos, Peru Study (Johnson et al., 2004) revealed that there was an important disconnect between the views that pigs as a known major reservoir of leptospirosis transmission and traditional views of pigs as part of a human–environment interaction. Integration of such diverse local knowledge with scientific knowledge has therefore been emphasized by the Ecohealth approaches to address tropical viral emergence and reemergence problems.

Application of an Ecohealth approach in understanding HIV/AIDS transmission in West Africa (Lewis, 2005) is another good example of its merits and strengths in explaining the role of complex ecological and societal spheres in viral disease transmission. HIV/AIDS have direct but distant links to the natural environment in the evolution of the virus and its transmission from primate reservoirs to human populations. Understanding global pandemic of HIV/AIDS includes the causal relationships between historical events, contemporary political systems, environmental disruption, poverty, and social conditions – including urbanization and migration – that lead to conditions that may enhance the transmission of the HIV. While HIV has roots in ecological disruption and limited impact on natural ecosystems, to develop effective prevention and control strategies, one requires to fully understand the complexities of the social systems in which it is embedded. In Ghana, for example, HIV was introduced by Ghanaian commercial sex workers who left the Volta region during an economic downturn and migrated to Abidjan, Cote d'Ivoire (Sauve et al., 2002). The HIV seropositivity rate was already high in Abidjan, and Ghanaians were exposed to HIV. Upon their return to the Volta region, newly infected Ghanaians introduced HIV to their homeland

(Sauve et al., 2002). The transmission of the virus was thus associated with the contemporary African economies and societies. The spread of HIV/AIDS can also be viewed as the unintended consequence of the importation of Western values and lifestyles to the continent of Africa. Therefore, the Ecohealth lens combining social, political, economic, and cultural aspects can assist explaining the complex transmission dynamics of infectious disease effectively.

Finally, it is easier to visualize the links between a social-ecological framework and understanding emerging infectious diseases, such as dengue and leptospirosis, than links to understanding HIV/AIDS. The former diseases have human behavioral components but their transmission is directly influenced by factors in the natural and/or human-built environment, whereas HIV has moved beyond the natural environment and became firmly embedded in various human-generated and sustained artificial environments, including the social, sexual, cultural, and political facets. Overall, the above discussion on the application of the Ecohealth approaches to the understanding of a wide variety of emerging infectious diseases worldwide provides us some significant conceptual and practical apparatuses to our efforts in understanding dengue disease transmission in Bangladesh and elsewhere. Also, it enables us to delineate, in part, the distinctiveness of dengue virus (DENV) transmission than other EID transmissions.

2.4 Ecohealth Conceptual Framework for Dengue Transmission Research

To understand the discourse of disease transmission research and its associated conceptual frameworks, one needs to assess the evolution of ideas concerning health, illness, and wellness. Such frameworks intend to explain the causal linkages or pathways of determinants and consequences of various factors associated with the status of population health and disease burden at the individual and societal levels. Here, my interest is in developing a conceptual framework to explain dengue disease transmission in a population in urban areas of the developing countries, cohort, from the perspective of social-ecological systems and human actions.

In the late 19^{th} century, with the development of Robert Koch's "Germ Theory", based on the dynamic equilibrium between host, environment and agent, the first recorded human health model (Called 'The Ecological model' or 'Health triad') was developed (Thrusfield, 1995). However, current patterns of disease do not always correspond to this model's assumption that all diseases have only one causal agent and that all exposed individuals become diseased (Levins et al., 1994). Keeping this limitation in mind, in 1975 Morris developed the 'Socioecological Model', which incorporated a multifactorial cause and effect model for both infectious and non-infectious disease.

In 1977, Travis developed the 'Illness-Wellness Continuum Model' to challenge the WHO definition of health - which he saw as virtually unattainable. 'The Illness-Wellness Continuum Model' argues that within ecosystems, human health is not an end-state but rather a continuum with the limitation of how one's socioeconomic and biophysical environments influence health (vanLeewen et al., 1999). Throughout the 1970s, more holistic models have evolved, for example by Lalonde's (1974) work which included four central influences on human health (environment, lifestyle, human biology, and health care system).

With the paradigm shift of WHO's definition of health in 1986, Hancock and Perkins (1985) developed the 'Mandala of Health', the first model to represent a nested hierarchy of influences on individual health. Since then, there has been growing interest over the last two decades in synthesizing the concept of human health, health promotion and sustainable development. Subsequently, various models (i.e. 'Community Ecosystem Model' by Hancock in 1993, 'The Health Determinants Model of Health' by Evans and Stoddart in 1990, 'The Butterfly Model of Health for Ecosystem Context' by vanLeewen et al., in 1999) have been developed to provide an ecological or ecosystemic way of understanding health, health and sustainable development, and healthy communities.

All of these models can be viewed as an understanding of the 'wholeness' of health by describing the dimensions and determinants of human health and ecosystem health and their interrelationships. However, disease as a determinant of human health within an ecosystem and the causal linkages between disease emergence, resurgence and transmission with ecosystems transformation has not been elucidated in any model (i.e. how socioeconomic and biophysical factors are linked with complex character and non-linear behavior of the human-natural systems in which host-pathogen systems are embedded).

By applying an Ecohealth research approach, I expect to determine how the key ecological variables and system properties can explain the transmission of dengue among a given population. My study also intends to further the knowledge of how an integrated, multi-level approach to human organizational hierarchy (i.e. at household and neighborhood/regional scales) affects dengue disease transmission. By applying an inductive approach, I plan to observe closely the objective reality of dengue disease transmission in the city of Dhaka, Bangladesh and subsequently develop a conceptual framework describing the socioeconomic and ecological determinants and their interrelationships as a causal loops for dengue transmission within the complex social-ecological systems. In addition, I intend to encompass the role of human choices and preferences that may function autonomously outside the domain of natural laws. My conceptual framework will specifically consider the multiple layers of social and ecological determinants that operate with nested hierarchical influences upon human exposure to dengue virus through *Ae. Aegypti* vectors.

2.5 Dengue Vector and Virus Dynamics

2.5.1 Vector abundance and density

In many tropical countries, a positive association between vector density and dengue infection has been cited (Foo et al., 1985). However, Gubler (1997) pointed out that the minimum vector density below which arbovirus transmission ceases has been debated for many years with no clear resolution. For example, in Singapore, where vector density has been maintained at extremely low levels through vector control program, DHF/DSS outbreaks were occurring even when the house index dropped to 2% in the 1990s (Goh, 1997). It has been argued that the nature of this relationship will vary temporarily and spatially depending on factors like human herd immunity, density of human hosts, characteristics of mosquito-human interaction, virus virulence and climatic variability like temperature and humidity (Scott and Morrison, 2003).

2.5.2 Type and size of water filled containers

The type and size of water filled containers have important implications for vector indices. An entomological countrywide study conducted in Trinidad (Focks and Chadee, 1997) found that the containers most responsible for the mosquito population were outdoor drums, water tanks, buckets, discarded tires, tubs, and other small discarded miscellaneous containers such as drink bottles, coconut shells, and cans. These containers accounted for more than 90 percent of all *Ae. aegypti* pupae. However, the relationship between the role of pupae-holding containers and the varying vector population remains unclear (Rodhain, 1997).

Epidemiological studies assessing the role of different types and sizes of larval development sites in dengue infection also have been conducted. Several cross-sectional studies and a hospital-based case-control studies have found a significant association between dengue infection and number of potential larval development siteson the premises (Kaplan et al., 1983), such a sun-covered medium size (50-200 litres) water filled containers (Koopman et al., 1991), large iron water tanks (holding thousands of gallons) within two house-blocks (McBride et al., 1998) and the presence of domestic animals as a surrogate for animal water pans (Waterman et al., 1986).

Statistical differences in pupal abundance were observed with respect to container types in Mexico (Arredondo-Jimenez and Valdez-Delgado, 2006). The most important in terms of pupal production was the cement basin, which is present in almost 100% of households. This type of container is needed in most tropical countries (including India, Sri Lanka, Bangladesh, and Thailand) due to frequent interruptions of the piped water supply. The presence of any container type was highly dependent on the domestic water requirements of the households, and which in turn varied with season (Midega et al., 2006). It is well-established that particular container types can sustain larger populations of immature *Ae. aegypti* than other development sites in the same area (Chadee, 2004). Overall, large containers tend to produce more pupae than smaller containers. In many studies, outdoor cement basins, metallic and plastic drums and discarded tires are the most epidemiologically important container types with consistent pupal productivity.

2.5.3 Seroepidemiology of dengue: Incidence and prevalence of dengue

An epidemiological approach requires specific indicators to be able to calculate the frequency of the disease. The measure of dengue infection can be made either by directly determining the occurrence of new symptomatic cases (disease incidence) in a risk population within a given period, or indirectly, by calculating the prevalence of anti-dengue antibodies in healthy people previously infected in a determined population. The dengue disease incidence is the measure used to to predict the magnitude of dengue epidemics (i.e. the impact on public health, and the best way to proceed to mitigate the consequences), while the disease prevalence permits us to know the magnitude of transmission in a given period, how the virus is circulating, and which age groups are most affected (Runge-Ranzinger et al., 2008; Gordis and Saunders, 2000). The simultaneous analysis of these two measures of disease and infection permits us to understand the dynamics of the dengue virus, determine the proportion of symptomatic and asymptomatic cases, and establish the risk factors associated with the disease. Since dengue is an acute disease, the incidence is the best way to determine its frequency. Since immunological conversion is a prevalent condition, seroprevalence of anti-dengue antibodies is the best way to determine previous infections with dengue virus; both are usually reported in epidemiological surveillance data (WHO, 2009).

Most epidemiological studies on dengue have been carried out to determine which proportion of the population has been previously infected by the dengue virus, which age group is more affected, and which virus serotypes are present in the population. In Indonesia in 1995, 1,837 children from 4 to 9 years old were studied twice over a one-year interval to estimate dengue seroprevalence (Espino et al., 2010). At the beginning of the study, 56.1 %

of the children were positive for dengue antibodies, while at the end of the study, 26.8 % of the seronegative children were seroconverted. In Singapore, a cross-sectional seroprevalence study was conducted to estimate the proportion of adults (18 to 45 year old) with dengue antibodies; 133 of 298 (45%) enrolled participants tested positive (Thai et al., 2005). The prevalence increased with age, from 17% 18 - 25 year group to 44% and 74% in 25 - 35 and 36 - 45 year groups, respectively. Singapore is one of the few Asian countries to have successfully reduced the incidence of dengue cases (Wilder-Smith et al., 2005). Antibody prevalence to DENV increased from 53% for the 7 year old children to 88% in the 13 year old children. (Thai et al, 2005).

The study of Teixeira in Brazil revealed a seroprevalence of 68.7% (Teixeira and Medronho, 2008). In the Dominican Republic, 98% of the 1,008 adults recruited at a blood bank and 56 % of children under 10 visiting a Hospital in Santo Domingo tested positive for dengue IgG. Among children, the prevalence of antibodies increased by age (Yamashiro et al., 2004). The seroprevalence of dengue antibodies in children under 11 years of age was 19.9% (Iturrino-Monge et al., 2006).

2.6 Socioeconomic and Ecological Factors in Dengue Transmission in an Urban Context

2.6.1 Human population density

Dengue is a classic example of how human population expansion has driven the emergence of infectious disease (EIDs) via increased human population density, especially in urban areas (Daszak et al., 2000). High human population density and high level of infestation by *Ae. aegypti* are driving factors for high rates of dengue transmission (Kuno, 1995; Teixeira et al., 2008). However, population density alone (in the absence of *Ae. aegypti* infestation) is not positively correlated with dengue seroprevalence (Almeida et al., 2007; Ali et al., 2003). This lack of correlation could be explained by the presence of large high-rise dwellings where the population density is high, but the inhabitants do not interact closely (Almeida et al., 2007).

Considering the complex structure and heterogeneity of urban areas, even a low level of vector infestation could lead to an epidemic in a densely populated area, whereas a similar infestation would not be sufficient to maintain transmission in an area with a larger population dispersion. Ali et al.'s (2003) study in Dhaka, Bangladesh observed that population density did not independently correlate with incidence of dengue disease, since presence of an infected vector population is the critical factor. Thus, considering the different patterns of urban occupation, population density is not an accurate measure of dengue risk in urban areas.

2.6.2 Water source

A population-based cross-sectional study of 1,608 individuals and households, assessing the role of demographic and environmental variables in the prevalence of dengue infection, found that piped sources of drinking water were significantly associated with dengue infection compared to using wells or river waters (Hayes et al., 1996). The limitation of this study is that the authors did not control for factors regarding water storage or the use of preventative measures for controlling dengue.

2.6.3 Vegetation type at neighborhood level

Vegetation type and vegetation cover greatly influence the distribution of mosquitoes via the various types of larval development sites (i.e. microhabitats) they create. Studies on the spatial distribution of the principal vector (*Ae. aegypti*) and secondary vector (*Ae. albopictus*) of dengue disease have shown that *Ae. aegypti* predominates in highly urbanized areas, whereas *Ae. albopictus* is not abundantin rural areas. For example, *Ae. albopictus* seems to be restricted to wooded areas next to human dwellings (O'Meara et al., 1993); areas without tall vegetation seem to attract few *Ae. albopictus* (Nguyen et al., 1974). Conversely, *Ae. aegypti* can be found in a variety of urban habitats - including highly urbanized areas without wooded vegetation - although little information is available on how vegetation type correlates with mosquito ecology (Cox et al., 2007; Vezzani and Carbajo, 2008). In their study, Cox and Vezzani confirmed significant association between the *Ae. aegypti* and *Ae. albopictus* developmental sites and the shade provided by local vegetation. This suggests that shade is the main factor determining developmental site quality, as unshaded locations are somewhat less likely to house mosquitoes - possibly due to high temperatures. Short grass in the neighborhood is another factor correlated with unsuitability for *Ae. aegypti* development (Vezzani and Carbajo, 2008).

2.6.4 Housing structure characteristics at household level

An association between house construction materials and style of the house with dengue infection has been established by a number of studies in various parts of the tropics. A study conducted in Puerto Rico (Waterman et. al., 1986), after adjusting for other environmental and behavioral variables, found that wood construction material and slum housing are significantly associated with increased risk of dengue infection. The authors suggest these characteristics may favor the presence of mosquitoes and the interactions of mosquito and humans. In addition, they found in comparing wood/concrete houses with socio-economic status that those of the low socio-economic level living in wood houses had the lowest risk when using screens in the house.

2.7 Individual (Self) Risk Perception and Behavior

2.7.1 Risk perception of dengue disease, vector, and its transmission

Research has demonstrated that self-perceptions of risk are influenced by five major theories: knowledge theory (people perceive things to be dangerous because they know them to be dangerous), personality theory (risk avoidance tendency; e.g. men tend tend to judge risk as less problematic than women), economic theory (the poor presumably feel vulnerable and the rich are more willing to take risks), political theory (holding office grants social advantages), and cultural theory (individuals choose risk in order to support their way of life) (Wildavsky & Dake, 1990). Self-risk perception of human health can be justified by Health Belief Model (HBM) developed by social psychologists, which is a conceptual formulation for understanding why individuals choose to engage in a wide variety of health-related topics (Janz & Becker, 1984). The conceptual formulation is based on five components, namely perceived susceptibility, perceived severity, perceived benefit, perceived barriers, and self-efficacy (Hochbaum et al., 1958). Perceived susceptibility is a person's subjective perception of the risk of developing a particular health problem. Perceived severity is defined as concerns about the seriousness of the health problem and its consequences. Perceived benefit refers to the individual's beliefs in the effectiveness of action to reduce the health problem severity. Perceived barriers are the perceptions of potential obstacles to health and self-efficacy refers to the confidence that one can successfully practice the behavior required to produce the outcome (Strecher and Rosenstock, 1997).

It is very important to understand people's self-risk perception regarding dengue in order to construct dengue-related messages to educate people or to guide campaigns focusing on community-based vector control programs (Phuanukoonnon et al., 2006). Studies to understand how an individual perceives the knowledge and risk of dengue vector abundance and water storage and /or usage capacity in a single household were first conducted in Thailand in 1988 (Phuanukoonnon et al., 2006) for developing mosquito larval-control health education messages. A number of studies have also shown that the link between disease and disease causal elements are generally understood by the population. In Thailand, study result (Phuanukoonnon et al., 2006) shows that people can distinguish DHF from other diseases, but perceive of mosquitos as more of a nuisance than a disease vector. This is due to the continual presence of mosquitoes year-round (Phuanukoonnon et al., 2006). They also believe that *Ae. aegypti* control programs to be ineffective, as mosquitos persist despite larval control initiatives.

In Brazil, people living in under-privileged socio-sanitary neighborhoods perceived water scarcity to be of greater concern than dengue. As they do not have a reliable running water supply, people perceive greater risk in failing to store water, even though doing so increases vector production and dengue risk (Caprara et al., 2009). In two Columbian towns (Melgar and Girardot) it was found that risk perception regarding dengue arises only when it is linked to a neighbor (Suarez et al., 2009). In summary, dengue risk perception and social conditions are linked in a complex relationship and HBM is less powerful at explaining this.

Overall, self-risk perception of disease entails broader social, cultural, economic dynamics than self-knowledge, skills and resources.

2.7.2 Frequency of water replacement

Some studies suggest an association between the frequency of the water replacement and storage locations within the household dengue infection. For example, in Malayasia, differences in DHF incidences among three culturally different communities (Chinese, Malays, and Tamils) were observed between 1975-1987. It was postulated that these differences were due to differences in their water storage and use practices (Sekhar and Huat, 1992). Among the three communities, the Chinese community has the highest infection rate as they do not change their stored water every day. The Tamil communities, who stored water outside their house and went out to obtain water every day, exhibited the lowest rate. In Singapore, similar differences in dengue rates among the same ethnic groups were observed between 1990 and 1994. The morbidity rates among Chinese, Tamils and Malays were 54.1, 36.0, and 19.8 per 100,000, respectively (WHO, 1995).

Factors such as variations in water depth and the place in the household that water was stored may affect mosquito development and the interaction between mosquitoes and people. In summary, important questions remain unanswered regarding the influence of developmental sites, different container types, whether the container is partially covered, and the frequency of water replacement on dengue risk.

2.7.3 Water use patterns at household level

Several factors have been suggested as being imprtant to mosquito development (Focks et al, 1993; 1995), including type and size of potential larval development sites, their placement, frequency of water replacement, and the characteristics of the container covering (such as the material used to cover water receptacles and the tightness of the covering). All these factors are important in the development, survival and feeding behavior of the *Ae. aegypti*. For example, the type and size of the water container and water depth affect hatching, larval development and the survival of mosquito larvae. In some regions of developing countries where a potable water supply does not exist, tanks for storing rainwater are common (Caprara et al., 2009). Oviposition is affected by the presence of water, the size of the container, water temperature, and the presence of the other container types in the environment. In addition, it is postulated that larvae and pupae abundance within wet containers is related to oviposition, temperature, food availability, and fluctuations in water depth. Consequently, some containers may have a numerous immature mosquitoes depending on the number and types of factors present, but the production of adults may be limited. Kuno (1995) suggests that the type and size of the container influences the overall body size of adult female *Ae. aegypti*, and that small mosquitos must feed more frequently, amplifying the dengue transmission rate. Therefore, not only the number of adult mosquitoes but also their relative size may influence disease transmission.

2.7.4 Risk perception and preventive behavior: Bed net and house screen use

The role of bed nets in the prevention of dengue infection is debatable. Some authors consider bed nets to be ineffective due to the specific behavior of *Ae. aegypti*. These mosquitos are most active during the day - usually mid-morning and late afternoon - when few people use bed nets. Others suggest that some biting occurs in the dark (Gordon and Young, 1921) and just after dawn (McCleland, 1960). Studies conducted in East Africa have shown that biting activity also occurs at night and early morning (Trpis and Hauserman, 1986). Consequently, they recommend the use of bed nets even by those who do not rest in the afternoon. Two population based cross-sectional studies (Koopman et al., 1991; Rodriguez-Figueroa et al., 1995) found that the use of bed net use increases the risk of infection. McBride et al. (1998) and Ko et al., (1992) found no association between bed net use and infection. However, alternate explanations for these findings are possible. For example, the results showing positive association could be due to differential mosquito exposures, for example if those using bed nets at night were intensely bitten during the daytime because they stayed home all day. Also the presence of social desirability bias could influence the association if those who had the disease wanted to comply with a well-publicized measure. This is a real problem in places where those not complying with bed net use have to pay a fee. These potential confounders or biases were not discussed by the authors. Kuno (1995) suggests that differential exposure is likely when the areas are not heavily infested. Also, the lack of independent effect of some of the studies could be the result of misclassification errors resulting from the low specificity of the dichotomous response to the question “do you use a bed net?” Bed net use is one of the most commonly recommended measures by dengue control programs but the evidence of their efficacy is questionable at best.

Screens on doors and windows can reduce the number of mosquitoes inside a building, provided that doors are kept closed and there are no larval development sites inside of the screened area. Studies conducted in Taiwan (Ko et al., 1997) and Australia (Murray-Smith, 1996), have found that those living in screened houses had a significantly lower risk for dengue infection as compared with inhabitants of unscreened houses. Ko et al. (1997) also found an interesting dose response relationship. People living in fully-screened houses had the lowest odds ratio (0.18 and 95% CI: 0.06-0.56) when compared with those in partially screened or unscreened houses. The unscreened houses showed the highest risk.

2.7.5 Spatial mobility and movement of household members

The understanding of human mobility and the development of quantitative theories and qualitative models is of key importance to the research of human infectious disease dynamics on geographical scales (Brockmann et al., 2009). Long range human mobility in our globalized world is responsible for the rapid geographical spread of emerging infectious diseases like severe acute respiratory syndrome (SARS) in 2003 or, more recently, the H1N1 strain of Influenza A.

There is much historical evidence of the spread of disease through human mobility. Mobility of people has contributed to the transmission of malaria (Prothero, 1977) in Africa, and smallpox in Bangladesh and eastern provinces India (WHO, 1975). Thirty years ago, Prothero provided a typology of different movements (circulatory movements, where individuals return home after some period, and migratory movements where permanent changes of residence occur), and characterized them by their spatial and temporal scales. He suggested that knowledge of movements would help to explain the incidence and prevalence of disease in a population and provide informed option for control (Prothero, 1977). One good example of this is the spread of dengue virus globally via commercial shipping routes (Gubler, 1997).

At a smaller scale, individual human movement is a critical behavioral factor underlying observed patterns of vector-borne pathogen transmission because movement determines exposure to infectious agents, i.e. bites from infected mosquito vectors (Stoddard et al., 2009). At broad spatial scales (e.g. national, international) individual movements drive pathogen introduction and reintroduction. Dengue virus is mostly transmitted when people are engaged in daily activities (Kuno, 1995) as *Ae. aegypti*, the principal vector of dengue virus, bites during the day (Christophers, 1960). Although *Ae. aegypti* disperses only short distances (Harrington et al., 2005) and is heterogeneously distributed within urban areas (Schneider et al., 2004; Getis et al., 2003), humans move frequently at local scales, increasing risk of contact with mosquitos (De Benedictis et al., 2003; Kuno, 1995; Favier et al., 2005; Pongsumpun et al., 2008).

2.8 Local Knowledge and Community Perspectives of Dengue

2.8.1 Significance of local knowledge and community perspectives

The origin and evolution of dengue virus (DENV) although date back to millennia, its transmission to affect humans as a severe illness is a relatively new phenomenon. Within the domains of Traditional Ecological Knowledge (TEK), its scope and coverage have therefore been extremely limited. However, such limitations do not nullify the significance of Local (in the sense of geographically and socially micro-scale entities including small rural, remote, marginal human communities) Knowledge (LK) concerning cause, severity, transmission, methods of controlling and prevention of dengue viral infection and its associated diseases - dengue fever (DF), dengue hemorrhagic fever (DHF) and dengue shock syndrome (DSS).

This is because seeking sustainable solutions to dengue disease risk, especially among the urban population of the developing countries, require addressing not only technical and financial challenges, but also the deficiency in risk identification by the local community and the underpinnings of cultural beliefs, attitudes, and practices by the members that prevent solutions from being implemented successfully.

To make dengue disease and epidemic control programs successful, recent literature, particularly health science and applied research, emphasizes the importance of community knowledge, attitudes and practices as well their participation with a 'sense of ownership' to improve risk perception, risk reduction behavior as well as disease control effectiveness (Ebi and Semenza, 2008). Understanding how local community members perceive the risk associated with dengue disease and its vector, what are their attitudes towards prioritization and addressing the problem, is likely to advance finding a direction and solution of this issues, at least partially. Unfortunately, despite such known importance, limited efforts have been given thus far by the concerned institutions to know what dengue culturally means to community members at large as well as what it means for individuals in their everyday life (Suarez et al., 2005). In other words, dengue is scientifically identifiable and explainable, but not culturally understandable as it presents diverse cultural forms and a large variability of meaning; it thus bears heavily an element of socio-cultural construction (Gubler and Meltzer, 1999). In brief, dengue disease is one for which nominal traditional knowledge and little appropriate local knowledge exist as it is an example of "the kind of 'new' disease problem that societies in transition are facing" (Kendall et al., 1991; pp.260).

Dengue disease burden represents a complex 'bioanthroposocial' problem because it is viewed in varied perspectives by different social actors in different parts of the world. In short, the definition and meaning of 'dengue' is the result of people's cognition situated in a specific context and time in their life stories, irrespective of clinical conditions. The wide adaptations to new and modern contexts of dengue hence go beyond the frontiers only of expert scientific knowledge – as solely a clinical issue – and hence need serious attention to local experiential knowledge, belief system, norms and customs and their integration with health science and modern medical knowledge. Several recent studies have confirmed that local perceptions of dengue disease risk are a critical factor in the performance of intervening programs as they influence significantly the motivation towards participation in mosquito abatement (Gómez-Dantés and Willoquet, 2009).

Local knowledge, perception, and attitudes towards dengue and its control are closely linked with social, cultural, ecological and socioeconomic contexts, and therefore a high degree of variability has been recorded in the literature. Due to the fact that many disease risks are abstract and remote and most individuals are either overly optimistic or ignorant about his/her own personal risks in many situations, one important aspect of the mental representation of an abstract risk is whether it is considered acceptable or unacceptable. If the risk is viewed as acceptable, usually no further action is taken. Generally, in the developing world, at the family level, dengue is considered 'mild', and a common disease that does not require investment in time or money in health care, except when symptoms are severe (Gomez-Dantes and Willoquet, 2009). As it is known well that local meaning of a disease has profound implications for local interventions, it is worth noting here some recent empirical observations. Dengue is defined by local community members in Merida, Mexico, in terms a local classification of fevers into low-and high-grade (*irritacion* or *calenture* and *fiebre,* respectively) (Kendall et al., 1991), whereas in Colombia, dengue for the local context was described as the ‘folk flu syndrome’, ‘virosis’, or ‘just another cold’ (Suarez et al., 2009). In Malaysia, local community members were found to be confused about the term dengue with other febrile respiratory illnesses (Wong and AbuBakar, 2013). Despite outbreaks of the dengue and implementation of extensive public health education programs by the government in Honduras, local knowledge on dengue and its vector appeared to be very limited (Kendall et al., 1991).

In contrast, local people in Thailand referred dengue as *khai lueat ok,* a term related with ‘bleeding fever’, which reflected that there was no common term for the less severe form of the disease, and community members paid attention to dengue while only it transformed from dengue fever to dengue hemorrhagic fever (DHF). A higher level of awareness of dengue was noticed in a number of Latin American countries. For example, in Colombia, Quintero et al. (2009) found out that that 91.3% local community members knew about dengue, and 98% of them had the knowledge that dengue is transmitted to human by infected mosquito bites. Despite such higher level of awareness of dengue and its associated risk, human cognition and overt behavior in preventing or reducing the dengue disease risk have been found not positively and strongly correlated. People’s cognition is influenced considerably by the socio-cultural and ecological contexts, individuals’ position in social structure and personal experience. Kendall et al. (1991), for instance, observed in Honduras that mosquitoes here were considered as ‘community problem’ and its control was thought to be an issue of personal protection, outside the realm of community efforts, at the hands of governments or external authorities. Even though local community members were aware of the relationships between the mosquito breeding places and water storing behavior, Suarez et al. (2009) recorded in Colombia that they continued to store water for considerable longer duration in containers in their houses. Members from the lower socioeconomic strata felt constrained by their resource scarcity to incorporate dengue risk factor in their water and other household resource management despite their ‘sufficient’ knowledge of the impending risk.

Similar ‘risk attenuation’ was observed by Suarez et al. (2005) in their study of the local people in Villavicencio, Colombia who perceived mosquitoes as part of their everyday life and considered them as ‘another bug’ among many others in the tropical environment. The local residents also elicited that even though vector niche found in any kind of vase or water holding ornamental container, they were not associated with the vector’s proliferation. Suarez et al. noticed that, on the contrary, local people’s perception was associated more with status symbols of well-being and esthetic decorative objects of those vases than dengue mosquito breeding sites and their associated risk to DF, DHF and DSS. Deficiency in the understanding of the severity of dengue among the residents of Girardot and Melgar towns of Colombia was also registered by Suarez et al. (2009). Here, most of the people did not opt for the medical consultation as their first option, reflecting the failure of risk identification and/or some form of cognitive-dissonance behavior; the usual procedure in these communities began at home with self-medication, asking neighbors for advice. In some Asian countries, similar dengue risk-attenuation and cognitive-dissonance behavior regarding dengue treatment were registered. For example, in Thailand, some communities take extraction papaya leaves, frog soup, crab soup as effective medication for curing DF (Wong and AbuBakar, 2013). One of the explanations for this suggest local people do not perceive dengue as *dangerous* as other diseases that warrant professional medical treatment. Some local male community members in Thailand elicited that drinking *ubat kampong* (folk medicine) transformed their blood bitter and eventually mosquitoes would not bite (Wong and AbuBakar, 2013). Some elderly participants believed that thickened and hardened skin was a natural barrier against mosquito bites and therefore, the elderly were therefore less likely to be bitten by mosquitoes.

2.8.2 Significance of local level participation

Dengue control demands household level control that involves high level of local community participation and support in absence of anti-viral drugs and effective vaccine. The limited periodic vertically integrated public programs on vector control till now have relied on space spraying. By the mid-1990s it was evident, especially from the experience in Latin America, that effective and sustainable *Aedes aegypti* control could not be attained by targeting the adult mosquito; rather, success could be achieved by the elimination of larval habitats from the domestic environment or source reduction (Gubler and Clark, 1994, 1996; Schliessman and Calheiros, 1974). The vertically structured government programs (top-down) generally were not sustainable due to the lack of continual support by public funds and community members had no defined role or responsibility in program implementation and maintenance (Gubler and Clark, 1996: 171). Such programs did not require the direct involvement of community members and a broad range of stakeholders in implementation, nor did they allow communities to have an ownership through participation in decision-making, planning and evaluation. As a result, the sustainability of dengue prevention programs, particularly through vector control, has remained a major concern in many developing countries of the tropical world.

Cost-effective and socio-culturally suitable dengue prevention and control, through reduction of *Aedes aegypti* and *Aedes albopictus*, could provide a better policy option if such measures were developed by the initiative of local communities and involved the participation of stakeholders at all levels. In recent years, it has been further noticed that the programs that predominantly target the private domain and individuals' behaviour change, assuming that the large proportion of breeding sites lies within the household, neglect the aspects of local public services, infrastructure, and social-ecological environment (Boischio, 2009). The need for strengthening local organizations and the capacity of community members to effectively participate in decision-making, planning and implementation, and evaluation processes does not receive due attention in these type of programs. Building capacities and skills at the local level to take part effectively in decision-making, planning and implementation, and evaluation of community-oriented programs are vital for achieving results and success in health-related programs (Perez et al., 2007), and such capacity building efforts must be viewed as social learning process.

2.9 Dengue Research in Bangladesh: Current State of Knowledge

2.9.1 Empirical research on dengue and its transmission

The literature on dengue in Bangladesh began to accumulate when the first case of dengue fever, popularly known as 'Dacca fever' (Aziz et al., 1967), was recorded in the former East Pakistan territory. Two distinct periods of dengue research and contributions to the relevant literature in the context of Bangladesh can be identified: i) 1967-1999 (pre-2000 outbreak); and ii) 2000 and onward (post 2000 outbreak). Four studies carried out during the pre-2000 outbreak period deserve attention. The Integrated Control of Vector-Borne Disease (ICOVED) Project of the Directorate-General of Health Services in collaboration with WHO

(Yunus et al., 2001) provided the first evidence of dengue infection in Bangladesh. As stated earlier (Chapter 1; Section 1.5), in addition to confirming the presence of dengue in the country, this study also recorded some evidence of future potential outbreaks. Because dengue fever was not a major public health concern until the 2000 outbreak, only nominal efforts were made to investigate this disease and its transmission in Bangladesh. Among them, Hossain et al.'s (2003) work is noteworthy. By testing 225 serum samples from dengue patients and 184 blood donors in 1996 and 1997, they reaffirmed that dengue transmission was an ongoing infectious disease threat to the population well before 1996. The first scientifically designed survey was conducted in Chittagong in 1996-97 and showed an average ELISA positive rate of 17.5% (Yunus et al., 2001).

The post-2000 outbreak literature on dengue in Bangladesh is characterized by a response to the enhanced public concern about this disease and its burden. This relatively sizable literature primarily concentrated on three broad research areas: i) emergence, clinical manifestation and laboratory-based analysis of dengue outbreaks; ii) vector dynamics and transmission of dengue; iii) institutional performance in dengue control.

i) emergence clinical manifestation and laboratory based analysis of dengue outbreak: In a review of the factors of emergence of dengue in Bangladesh, Mahmood and Mahmood (2011) attempted to identify risk factors and levels of awareness of dengue. They identified macro-level factors including overpopulation, uncontrolled urbanization, and poor waste management. Rahman et al., (2002) conducted a hospital-based surveillance of 176 patients during the 2000 outbreak in Dhaka. They found DENV-3 serotype among eight patients, and 39.2% patients had DHF - the first reported cases in Bangladesh. A small pilot study to evaluate the strain of DENV responsible for the 2000 outbreak revealed that the envelope genes of DENV from 18 hospitalized patients were closely related to recently-emerged dengue type 3 viruses from neighboring Thailand and Myanmar (Poddar et al., 2006). Another study by Aziz et al. (2002) on molecular characterization of DENV supports the previous findings as this study also detected DENV 3 among all dengue patients except two in four hospitals in Dhaka. There are few other serology based studies associated with the 2000 outbreak in Dhaka (Pervin et al., 2004).

ii) vector dynamics and transmission of dengue: To date, only one scientifically sound and methodologically well-grounded empirical study on dengue vector mosquitoes and their spatial disctribution has been carried out in Bangladesh. This study was performed by Ali et al. (2003) during the post -2000 outbreak period. By conducting entomological surveys in all of 90 wards of the city of Dhaka, the study concluded that the key role in dengue transmission was played by *Aedes albopictus*, although *Aedes aegypti* was more prevalent in households. To evaluate *Aedes* development sites in Dhaka, Bashar et al. (2006) examined container productivity during the monsoon season of 2003. The study found clay jars, pots, pitchers, buckets, cement tanks, flower vases, and drums to be the most important indoor containers for mosquito breeding. Karim et al. (2012) examined whether the climatic factors data can be used to predict yearly dengue cases in Dhaka by evaluating dengue vector mosquito generation and development. A study by Banu et al., (2012) examined the space-time clustering of dengue fever transmission in Bangladesh. They concluded that DF transmission was clustered during three periods: 2000-2002, 2003-2005, and

2006-2009. The study further identified Dhaka as ‘the most likely cluster for DF in all three periods’ (p. 1086). The results also revealed that the geographical range of DF transmission has declined in the country over the last decade.

iii) institutional performance in dengue control : Most of the studies on governmental and non-governmental institutional interventions to control dengue in Bangladesh are anecdotal; they are primarily reported in daily newspapers, media, and technical reports. Therefore, the scientific value of these data is limited, though they can provide some valuable facts and figures about institutional interventions and their performance. In a detailed study of the role of the Dhaka City Corporation (DCC), Mahmmod (2006) elaborated the failure of DCC authority to procure the necessary larvicides in time to prevent the 2002 dengue outbreak.

A review of the literature on dengue in Bangladesh leads us to conclude that the present study is the first of its kind to encompass dengue vector dynamics and their association with population serology as well as both individual and institutional knowledge, attitudes, and practices (KAP) regarding dengue risk in Dhaka. The existing literature relied heavily on applying disciplinary approaches; by departing from these conventional approachess, the present study attempts to recognize the complex systems involved in disease transmission in terms of time and space, and applies a transdisciplinary approach to comprehend dengue transmission dynamics in Dhaka. To fill in this gap, the present study has attempted to conduct a population serological survey to determine the magnitude of past and recent dengue infections. Also, it aimed at examination of the degree of association between seroconversion among the population and dengue vector abundance in Dhaka. Overall, the present study lays a strong baseline for transdisciplinary approaches to understand not only dengue transmission in a setting of rapidly growing developing country, but also to undertake future research on other infectious diseases such as JEE, Chikungunya, and Yellow Fever.

2.9.2 Status of dengue risk in public health policy domain

Dengue is a recent phenomenon in Bangladesh, and the 2000 outbreak was unprecedented due to its scale, causing 5551 cases of dengue, of which 4385 were DF (78.9%), 1166 were DHF (21.1%), and 93 were fatal (1.6%). Even with gross underreporting due to a lack of an active surveillance system - as well as the poverty-stricken population's economic inability to seek medical treatment - the government health report revealed that dengue incidence in the larger cities of Bangladesh has remained a continuous phenomenon year-round. A trend analysis confirmed the resurgence of dengue outbreaks, of varying magnitude, during the 2000-2012 period. Although nominal literature is available on stakeholders' dengue risk perception, attitude and behavioral outcomes, Ahmed and Mahmood's (2006) qualitative analysis of the post-2000 period provides some valuable insights into policy responses to the 2000 dengue outbreak and post-2000 resurgences. In the absence of scientifically-designed surveillance systems in Bangladesh (Mahmood and Mahmood 2011), institutional responses to the DF and DHF epidemics of 2000 and 2002 relied upon information available from mass media and local public health concerns expressed through elected officials (such City Mayors and Ward Councilors) and public health personnel. The dengue epidemic prevention and control measures therefore remained in the form of post-facto interventions made as a result of public or political pressure placed upon the concerned authorities.

Mahmood (2006) alleged that the national government has largely failed to address the dengue problem. It was cited that the Dhaka City Corporation (DCC) failed to procure the necessary larvicides and adulticides to control *Aedes* mosquitos, and that the limited fumigation that was carried out was not effective. The procurement failure was explained as such: "It was asked why the DCC failed to collect the medicine in the year 2002. The source informed that since the DCC did not pay the previous dues [to] Rhone-Poulanc India for the same medicine [larvicide] procured earlier. The source further said that Rhone-Poulanc refused DCC to supply the medicine without payment of its previous dues" (p. 2).

Over the last decade, number public health sector and private sector (television, radio, newspapers) information campaigns regarding dengue risk with relation to *Aedes* mosquitos have been implemented. Nonetheless, the required specificity regarding dengue virus infection and transmission involving the host-vector-environment nexus in general was absent in such programs. In response to public and political pressures, the DCC authority reluctantly undertook periodic programs of spraying larvicides (e.g., DDT) and organophosphate insecticides (e.g. fenthion, malathion). A number of critiques have argued that these programs were largely ineffective (Mahmood, 2006; Mahmood and Mahmood, 2011). In explaining the 2002 dengue epidemic, the Daily Star (a local newspaper) reported that the DCC neither "approve [d the] purchase of larvicide to kill the *Aedes* mosquito larvae, [nor] … sent any sample of the larvicide to the plant protection wing for approval. The worst thing was [that] DCC did not have a plan at hand to face dengue attack despite warnings previous year that the fatal infection would come in a wave" (cited in Mahmood 2006, p.4).

Overall, although the dengue risk to the population of major cities in Bangladesh has been recognized in government policy notes and reports as having 'potential of epidemicity and endemicity', dengue has nonetheless remained a low-priority issue. The 2013 Government of Bangladesh Report on communicable disease control has suggested that:

"The communicable diseases of public health importance include malaria, Kala-azar and infestation with filarial and other worms, avian influenza and influenza by novel virus. The country has been facing emergence of zoonotic diseases like Nipah, anthrax, brucellosis and food and waterborne disease like hepatitis due to viruses, diarrheal disorders, enteric fever and leptospirosis" (p. 23). The report then added that anthropod-borne diseases like dengue and chikungunya with proven potential for epidemicity and endemicity are a threat to public health in the country. In terms of dengue surveillance and monitoring, periodical entomological surveys are conducted by the Ministry of Health and Family Welfare. For example, a larval survey was conducted during August 2012 in various local communities of the City of Dhaka, revealing the range of HI to be 6.67 to 34.62; CI from 8.33 to 89.36 and BI from 6.67 to 100. It is unlikely that the present passive surveillance of dengue will increase in priority unless large-scale outbreaks or epidemics drive media and public pressure on governments and other decision-making authorities.

2.10 Place of the Present Study in the Current Literature: Transdisciplinary Empirical Research on Dengue

Interest in multi-scale, multi-faceted causation of diseases has evolved through out the late 20th century and became an established approach in the disease causation discourse through the work of Nancy Krieger and her contemporaries in the 1990s (Krieger, 2001; 2002; Berkman & Kawachi, 2000). The general failure of controlling dengue vector in a sustainable manner, which led to reemergence of dengue both in Latin America and Southeast Asia, raised serious questions about biomedical, disciplinary-oriented interventions using insecticides and larvicides. Recognizing the limitations of such biomedical approach and incorporating social factors in dengue resurgence, the Special Program for Research and

Training in Tropical Diseases (TDR) of WHO and IDRC carried out a joint research initiative in Latin America in 2003-05. This initiative aimed at improving dengue prevention and control by better understanding its ecosystem-related, biological, and social ('eco-bio-social') determinants and developing community-centred ecosystem management interventions directed at reducing dengue vector larval habitats (Sommerfeld & Kroeger, 2012). Under this program two empirical studies were conducted, one in Brazil and one in Colombia.

Led by Andréa Caprara and his collegues (2009), the Brazilian study in the city Fortaleza provided valuable new insights regarding multi-factorial dynamics in dengue transmission. The study suggested that multiple factors influence dengue vector ecology, including large-scale phenomena such as social policy, migration, urbanization, city water supply; and medium and small-scale phenomena such as garbage disposal and housing conditions, community level knowledge of the disease, and related practices. The results revealed that irregularity of water supply does not affect households in priviledged areas, whereas in households from under priviledged blocks, where water supply is very irregular, the frequent use of water containers such as water tanks, cisterns, barrels, and pots helps create environmental conditions with larger number of larval development areas.

The Quintero et al. (2009) s' research in the Girardot and Melgar municipalities of Colombia focused on the role of containers in immature *Ae. aegypti* productivity, and found out that the presence of low water levels in containers leads to a seven-fold increase in the risk of finding immature forms of *Ae. aegypti* in the households. Interestingly, the study also observed an inverse association between socio-economic stratum and presence of the vector. The other Colombian study, carried out by Suárez et al. (2005), asserted that dengue is a unique ‘node of disease’ that can be described as a point of convergence between public health policies, the affected population, the environment, and the social dynamics created through such interactions. From the perspective of the health sector, dengue is illustrative as a disease, in that it creates an adverse impact on public health, but from a livelihood and social perspective, individuals in Colombia have learned to live and cope with it.

Encouraged by the newer findings on eco-bio-social determinats in Latin America, a five-year research and capacity building initiative to implement community-based interventions in six Asian countries (India, Sri Lanka, Indonesia, Phillipines, Myanmar, Thailand) was undertaken by TDR and IDRC (Sommerfeld and Kroeger, 2012). The dengue vector breeding study component of this research found that the most productive vector breeding sites were outdoor water containers - more so if uncovered, under shrubbery and unused for at least one week. For pupal production, peri-domestic and intra-domestic areas were observed to be much more significant than commercial and public spaces (except schools and religious gathering places). In examining the association between household level ecological and socio-demographic determinants of dengue in urban areas of Chachoengsao province in Thailand (2006-07), Koyadun et al. (2012) observed that dengue risk was most associated with households situated in the ecotope of mixed commercial and densely-populated urban residential areas, high historical dengue risk, and presence of household window screens. The socio-demographic model of the study revealed that dengue risk was most associated with householders aged more than 45 years and community efforts in environmental and waste management. The above six-country Asian studies experimented with various types of conventional and innovative interventions to prevent and control dengue vector in urban and peri-urban areas. In sites where water containers generated more than 70% of *Aedes* pupae, the interventions ranged from mechanical lid covers for containers to biological control. In places where small discarded containers were most prevalent, local groups experimented with solid waste management, composting, and recycling schemes. Such programs had a significant impact on vector densities at some sites while at other sites demonstrated varying effects. In this regard, Tana et al. (2012) argued that sustainable changes for dengue control require both a holistic approach that takes into accounts the eco-bio-social factors, and the active participation of the local community.

A critical review of the eco-bio-social determinants-oriented research and interventions into dengue disease control leads us to argue that in the absence of proper understanding of the transmission process, the focus of interventions has been only upon vector control. Although both large and small-scale factors of dengue vector dynamics were studied in some of the Latin American studies (Quintero et al., 2009; Suárez et al., 2009), none of the TDR/IDRC dengue studies considered the multi-scale interactive dynamics under a single framework; rather, large and small scale factors were considered separately. However, these regional (world) studies have laid a strong foundation for future Ecohealth-oriented research in other regions or countries.

The present research not only extends the Ecohealth-oriented investigation of questions relating to transmission, implementation of interventions, and policy formulation to Bangladesh, but also offers a new transdisciplinary framework for research on dengue transmission. It also offers ‘show case’ research outcomes regarding knowledge, attitudes, and practices with respect to dengue risk among the various stakeholders in society - specifically the decision makers, health practitioners, local leaders, and community members - and strategies for mobilizing them to undertake effective interventions.

References

Ali, M., Wagatsuma, Y., Emch,M. (2003). Use of a geographic information system for defining spatial risk for dengue transmission in Bangladesh: role for Aedes albopictus in an urban outbreak. *American Journal of Epidemiology, 69*(6), 634-640.

Almeida, M C de M., Caiaffa,W.T., Assunção,R.M. (2007). Spatial Vulnerability to Dengue in a Brazilian Urban Area During a 7-Year Surveillance. *Journal of Urban Health, 84*(3), 334–345.

Arredondo-Jimenez J. I,Valdez-Delgado, K. M. (2006). Aedes aegypti pupal/demographic surveys in southern Mexico: consistency and practicality. *Annals of Tropical Medicine and Parasitology, 100*(1), S17-S32.

Assessment, M. E. (2005). *Ecosystems and human well-being* Island Press Washington, DC.

Assessment, M. E. (2005). *Millennium ecosystem assessment synthesis report* Millennium Ecosystem Assessment.

Aziz, M. A., Gorham, .J R.,Greg,g M. B. (1967). "Dhaka fever"-an outbreak of dengue. *Pakistan Medical Journal of Research, 6,* 83-92.

Aziz, M., Hasan, K., Hasanat, M., Siddiqui, M., Salimullah, M., Chowdhury, A., . . . Hassan, M. (2002). Predominance of the DEN-3 genotype during the recent dengue outbreak in Bangladesh.

Banu, S., Hu, W., Hurst, C., Guo, Y., Islam, M. Z., & Tong, S. (2012). Space-time clusters of dengue fever in Bangladesh. *Tropical Medicine & International Health, 17*(9), 1086-1091.

Berkes, F, Colding, J., Folke,C. (2003). *Navigating social-ecological systems*. Cambridge: Cambridge University Press.

Berkes, F.,Folke C. (Ed.). (1998). *Linking social and ecological systems*. Cambridge: Cambridge University Press.

Berkman, L. F., & Kawachi, I. (2000). *Social epidemiology* Oxford University Press.

Blalock, H. M. (1979). *Social statistics (2nd ed., rev.)*. New York: McGraw-Hill.

Boischio, A. et al. (2009). "Health and sustainable development: challenges and opportunities of ecosystem approaches in the prevention and control of dengue and Chagas disease " *Cad. Saúde Pública* 25(supl.1): S149-S154.

Brockmann, D., David, V., Gallardo,A.M. (2009). Human mobility and spatial disease dynamics.In Chmelik, C., Kanellopulos, N., Karger, J., and Theodorou, D. (eds.). Diffusion Fundamentals III. Leipzig, Germany: LeipzigerUniversitatsverlag.pp. 55-81.Brown, T., & Duncan, C. (2002). Placing geographies of public health. *Area, 34*(4), 361-369.

Bustamante, D. M., Monroy, C., Pineda, S., Rodas, A., Castro, X., Ayala, V., ... & Trampe, R. (2009). Risk factors for intradomiciliary infestation by the Chagas disease vector Triatoma dimidiatain Jutiapa, Guatemala. *Cadernos de Saúde Pública, 25*, S83-S92.

Caprara, A., Lima, J. W. O.,Marinho, A. C. P. et al. (2009). Irregular Water Supply, household usage and dengue: a bio-social study in the Brazilian Northeast. *Cad. Saude Publica, 25*(Sup 1), S125-S136.

Chadee, D. (2004). Key premises, a guide to Aedes aegypti (Diptera: Culicidae) surveillance and control. *Bulletin of Entomological Research, 94*(03), 201-207.

Chivian, E. (2001). Environment and health: 7. Species loss and ecosystem disruption — the implications for human health. *Cmaj, 164*(1), 66-69.

Christophers, S. R. (1960). *Aedes aegypti (L.) The Yellow Fever Mosquito.* Cambridge: Cambridge University Press.

Cook, A., Jardine, A., Weinstein,P. (2004). Using Human Disease Outbreaks as a Guide to Multilevel Ecosystem Interventions. *Environ Health Perspect., 112*(11), 1143-1146.

Cox, J., Grillet, M.E., Ramos, O. M., Amador, M., Barrera,B. (2007). Habitat segregation of dengue vectors along an urban environmental gradient. *American Journal of Epidemiology, 76*, 820-826.

Dakubo, C. Y. (2010). *Ecosystems and Human Health: A Critical Approach to Ecohealth Research and Practice*. New York: Springer.

Daszak, P., Cunningham A. A., Hyatt,A.D. (2000). Emerging Infectious Diseases of Wildlife-Threats to Biodiversity and Human Health. *Science, 287*, 443-449.

De Benedictis, J, Chow-Shaffer, E, Costero, A, Clark, GG, Edman, JD,et al. (2003). Identification of the people from whom engorged Aedes aegypti took blood meals in Florida, Puerto Rico, using polymerase chain reaction-based DNA profiling. *American Journal of Epidemiology, 68*, 437-446.

Dubos, R. (1968). *Man, Medicine and environment*. New York: New American Library.

Ebi, K. L., & Semenza, J. C. (2008). Community-based adaptation to the health impacts of climate change. *American journal of preventive medicine*, *35*(5), 501-507.

Epstein, P. R. (1995). Emerging disease and ecosystem instability: new threats to public health. *American Journal of Public Health, 85*(2), 168-172.

Espino, E., Comach, G., Sierra, G., Guzmán, D., Camacho, D., & Cabello, M. (2010). Incidencia de infecciones sintomáticas y asintomáticas por virus dengue en Maracay, Venezuela: 2006–2007. *Bol.Mal.Salud Amb, 50*, 65-74.

Espino, F., Marco, J., Salazar, N. P., Salazar, F., Mendoza, Y., & Velazco, A. (2012). Community-based dengue vector control: experiences in behavior change in Metropolitan Manila, Philippines. *Pathogens and Global Health, 106*(8), 455-460.

Evans, A. S. (1976). Causation and disease: the Heule Koch Postulatis revisted. *Yale J Biol Med, 49*, 175–195.

Evans, R. G., & Stoddart, G. L. (1990). Producing health, consuming health care. *Social Science & Medicine*, *31*(12), 1347-1363.

Fávaro, E. A., Mondini, A., Dibo,M.R.et al. (2008). Assessment of entomological indicators of Aedes aegypti (L.) from adult and egg collections in São Paulo, Brazil. *Journal of Vector Ecology, 33*(1), 8-16.

Favier, C., Schmit, D., Muller-Graf, C.D.M., Cazelles, B., Degallier, N.,et al. (2005). Influence of spatial heterogeneity on an emerging infectious disease: the case of dengue epidemics. *Proc Biol Sci, 272*, 1171-1177.

Focks, D. A, et al. (1993). Dynamic life table model for *Aedes aegypti* (L.) (Diptera:Culicidae). Analysis of the literature and model development. *Journal of Medical Entomology, 30*, 1003-1017.

Focks, D. A, Chadee, D. D. (1997). Pupal survey: An epidemiologically significant surveillance method for *Aedes aegypti*:An example using data from Trinidad. *American Journal of Tropical MEdicine and Hygiene, 56*, 159-167.

Focks, D. A., Haile D. G., Daniels,E.et al. (1995). A simulation model of the epidemiology of urban dengue fever: literature analysis, model development, preliminary validation, and samples of simulation results. *American Journal of Epidemiology, 53*, 489-506.

Foo, L. C., Lim, T W., Lee,H.L.et al. (1985). Rainfall, abundance of Aedes aegypti and dengue infection in Selangor, Malaysia. *Southeast Asian Journal of Tropical Medicine and Public Health, 16*, 560-568.

Forattini, O. P. (1986). *Rev. Saude Publica, 20*, 244-250.

Forget, G., Lebel, J.,(2001). (2001). An ecosystem approach to human health. *Int J Occup Environ Health, 7*(2 Suppl), S3–S38.

Fox, N.J. (1991). Postmodernism, rationality and the evaluation of health care. *Sociol Rev, 39*(4), 709–744.

Fox, N.J. (1994). *Postmodernism, sociology and health*. Toronto: University of Toronto Press.

Getis, A, Morrison, A, Gray, K, Scott,T. (2003). Characteristics of the spatial pattern of the dengue vector, Aedes aegypti, in Iquitos, Peru. *American Journal of Epidemiology, 69*, 494-505.

Goh, K. (1997). A re-emerging infectious disease in Singapore. *Annals of the Academy of Medicine in Singapore, 26*, 664-670.

Gómez-Dantés, H., & Willoquet, J. R. (2009). Dengue in the Americas: challenges for prevention and control. *Cadernos de Saúde Pública, 25*, S19-S31.

Gordon, R. M., Young,C.J. (1921). The feeding habits of Stegomyia calopus Meigen. *Annals of Tropical Medicine and Parasitology, 15*, 265-268.

Green, L.W. , O'Neill, M. , Westphal, M .,Morisky, D. (1996). The challenges of participatory action research for health promotion. *Health Promotion Educ, 3*, 3–5.

Gubler, D. J., Clark, G. G. (1994). "Community-based integrated control of Aedes aegypti: A brief overview of current programs." *Am J Trop Med Hyg* 50(Suppl): 50-60.

Gubler, D. J., Clark, G. G. (1996). "Community Involvement in the Control of Aedes aegypti." *Acta Tropica* 61: 169-179.

Gubler, D. J., & Meltzer, M. (1999). Impact of dengue/dengue hemorrhagic fever on the developing world. *Advances in virus research, 53,* 35-70.

Gubler, D. (1998). Resurgent Vector-Borne Disease as a Global Health Problem. *Emerging Infectious Disease, 4*(3), 442-450.

Gubler, D. J. (Ed.). (1997). *Dengue and dengue hemorrhagic fever: its history and resurgence as a global public health problem* CAB International.

Gunderson, L. H., Holling,C.S. (2002). *Panarchy: understanding transformations in human and natural systems*. Washington, D. C.: Island Press.

Hancock, T., P. F. (1985). The Mandala of health: a conceptual model and teaching tool. *Health Promotion, 24,* 8-10.

Harrington, L.C., Scott, T.W., Lerdthusnee, K., Coleman, R.C., Costero, A.,et al. (2005). Dispersal of the dengue vector Aedes aegypti within and between rural communities. *American Journal of Epidemiology, 72,* 209-220.

Hayes, C. G., Philips, I. A., Callahan,J.D. (1996). The epidemiology of dengue virus infection among urban, jungle and rural populations in the Amazon region of Peru. *American Journal of Epidemiology, 55*(4), 459-463.

Hochbaum, G. M. (1958). Public participation in medical sreening program: A sociopsychological study. *PHS Publication, 572*

Hossain, M. A., Khatun, M.,Arjumand, F. et al. (2003). Serologica evidence of dengue infection before onset of epidemic, Bangladesh. *Emerging Infectious Disease, 9*(11), 1411-1414.

Israel, B. A., Schulz, A. J., Parker, E. A., Becker, A. B., Allen, A. J.,et al. (Ed.). (2003). *Critical issues in developing and following community based participatory research principles*. San Francisco: Jossey-Bass.

Iturrino-Monge R, Avila-Aguero C, Moya-Moya T,Canas-Coto A et.al. (2006). Seroprevalence of dengue virus antibodies in asymptomatic Costa-Rican children, 2002-2003: A pilot. *Pan American Journal of Public Health, 20*(1), 39-43.

Ijumba, J. N., & Lindsay, S. W. (2001). Impact of irrigation on malaria in Africa: paddies paradox. *Medical and veterinary entomology*, *15*(1), 1-11.

Johnson, M. A., Smith, H., Joseph, P., Gilman, R. H., Bautista, C. T., Campos, K. J., ... & Vinetz, J. M. (2004). Environmental exposure and leptospirosis, Peru. *Emerging infectious diseases*, *10*(6).Janz, N. K., Marshall, H. B. (1984). The health belief model: A decade later. *Health Education Quaterly, 11*(1), 1-47.

Kalayanarooj, S., Vaughn, D. W., Nimmannitya, S., Green, S., Suntayakorn, S., Kunentrasai, N., . . . Ennis, F. A. (1997). Early clinical and laboratory indicators of acute dengue illness. *The Journal of Infectious Diseases*, *176*(2), 313-321.

Kaplan, J. E., Eliason, D. A., Moore, M. et al. (1983). Epidemiological investigations of dengue infection in Mexico, 1980. *American Journal of Epidemiology, 117*(3), 335-343.

Kaplan, G.A., Lynch,J.W. (1997). Whither studies on the socioeconomic foundations of population health. *American Journal of Public Health, 87*, 1409-1411.

Karim, M. N., Munshi, S. U., Anwar, N., & Alam, M. S. (2012). Climatic factors influencing dengue cases in Dhaka city: a model for dengue prediction. *The Indian Journal of Medical Research, 136*(1), 32.

Kay, J., Regier, H.A., Francis, M., Francis,G. (1999). An ecosystem approach for sustainability: addressing the challenge of complexity. *Futures, 31*, 721-742.

Kendall, C., Hudelson, P., Leontsini, E., Winch, P., Lloyd, L., & Cruz, F. (1991). Urbanization, dengue, and the health transition: anthropological contributions to international health. *Medical Anthropology Quarterly*, *5*(3), 257-268.

Ko, Y. C. (1989). Epidemiology of dengue fever in Taiwan. *Kaohsiung J. of Medical Science, 5*, 1-11.

Ko, Y. C., Lee, C. H., Chen, M. J., Huang, C. C., Chang, W. Y., Lin, H. J., . . . Chang, P. Y. (1997). Risk factors for primary lung cancer among non-smoking women in Taiwan. *International Journal of Epidemiology, 26*(1), 24-31.

Koopman, J. S., Prevots, D. R., Van Martin, M. A. et al. (1991). Determinants and predictors of dengue infection in Mexico. *American Journal of Epidemiology, 133*, 1168-1178.

Koyadun, S., Butraporn, P., & Kittayapong, P. (2012). Ecologic and sociodemographic risk determinants for dengue transmission in urban areas in Thailand. *Interdisciplinary Perspectives on Infectious Diseases.*

Krieger, N. (2001). Theories for social epidemiology in the 21st century: an ecosocial perspective. *International Journal of Epidemiology, 30*(4), 668-77.

Krieger, N. (2002). A glossary for social epidemiology. *Epidemiological Bulletin, 23*(1), 7-11.

Kuno, G. (1995). Review of factors modulating dengue transmission. *Epidemiologic Review, 17*(2), 321-335.

Labonte, R. (1991). Econology:integrating health and sustainable. Part one: theory and background. *Health Promotion*, *6*, 49-65.

Lalonde, M. (1974). *A new perspective on the health of Canadians.* Ottawa, Ontario.

Laverack, G., Labonte,R. (2000). A planning framework for community empowerment goals within health promotion. *Health Policy Plan. 15*(3), 255-262.

Levins, R., Awebuch, T.,Brinkmann, U. (1994). The emergence of new diseases. *American Scientist, 82,* 83-91.

Lewis, N. D. (2005). Is the social–ecological framework useful in understanding infectious diseases? The case of HIV/AIDS. *EcoHealth*, *2*(4), 343-348.

Lincoln, Y. (1992). Fourth generation evaluation, the paradigm revolution and health promotion. *Canadian Journal of Public Health*, *86*, S6-S10.

Mahmood, B. A. I., & Mahmood, S. A. I. (2011). Emergence of Dengue in Bangladesh a major international public health concern in recent years. *Journal of Environmental Research and Management, 2,* 035-041.

Mahmood, S. A. I. (2006). Dengue: An Epidemic Is Largely a Failure in Public Health Administration! The Role of Dhaka City Corporation, DCC of Bangladesh. *World Health and Population,* doi:doi:10.12927/whp.2005.17900 .

Mc Bride, W. J., Mullner, H., Muller, R.,et al. (1998). Determinants of dengue 2 infection in residents of Charter Towers Northern Queensland. *American Journal of Epidemiology, 148,* 1111-1116.

McCleland, G. A. H. (1960). Observations on the mosquito Aedes (Stegomyia) aedes (L) in East Africa II. The biting cycle in domestic population on the Kenya Coast. *Bull of Entomological Research, 50*, 687-696.

Midega, J. T., Nzovu, J., Kahindi, S., Sang, R. C., & Mbogo, C. (2006). Application of the pupal/demographic-survey methodology to identify the key container habitats of Aedes aegypti (L.) in Malindi district, Kenya. *Annals of Tropical Medicine and Parasitology, 100 Suppl*(1), S61-S72.

Minkler, M. (1994). Challenges for health promotion in the 1990s: social inequities, empowerment, negative consequences, and the common good. *American Journal of Health Promotion, 8*(6), 403-413.

Moncayo, A. C., Hice, C. L., Watts, D. M., de Rosa, A. P. T., Guzman, H., Russell, K. L., ... & Tesh, R. B. (2001). Allpahuayo virus: a newly recognized arenavirus (Arenaviridae) from arboreal rice rats (Oecomys bicolor and Oecomys paricola) in northeastern Peru. *Virology*, *284*(2), 277-286.

Monath, T. P. (1994). Yellow fever and dengue--the interactions of virus, vector and host in the re-emergence of epidemic disease. *Seminars in Virology, 5*(2), 133-145.

Murry-Smith, S., W.,P. (1996). Field epidemiology of an outbreak of dengue fever in Charters Towers, Queensland:are insect screen protective? *Australian and New Zeland Journal of Public Health, 20*(5), 545-547.

Nguyen, D.Q., Dihn, V.R. & Chow,C.Y. (1974). Aedes mosquito surveillance in the republic of Vietnam. *Southeast Asian Journal of Tropical Medicine and Public Health, 5*, 569-573.

Nielsen, N. O. (2001). Ecosystem approaches to human health. *Cad Saúde Pública*, (Suppl), 69-75.

Okello-Onen, J., Mboera, L. E., & Mugisha, S. (2012). Malaria Research and Management Need Rethinking: Uganda and Tanzania Case Studies. In *Ecohealth Research in Practice* (pp. 139-151). Springer New York.

O'Meara, GF, Gettman, AD, Evans, LF and Curtis,GA. (1993). The spread of Aedes albopictus in Florida. *American Entomologist, 39*, 163-172.

Odum, E. P. (1953). *Fundamentals of ecology*. Philadelphia, PA: W. B. Saunders.

Pedersen, D. (1996). Disease ecology at crossroads: man-made environments, human rights and perpetual development utopias. *Social Sci Med, 43*(5), 745–758.

Perez, D. (2007). "Community participation in Aedes aegypti control: a sociological perspective on five years of research in the health area "26 de Julio", Havana, Cuba." *Tropical Medicine & International Health* 12(5): 664 - 672.

Pervin, M., Tabassum, S., Ali, M., & Mammon, S. (2004). Clinical and laboratory observations associated with the 2000 dengue outbreak in Dhaka, Bangladesh. *Dengue Bull, 28,* 96-106.

Phuanukoonnon, S., Brough, M.,Bryan, J. H. (2006). Folk knowledge about dengue mosquitoes and contributions of health belief model in dengue control promotion in Northeast Thailand. *Acta Tropica*, *99*, 6-14.

Poddar, G., Breiman, R. F., Azim, T.,Thu, H. M. et al. (2006). Short Report: Origin of dengue type 3 viruses associated with the dengue outbreak in Dhaka, Bangladesh, in 2000 and 2001. *American Journal of Tropical Medicine and Hygiene*, *74*(2), 263-265.

Pongsumpun, P., Garcia Lopez, D., Favier, C., Torres, L., Llosa, J., & Dubois, M. (2008). Dynamics of dengue epidemics in urban contexts. *Tropical Medicine & International Health, 13*(9), 1180-1187.

Prothero, R. M. (1961). Population movements and problems of malaria eradication in Africa. *Bulletin of the World Health Organization, 24,* 405.

Prothero, R. M. (1965). *Migrants and Malaria*. London: CAB Direct.

Prothero, R. M. (1977). Disease and mobility: a neglected factor in epidemiology. *Int J Epidemiol, 6,* 259–267.

Quintero, J., Carrasquilla, G., Suárez, R., González, C., & Olano, V. A. (2009). An ecosystemic approach to evaluating ecological, socioeconomic and group dynamics affecting the prevalence of Aedes aegypti in two Colombian towns. *Cadernos De Saude Publica, 25*(SUPPL. 1), S93-S103.

Rahman, M., Rahman, K., Siddque, A., Shoma, S., Kamal, A., Ali, K., . . . Breiman, R. F. (2002). First outbreak of dengue hemorrhagic fever, Bangladesh. *Emerging Infectious Diseases, 8*(7), 738-740.

Rapport, D. J. (1999). Epidemiology and ecosystem health: natural bridge. *Ecosystem Health, 5*(3), 174-180.

Reiter, P., Sprenger,D. (1987). *Am. Mosq. Control Assoc. J., 3*, 494-500.

Rico-Hesse, R. (Ed.). (2010). *Dengue Virus Virulence and Transmission Determinants*. Verlag Berlin Heidelberg: Springer.

Rodhain, F., & Rosen, L. (1997). Mosquito vectors and dengue virus-vector relationships. *Dengue and Dengue Hemorrhagic Fever,* 45-60.

Rodriguez-Figueroa, L., Rigau-Perez, J G., Suarez, E. L.,et.al. (1995). Risk factors for dengue infection during an outbreak in Yanes, Puerto Rico in 1991. *American Journal of Epidemiology, 52*, 496-502.

Runge-Ranzinger S, Horstick O, Marx M,Kroeger A. (2008). What does dengue disease surveillance contribute to predicting and detecting outbreaks and describing trends? *Tropical Medicine and International Health, 13*(8), 1022-1041.

Sauvé, N., Dzokoto, A., Opare, B., Kaitoo, E. E., Khonde, N., Mondor, M., ... & Pépin, J. (2002). The price of development: HIV infection in a semiurban community of Ghana. *Journal of acquired immune deficiency syndromes (1999), 29*(4), 402-408.

Schliessman, D. J., Calheiros, L.B. (1974). "A review of the status of yellow fever and Aedes agypti eradication programs in the Americas." *Mosquito News* 34: 1-9.

Schneider, J. R., Morrison, A. C., Astete, H., Scott, T. W., Wilson, M. L. (2004). Adult size and distribution of Aedes aegypti (Diptera: Culicidae) associated with larval habitats in Iquitos, Peru. *J Med Entomol, 41*, 634-642.

Schulz, A. J, K. J.,Galea.S. (2002). Addressing social determinants of health: community-based participatory approaches to research and practice. *Health Educ Behav, 29*(3), 287-295.

Scott, T. W., Morrison, A. C. (Ed.). (2003). *Aedes aegypti density and the risk of dengue-virus transmission*. The Netherlands: Kluwer Academic Publishers.

Sekhar, K. C., Huat, O. L. (1992). Epidemiology of dengue / dengue hemorrhagic fever in Malayisa: A retrospective epidemiological study 1973-1987. *Pacific Journal of Public Health, 6*, 15-25.

Sommerfeld, J., & Kroeger, A. (2012). Eco-bio-social research on dengue in Asia: a multicountry study on ecosystem and community-based approaches for the control of dengue vectors in urban and peri-urban Asia. *Pathogens and Global Health, 106*(8), 428-435.

Stoddard, S. T., Morrison, A. C., Gonzalo,M.et al. (2009). The Role of Human Movement in the Transmission of Vector-Borne Pathogens. *PLoS Neglected Tropical Disease, 3*(7), 481.

Strecher, V. J., Rosenstock, I. M. (Ed.). (1997). *The Health Belief Model*. San-Francisco: Jossey-Bass.

Suárez, R., González, C., Carrasquilla, G., & Quintero, J. (2009). An ecosystem perspective in the socio-cultural evaluation of dengue in two Colombian towns. *Cadernos de Saúde Pública, 25*, S104-S114.

Suarez, M. R., Olarte, S. M. F., Ana, M. F. A., & Gonzalez, U. C. (2005). Is what I have just a cold or is it dengue? Addressing the gap between the politics of dengue control and daily life in Villavicencio-Colombia. *Social Science & Medicine, 61*(2), 495-502.

Susser, M, S. E. (1996). Choosing a future for epidemiology: eras and paradigms. *American Journal of Public Health, 86,* 668–673.

Tana, S., Abeyewickreme, W., Arunachalam, N., Espino, F., Kittayapong, P., Wai, K., . . . Sommerfeld, J. (2012). Eco-Bio-Social research on dengue in Asia: General principles and a case study from Indonesia. *Ecohealth Research in Practice* (pp. 173-184) Springer.

Tansley, A. G. (1935). The use and misuse of vegetational terms and concepts. *Ecology, 16*, 284–307.

Teixeira, M., Barreto, M., Costa. N., Ferreira, D.,Vasconcelos, P. (2002). Dynamics of dengue virus circulation: a silent epidemic in a complex urban area. *Tropical Medicine and International Health, 7*, 757-762.

Teixeira, Tatiana Rodrigues de Araujo, & Medronho, R. d. A. (2008). Indicadores sócio-demográficos ea epidemia de dengue em 2002 no Estado do Rio de Janeiro, Brasil. *Cad.Saúde Pública, 24*(9), 2160-2170.

Thai, K., Binh, T, Giao, P., Phoung, H., Hung. Le. Q. et al. (2005). Seroprevalence of dengue antibodies, annual incidence and risk factors among children in southern Vietnam. *Tropical Medicine and International Health, 10*(4), 379-386.

Thrusfield. M. V. (1995). *Veterinary Epidemiology*. Oxford: Blackwell Science.

Trpis, M., Hauserman,W. (1986). Dispersal and other population parameters of *Aedes aegypti* in an African village and their possible significance in epidemiology of vector-borne diseases. *American Journal of Epidemiology, 35*, 1263-1279.

United States. Department of Health. (1996). *Physical activity and health: a report of the Surgeon General* DIANE Publishing.

VanLeeuwen, J. A., Waltner-Toews, D., Abernathy, T., Smith,B. (1999). Evolving models of human health toward an ecosystem context. *Ecosystem Health, 5*(3), 204-219.

Vezzani, D., & Carbajo, A. E. (2008). Aedes aegypti, Aedes albopictus, and dengue in Argentina: current knowledge and future directions. *Memórias do Instituto Oswaldo Cruz, 103*(1), 66-74.

Waltner-Toews, D. (2001). An ecosystem approach to health and its applications to tropical and emerging disease. *Cad Saúde Pública, 17*, 7-36.

Waterman, S. H., Novac, R. J.,Sather, G. E. et al. (1986). Dengue transmission in two Puerto Rican communities in 1982. *American Journal of Tropical MEdicine and Hygiene, 34*, 625-632.

Weaver, S. C., Salas, R. A., de Manzione, N., Fulhorst, C. F., Duno, G., Utrera, A., ... & Tesh, R. B. (2000). Guanarito virus (Arenaviridae) isolates from endemic and outlying localities in Venezuela: sequence comparisons among and within strains isolated from Venezuelan hemorrhagic fever patients and rodents. *Virology, 266*(1), 189-195.

WHO. (1948). *Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference.* New York: World Health Organization.

WHO. (1975). *Weekly Epidemiological Record, 165.* Geneva: World Health Organization.

WHO. (1978). *Amla-Ata 1978.* Geneva: World Health Organization.

WHO. (1986). Health promotion: Ottawa charter. *International Conference on Health Promotion,* Geneva, Switzerland.

WHO. (1995). Dengue and dengue haemorragic fever 1990-1994. *Singapore Weekly Epidemiologic Record, 70*, 334-335.

WHO. (1997). *Dengue Hemorrhagic Fever, Diagnosis, treatment, prevention and control.* Geneva: World Health Organization.

WHO. (2009). DengueNet, Available at: http://www.who.int/denguenet.

Wilcox, B. A.,Gubler, D. J. (2005). Disease Ecology and the Global Emergence of Zoonotic Pathogens. *Environmental Health and Preventive Medicine, 10*, 263–272.

Wilcox, B. A., Colwell,R.R. (2005). Emerging and reemerging infectious diseases: Biocomplexity as an interdisciplinary paradigm. *Ecohealth, 2*(4), 244-257.

Wilcox, B. A., Gubler, D.J. (2005). Disease ecology and the global emergence of zoonotic pathogens. *Environmental Health and Preventive Medicine, 10*, 263-272.

Wildavsk,y A., D. K. (1990). Theories of risk perception: Who fears what and why? *The MIT Press, 119*(4), 41-60.

Wilder-Smith, A., & Schwartz, E. (2005). Dengue in travelers. *New England Journal of Medicine, 353*(9), 924-932.

Wilson, E. O. (1998). Integrated Science and The Coming Century of The Environment. *Science, 279*(5359), 2048-2049.

Wong, L. P., & AbuBakar, S. (2013). Health beliefs and practices related to dengue fever: a focus group study. *PLoS neglected tropical diseases*, *7*(7), e2310.

Yamashiro T, Disla M, Petit A, Taveras D, Castro-Bello M,Lora-Orste M et al. (2004). Seroprevalence of IgG specific for dengue virus among adults and children in Santo Domingo, Dominican Republic. *American Journal of Tropical Medicine and Hygiene*, *71*(2), 138-143.

Yunus, E. B., Bangali, A. M., Mahmood, M. A. H., Rahman, M. M., Chowdhury, A., & Talukder, K. (2001). Dengue outbreak 2000 in Bangladesh: from speculation to reality and exercises. *Dengue Bulletin*, *25*, 15-20.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter details the operational considerations in carrying out this research. The framework of my thesis is based on four key elements (Creswell and Clark, 2007; Crotty, 1998): a) the epistemology (i.e. theory of knowledge) informing the research, b) the theoretical perspective (i.e. philosophical worldview) driving the methodology c) the methodology of the research (i.e. the method of research and analysis), and d) the research techniques and procedures.

For the purpose of using standard lexicon, the research design, philosophical worldview, and strategy of inquiry are used in this research in terms of Creswell's (2013) clarification of these concepts. Theory of knowledge means the conceptual perspectives claim by the researcher to inform the research (e.g. objectivism, subjectivism etc.). Philosophical worldview refers to the general orientation that the researcher assumes by which to understand the world, and thereby guide their actions (Creswell, 2009; 2013); strategy of action/ inquiry provides a specific direction for procedures in research design (Creswell, 2009; 2013); and, finally, research methods are the forms of data collection, analysis and interpretation that the researcher employs in their research (Creswell, 2007; 2009; 2013).

The purpose of this thesis is to enhance our conceptual understanding of dengue transmission processes by applying a transdisciplinary, holistic epistemological framework (i.e. human-environment dialectic system thinking), to determine the eco-bio-social factors responsible for dengue transmission, and to develop methods to integrate these determinants with human preferences and choices. The epistemological perspective of my research is to integrate the social and ecological determinants of disease, along with endogenous biological factors (molecular, cellular, and organ systems) through an ecosystem approach to health. To this end I will follow a 'pragmatic worldview' within a mixed-method research design, guided by a transdisciplinary research methodology.

3.1.1 The epistemological perspective

Intrigued by notions of multi-causality, epidemiologists began to question the *a priori* nature of the premises of the "web of causation" and to look deeper into the understanding of complex phenomena underlying disease causation. The context here implies the social, ecological, temporal conditions within which diseases occur at the individual or population scale. The multiplication of efforts to integrate social and ecological determinants of health and disease, along with endogenous biological factors (molecular, cellular and organ systems), has extablished numerous links between the work of biomedical proponents and social epidemiologists. The convergence of the theoretical lenses in aetiologic, epidemiologic and health studies has produced several notable integrative theoretical approaches, most prominent among which are the *"ecosocial theory"* (Krieger, 1994; 2001), *"social-ecological systems perspective"* (McMichael, 1999), and *"Ecosystem approaches*" to health (Waltner-Toews and Kay, 2005; Lebel, 2003; Charron, 2012). Common aspects of these approaches include: a) interconnectedness and interdependency between biological, ecological, and social spheres, b) multilevel thinking, and c) a holistic frameworks. However, these approaches do differ greatly in structure and emphasis on analysis, and in determination of the intervention types.

‘Ecosocial theory’, introduced first in 1994 by Nancy Krieger, applied a metaphor of an evolving organic structure of life connected from micro to macro scales, with the social structure in which various core social groups act to strengthen or to change them (Krieger, 2001:p 671). This theoretical approach seeks to integrate social and biological reasoning and a dynamic, historical, and ecological perspective in order to develop new insights into determinants driving population distribution of disease and social inequalities in public health. It also emphasizes multi-scale analysis with a focus on current and changing population health patterns as well as integrating every level of biological, ecological, and social organization. Overall, an ecosocial framework requires situating the social context of factors of population health to understand the disease dynamics.

The social-ecological systems theory recognizes the role of the human dimension in shaping ecosystem processes and dynamics. This theoretical approach emphasizes the integrated nature of humans in nature and that the delineation between social and ecological systems is artificial and arbitrary. Overall, social-ecological systems feature powerful reciprocal feedbacks and act as complex adaptive systems. In order to frame an epidemiological problem under the integrated social-ecological systems lens, multiple biological, ecological, behavioral, and societal levels and dimensions must be considered.

The epistemological perspective of my research is to understand how the social and ecological variables function within a complex system-causing emergence of a disease (e.g. dengue) in the socio-ecological systems we live in. The ‘ecohealth’ lens focuses on the interaction between the ecological and societal dimensions of a given situation, their effect on human health, how individuals and populations receive utility or impact ecosystems, implications for the quality of ecosystems, and sustainability. In the context of emerging infectious diseases including dengue, the ecohealth lens embodying an integrated social-ecological systems theory provides the scope to encompass transdisciplinarity, participatory research, and equity and equality issues. Therefore, by adopting the ecohealth approach, my thesis research emphasizes analysis of a) social-ecological systems theory, b) transdisciplinary perspectives on virology, entomology, ecology, social anthropology, sociology, and psychology, c) participation of community members, local leaders, health professionals, medical experts, regulators and policy makers, and d) gender equity and social class perspectives.

3.1.2 Pragmatism as philosophical worldview

It is important to define an explicit theoretical framework within which research is conducted, as a researcher's choice of theory constrains the study's content and research methods (Tudge, 2000). As Kearney (1984) succinctly explained, worldview is a "culturally organized macrothought: those dynamically inter-related basic assumptions (i.e. presuppositions) of a people that determine much of their behavior and decision making, as well as organizing much of their body of symbolic creations…and ethnophilosophy" (p.1).

By examining the ontology, epistemology, and methodology associated with different worldviews (i.e. positivism, post positivism, critical theory, and constructivism), it can be argued that questions of method are secondary to questions of paradigm or worldview (Guba &Lincoln, 1994). Positivist/post positivist[2] researchers rely on quantitative methods that are essentially experimental and manipulative in an attempt to falsify hypotheses.

[2]Creswell (2007) provided a clear clarification about positivist/post positivist research in which he referred 'post-positivistism' to the thinking following positivism, challenging the conventional notion of the absolute truth of the knowledge and considering that we can not be 'positive' about our claims of knowledge when investigating the behavior and actions of humans. Here, a call for examining causes that influence outcomes is emphasized (for more details see Philips & Burbules, 2000).

By contrast, researchers whose worldviews are critical, theoretical, or constructivist use qualitative methods that are dialogical, hermeneutic, or dialectical (Creswell, 2009; Guba & Lincoln, 1994). Therefore, a researcher's adoption of specific worldview has profound implications for his/her notion of reality, the type of theory that he/she finds appropriate, the types of methods used to analyze and interpret data.

The theoretical framework of my research is based on a pragmatic view of "knowledge in practice" (i.e. pragmatism). The pragmatic worldview advocates 'a need-based or contingency approach to research method and concept selection' (Johnson &Onwuegbuzie, 2004: p. 17), in which researchers are free to determine what methods work best to answer the concerned research questions. This worldview holds that both theory and empirical observation are vital to both quantitative and qualitative paradigms and in the existence of both subjective and objective orientations, utilizing both deductive and inductive logic (Onwuegbuzie, 2000).

3.1.2.1 Pragmatism as the philosophical driver for mixed method research design

There is a broad consensus within the field of mixed-method research that the rationale for this approach is pragmatic one. Rather than starting from particular philosophical assumptions or convictions, "the paradigm of pragmatism can be employed as the philosophical underpinning for using mixed methods" (Tashakkori and Teddlie, 1998: p. 167). Pragmatism also assists to shed light on how research approaches can be mixed successfully (Hoshmand, 2003) to offer the best opportunities for answering important research questions. Mixed-method research is emerging as a dominant paradigm in health science research in recent years as a means of addressing the complex and multi-faceted research problems often encountered in the health care sector (Caracelli and Riggin, 1994; Casebeer and Verhoef, 1997; Morgan, 1998; Tashakkori and Teddlie, 1998). Within health sciences research, a mixed-methods approach is justified on pragmatic rather than ideological grounds, to help researchers engage with the complexity of health, health care, and the environment in which studies take place (O'Cathain et al., 2007). The challenges of capturing the complexity of infectious disease outbreak and transmission, particularly its social-ecological dynamics, require an inclusive, pluralistic and complimentary approach to research. Many research questions are best and most fully answered through mixed-method-based research questions.

3.1.3 The need of transdisciplinarity in understanding dengue transmission

The specific definitions of multidisciplinary, interdisciplinary, and transdisciplinary research are much-debated in the literature, but these terms are generally ambiguously defined and interchangeably used, creating a situation that Leathard terms a "terminological quagmire" (Leathard, 1994). It is thus important to establish the differences between these three concepts. 'Multidisciplinarity' is defined as a process for juxtaposing disciplines in an additive, rather than integrative manner so that disciplinary perspectives are not altered, but simply contrasted (Klein, 1990). It is also commonly agreed among scholars that, in contrast to 'multidisciplinarity', 'interdisciplinarity' is a synthesis of two or more disciplines, where the disciplines collaborate in such a way that each discipline takes up some of the tenets of the other(s) (Klein, 1990; Rosenfield, 1992; McDonnell, 2000). In practice, multidisciplinary teams work in parallel or sequentially from their respective disciplinary bases to address a common problem, whereas interdisciplinary teams work using a shared conceptual framework, drawing together discipline-specific theories, concepts, and approaches to address a common problem (Rosenfield, 1992).

Numerous research questions and problems have been characterized as being greater than the sum of their parts; that is, they cannot be addressed either by using multiple disciplines or by focusing on the linkages between disciplines and forming synthesis. Rather, such problems require a holistic, transcended perspective, which is encapsulated in the transdisciplinary approaches. Contrasting with 'multidisciplinarity' and 'interdisciplinarity', 'transdisciplinarity' provides holistic schemes that subordinate disciplines, which examine the dynamics of whole systems. 'Transdisciplinarity' moves beyond 'interdisciplinary' combinations of academic disciplines to a new understanding of the relationship of science and society embodied in the notion of 'transectorality' and science for/with society (Klein, 2004). Després and her colleagues' (Després et al., 2004) citation is helpful in clarifying the genesis of transdisciplinarity, which states that the difference between interdisciplinary and transdisciplinary contributions stems from the Latin prefix 'trans' which denotes transgressing the boundaries defined by traditional disciplinary modes of enquiry. As indicated above, final conclusions in transdisciplinary research are more than the sum of disciplinary components and the approaches do not constitute the 'mixing of disciplines' (i.e. interdisciplinary approach) but rather the'fusion of disciplines'. In practice, in applying transdisciplinarity to the assessment of research questions, research teams work together using a shared and transformed conceptual framework, drawing from discipline-specific theories, concepts, and approaches to address a common problem (Klein, 1990).

Transdisciplinarity requires consideration of 'horizontal' and 'vertical' integration of perspectives or notions. 'Horizontal' integration is defined as integration across knowledge perspectives from different disciplines, while ‘vertical’ integration refers to integration among different types of knowledge users, ranging from local communities and cultures to NGO staff and academics (Perkes et al., 2005). In the context of human health issues and their connections to ecological elements, Wilcox and numerous other scholars (Wilcox et al., 1996; Wilcox and Colwell, 2005) have argued that a horizontal integration of ecological, biological and societal factors is required to encapsulate the complexity involved with host-pathogen interactions in the social-ecological systems, and disease emergence within them.

A vertical integration of knowledge-perspectives has been emphasized by Lebel (2003) in his linking of ‘transdisciplinarity’, ‘participation’ and ‘equity’ as the three pillars of Ecohealth. Understanding the dynamics and conditions of human infectious diseases is not possible without embedding them within the social system in which human reside (Breilh, 2003). Transdisciplinarity defines an infectious disease problem in terms of an open, dynamic system operating at multiple levels with the notion of nested, independent nature of social and ecological systems (Albrecht et al., 2001). The multi-factorial nature of the transmission dynamics and prevention and control of infectious disease like dengue clearly demands inclusion of expertise across various scientific and humanities disciplines and across varying knowledge sources, from indigenous to academic. Even when such comprehensive horizontal integration is achieved, it can remain ‘academic integration’ only if and when the research neglects the need for simultaneous vertical integration (i.e. integration among different types of knowledge users).

Understanding dengue virus transmission from both a microbiological and ecological perspective requires investigation into multiple scales ranging from the microbial to landscape changes. Also, a transdisciplinary approach, where “the integrating language of relationships is taken to the extent of there being a transcendent language, a metalanguage, in which terms of all pertinent disciplines are, or can be, expressed" (McDonnell, 2000: p. 27), is being recognized as more effective in comprehending and explaining complex, interwoven problems regarding health and diseases. In using such a lens, representatives of various disciplines are encouraged to *transcend* their separate conceptual and methodological orientations to develop a shared approach to a problem and its associated research.

Nonetheless, the roles of humans as decision-making and determining agents in the disease transmission process has not yet been fully investigated, while their place as hosts and ecosystem change agents (e.g. through deforestation or excavation of canals for irrigation etc.) cannot be underestimated. Human involvement has multitude of facets, including personal behavior regarding mobility and migration, water use, and water container use. In addition, humans also play societal roles as city planners and builders, and as, traders transporing large quantities of people and commodities. Such process is important determinants in dengue disease transmission. The conventional disciplines of psychology, sociology, economics, geography, anthropology, which compartmentalize knowledge, are limited in their capacity to capture such interconnected relationships in human spheres of influence. A transdisciplinary, horizontally and vertically integrated, approach is thus necessary to comprehend the complex dynamics of coupled social-ecological systems and human actions. I therefore argue that, to improve our understanding of the emerging infectious diseases including dengue, a transcended model of complex socio-ecological systems and human actions as active agent of choice, preference and change, must be generated.

3.2 Study Design

Considering the complexities involved with the socioecological systems in which dengue prevalence and disease burden take place - particularly in the area of interlinks between the virus, vector, and host - a multi-stage, stratified sample design was selected for my study. Multi-stage study design is cost-efficient as sampling is done in two or more stages where data are expensive to collect (Whitemore and Halpren, 1997). Although multi-level, multi-stage study designs have many applications including validation sub-studies, case-control studies, biased case-control sampling designs, and observational studies, in my studythe data were sampled in stages by design. The primary sampling unit (PSU) for surveys was the individual household (‘poribar/khana’). The rationale for the choosing the household as the PSU was grounded in its role as the key social decision-making hub, which has profound effects upon socio-ecological systems. A household, according to the United Nations (2008: pp. 100-101) definition, is ‘ a socio-economic unit, consisting of individuals who live together’ - more specifically, a separate unit of accommodation (individual home or apartment) and the immediately surrounding premises irrespective of the number of people residing within the unit. A household in Bangladesh usually consists of a group of persons who share living quarters and their principal meals. The size of an individual household may therefore vary from a single individual to an extended family.

3.2.1 Materials and methods

To understand dengue transmission, it is critical to encompass entomological, serological and societal dimensions in an integrated manner. In my research, these aspects were incorporated as major components of the study design (Following Creswell and Plano's typology of mixed method study design (1994), an explanatory design was formulated (See Appendix XIX). A total of four entomological surveys were completed to investigate dengue vector abundance. Three population serosurveys were conducted to analyze the presence of dengue antibody among population. In order to understand how local community members comprehend dengue transmission, a socio-economic survey on knowledge, attitude, and practice was completed during the monsoon season in 2011. In order to determine how socioeconomic and demographic characteristics and specific cultural, social, and expected norms might influence these views, more in-depth focus group discussions (FGDs) and face-to-face interviews of key informants were organized during the months of January-August 2012.

3.2.1.1 Study site

Located in South Asia, Bangladesh is a low-lying tropical country with an area of 144,000 square kilometers. Bangladesh is bordered on the west, north, and east by a 2,400-kilometer land frontier with India and, in the southeast, by a short land and water frontier (193 km) with Myanmar, with a coastline of 710 kilometers in the south (Figure 3.1). Geophysically, Bangladesh is characterized by two distinctive features: a broad deltaic plain and a small hilly region in the far southeast and the Sylhet division in the northeast. The rivers of Bangladesh mark both the physiography of the nation and the life of the people.

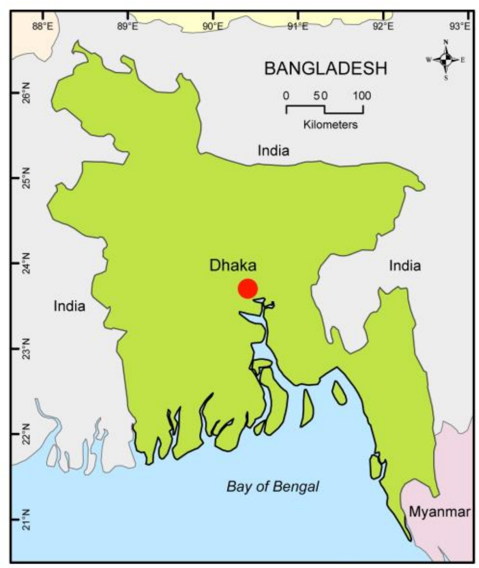


Figure 3.1: Location of Bangladesh and the neighbouring countries in South Asia; (Source: ESRI, 2003)

The peak of the maximum temperatures is observed in April (40.6°C or more), the beginning of pre-monsoon season. Monsoon is both hot and humid, and brings heavy torrential rainfall (four-fifths of the mean annual rainfall) throughout the season.Warm conditions generally prevail throughout the season, although cooler days are also observed during and following heavy downpours.Monsoon rains start from the end of May and continue until mid-October. Post-monsoon is a short-livied season characterized by withdrawal of rainfall and gradual lowering of nighttime minimum temperature. The city of Dhaka is the capital of the country, characterized by the 'Primate City' attributes of the developing world. In consideration of its socioeconomic, political and demographic significance, the Dhaka City Corporation is chosen as the study site for the present study. Ranked as the 9th largest city in the world (World Bank, 2010), the City of Dhaka is also among the most densely populated (WHO and UNICEF; 2012). The Dhaka Metropolitan Development Plan (DMDP) has forecasted that the average density of the gross built up urban areas would be 209 person /acre in the year 2015, but according to the 2001 census the average density of Dhaka city has already reached 214 person/acre (DMDP, 1997). Economic indicators show that the per-capita GDP (Gross Domestic Product) of the people of Bangladesh is nearly US$ 848 (in

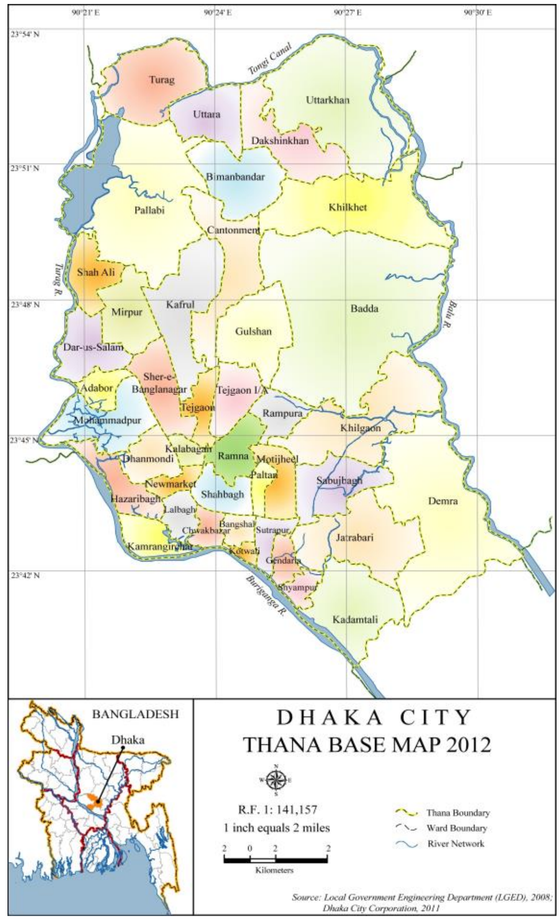


Figure 3.2 Location of Thanas (sub-districts) and Dhaka City in Bangladesh
(Source: Dhaka City Corporation, 2005)

2012). Around 31.5 percent people live below the poverty line in Dhaka (Bangladesh Bureau of Statistics, 2010). The city lies on the lower reaches of the Ganges Delta, which make Dhaka susceptible to flooding during the monsoon seasons owing to heavy rainfall and cyclones (Bangladesh Bureau of Statistics, 2001). Dhaka experiences a hot, wet and humid tropical climate, and the city has a distinct monsoon season, with an annual average temperature of 28 °C (82 °F) and monthly means varying between 20 °C (68 °F) in January and 32 °C (90 °F) in May (Bangladesh Bureau of Statistics, 2001). Nearly 80% of the annual average rainfall of 1,854 millimeters (73 in) occurs between May and September (Bangladesh Bureau of Statistics, 2001).

With diarrhoea and other infectious diseases (e.g. cholera, hepatitis A and E, typhoid, chikungunya) being prevalent year-round, dengue fever is not a new phenomenon in the City of Dhaka. The first outbreak of dengue fever (*Dhaka fever*) in Dhaka was documented in 1964, followed by a few scattered cases of DF during 1977-78. In 1996-97 dengue infections were confirmed in 13.7% of 255 fever patients screened at Chittagong Medical College, Bangladesh (Karim et al., 2012). The first major epidemic of dengue hemorrhagic fever in Bangladesh occurred in mid-2000, when 5,551 dengue infections were reported - mostly in three large cities and 17 smaller towns. Mortality rates have decreased significantly since the outbreak, but large numbers are still infected by dengue each year at fluctuating rates. From 2005 to 2009, Dhaka's 11 hospitals saw 3,130 admissions for dengue fever. These numbers, however, are generally considered to be under-representative, as many Bangladeshis are unable to seek medical treatment (Haque et al., 2012; Hashizume et al., 2012).

More than one-third of Dhaka's population is poor and lives in dense squatter settlements, their livelihood usually depending on daily wage earnings. Hospital reporting by this segment of the population is erratic, as many cannot economically afford to bear both the cost for treatment as well as lost wages for missing work.

3.2.1.2 Study and target population

In a statistical sense, the term 'population' denotes the aggregate units to which the survey results are to apply (Moser and Kalton, 1977). Following this, the population of the present study refers to all the households of the Dhaka City Corporation. A distinction between the 'target population' (i.e. the population for which the results are applicable) and the 'survey population' (i.e. the population actually covered) is useful here in order to understand the scope of the present study. In this case, the target population consists of all of households within the defined territory of Dhaka City Corporation, while the 'survey population' is limited only to households located in twelve wards (administrative units representing at least one local community) of Dhaka City Corporation. The households (*poribar/khana*) were considered to be the primary sampling unit of the study.

3.2.1.3 Sample size and sampling procedures

As a multi-level, multi-stage study design has been followed for selecting samples, a total of five stages were involved to achieve the final sample size for serological and entomological surveys. An additional step was involved for selecting samples for the Knowledge, Attitude and Practice (KAP) survey, Focus Ground Discussions (FGDs), and other face-to-face interviews.

3.2.1.3.1 Sample size for serological and entomological surveys

Stage one of the multi-stage study design concerns the categorization of city-wards by socio-economic status (SES). Reliable and precise data on household SES (HSES) by ward[3] are not available in Bangladesh. To procure the best proxy data, a Delphi Method (Needham & de Loe, 1990)-based study was sponsored by the IDRC dengue research project. Subsequently, a field-based investigation was conducted during May-June, 2011 by Shamsuddoha and Hossain (2011; see Appendix IV) from the Participatory Research and Development Initiative, Dhaka, Bangladesh. A map of the 90 administrative wards of the city was prepared for their ranking by three broad SES categories. The indicators of various socioeconomic statuses considered included a) housing type, b) type of roads and transportation infrastructure, c) supply of electricity, d) water supply infrastructure, e) access to markets, and f) health infrastructure. By consulting ten distinguished resource persons/experts, the 90 wards[♦] of the city were ranked and categorized under the above stated three SES classifications. This resulted in a sampling frame of wards by high, medium, and low SES. This procedure resulted in 14 high SES, 40 medium SES, and 36 low SES units (Table 3.1). Further details of this categorization of the city-wards into SES categories are available in Appendix IV.

In stage two, considering the aspects of financial cost, human resource requirements, and the time needed, as well as to minimize the margin of error in making population inferences, it was recognized that at least 10% of the ward-population needed to be sampled. This implied that a minimum of nine wards from the concerned stratified (low, medium and

[♦] ward refers toan administrative unit of the city, representated by an elected councilor to the Dhaka City Corporation governing authority, functions as a sub-unit of the governance of the city. The average size of a ward is 1543.2 sq. kms.

high SES) sampling frame were required to be randomly chosen. In consideration of the minimum required observations in contingency tables that would be acceptable as statistically sound, it was further decided that a total of 12 wards would be selected for the entomological and serological surveys. By employing a probability proportional sampling (PPS) method (Moser and Kalton, 1971), a total of 12 administrative wards (2 wards from high SES, 5 wards from medium SES, and 5 wards from low SES) for the entomological and serological study of my research were randomly chosen (Figure 3.3).

Table 3.1 Distribution of all wards of Dhaka City Corporation (N=90) and selected wards for study from different Socio-Economic Status (SES)

Socioeconomic Status	Ward No	Selected ward for study purpose
High (HSES)	1,3,18,19,20,22,23,32,38,49,50,53,54,57	**20,38**
Medium (MSES)	2,4,5,6,7,8,17,21,24,25,26,27,28,29,31, 33,34,35,36,37,39,40,41,42,43,44,45,46, 47,51,52,55,56,59,60,61,62,63,64,65	**25,26,35,40,60**
Low (LSES)	9,10,11,12,13,14,15,16,30,48,58,66,67,68 69,70,71,72,73,74,75,76,77,78,79,80,81, 82,83,84,85,86,87,88,89,90	**13, 58, 69,76,78**

In stage three, a spatial randomization procedure was followed wherein 100mX 100m grid cells were superimposed on each ward and then a total of 100 grid cells were randomly selected using a table of random numbers. Because the primary sampling unit was a household, 100 households were chosen from each ward, resulting in 1200 households (HHs) as a sampling unit for the surveys (200 HHs from high, 500 HHs from medium, and 500 HHs from low SES wards).

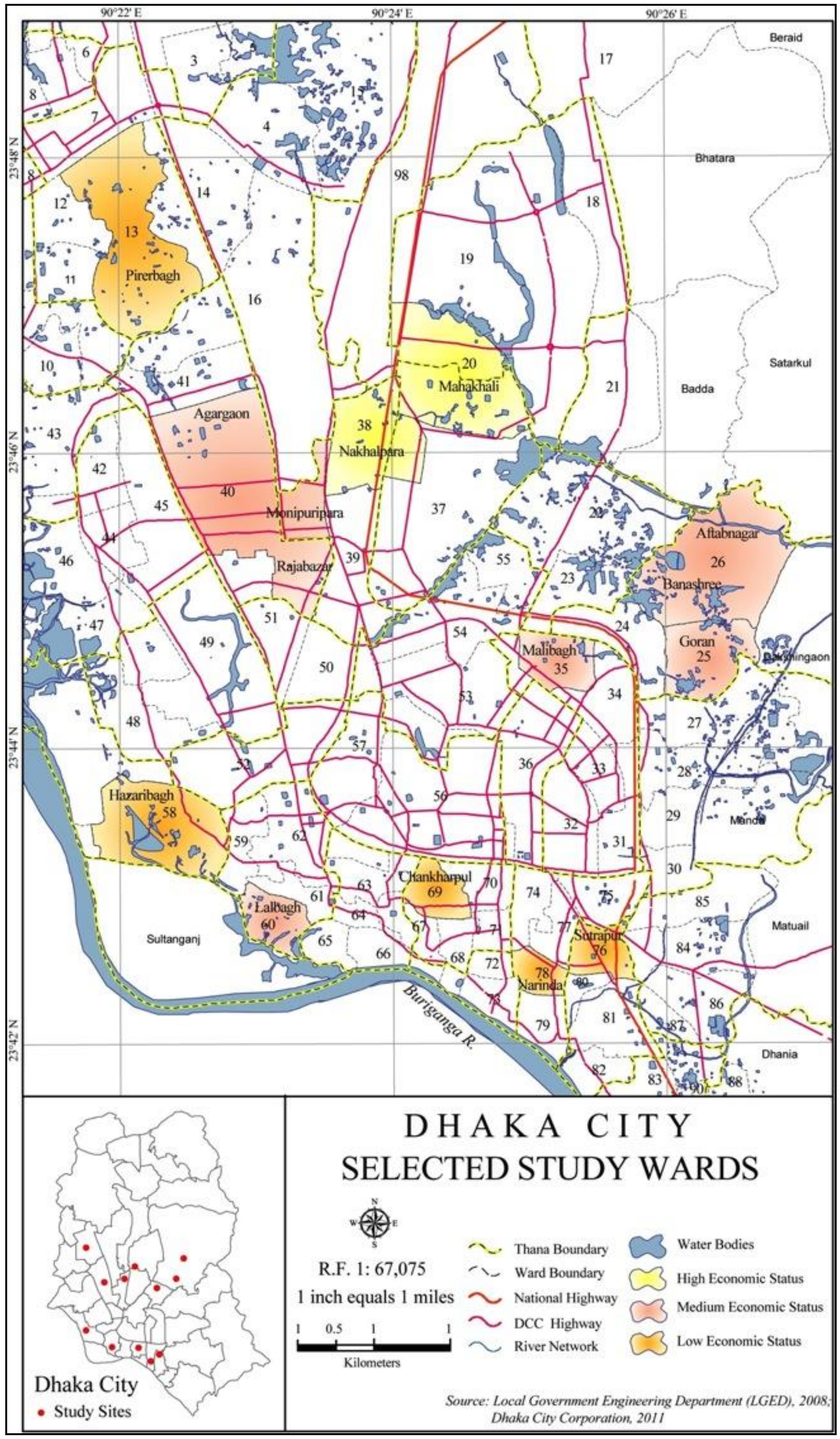


Figure 3.3 Location map of the selected twelve study wards in the City of Dhaka *

* Source: Source: Compiled after Dhaka City Corporation 2005, Bangladesh Bureau of Statistics 2011, Local Govt. & Engineering Dept. 2003

Figure 3.4: Example of a High Socio-Economic Status (HSES) ward (ward 20: Mohakhali) with 100m X 100m grid cells and two selected (500m X 700m) areas with real photograph within the neighborhood [Π]

[Π] Source: GoogleEarth imagery, 2011

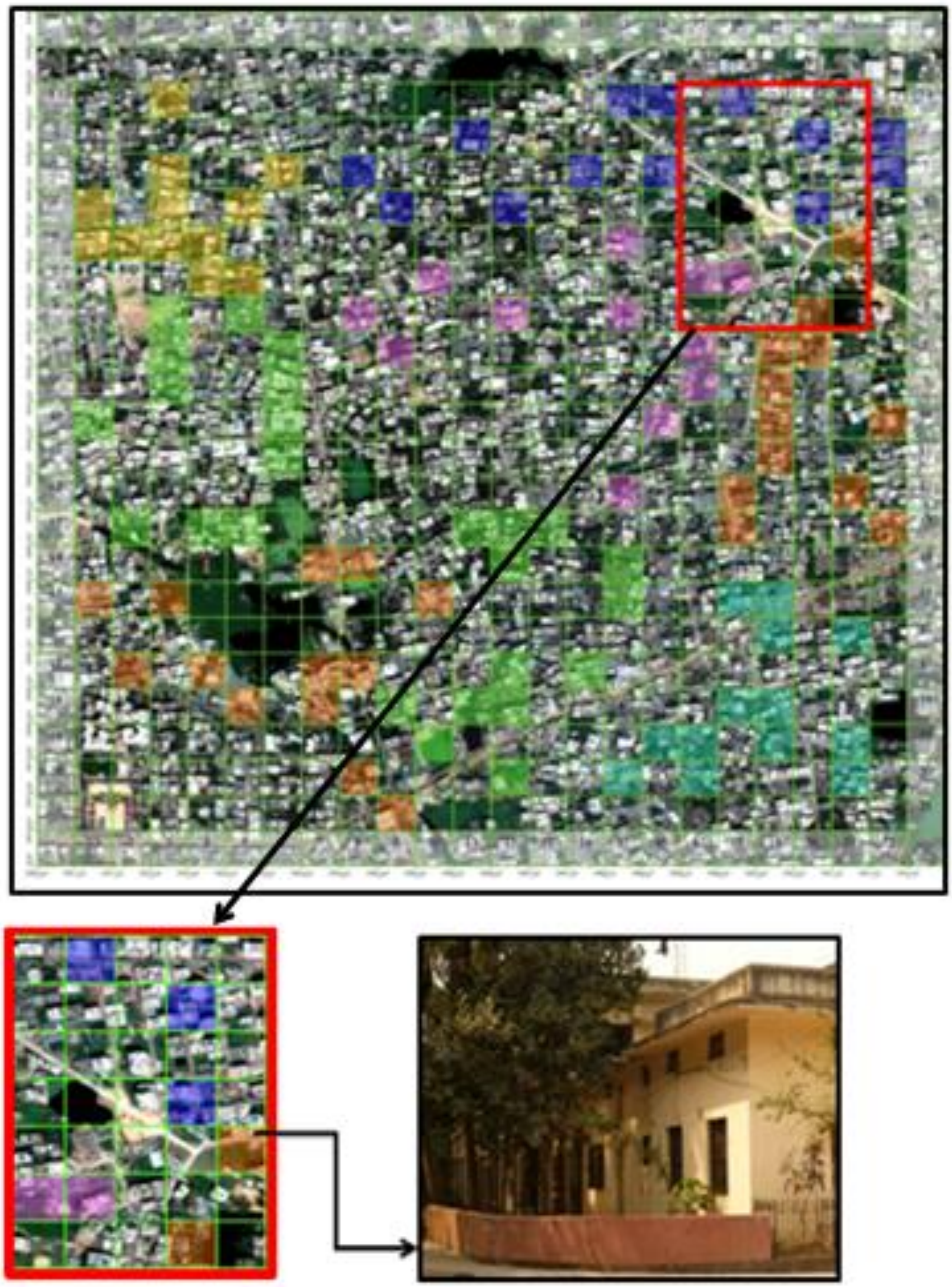


Figure 3.5: Example of a Medium Socio-Economic Status (MSES) ward (ward 69: Chankharpul) with 100m X 100m grid cells and one selected (500m X 700m) area with real photograph within the neighborhood [Π]

[Π] Source: GoogleEarth imagery, 2011

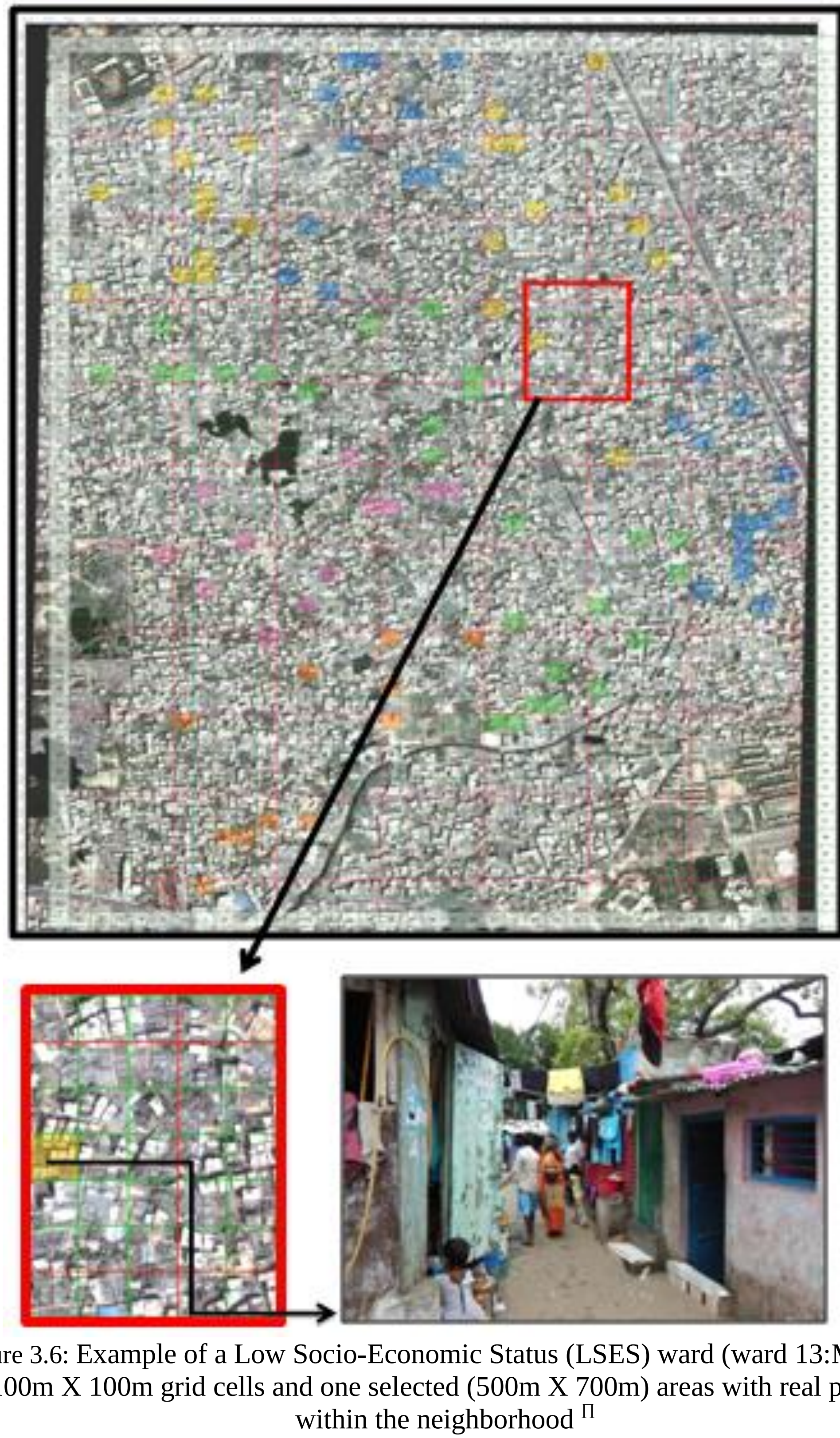


Figure 3.6: Example of a Low Socio-Economic Status (LSES) ward (ward 13:Meradia) with 100m X 100m grid cells and one selected (500m X 700m) areas with real photograph within the neighborhood [Π]

Π Source: GoogleEarth imagery, 2011

3.2.1.3.2 *<u>Sample size for Knowledge, Attitude, and Practice (KAP) survey and social research</u>*

To capture peoples' knowledge of dengue and its vector and their attitudes towards dengue prevention and control, a proportion (25%) of the original population sample was chosen with consideration to time, resources and acceptable margin of error (p value <0.05). In order to accomplish the objectives concerning the social and behavioral aspects of the research, a total of 300HHs were selected to participate in a KAP questionnaire survey. The above mentioned spatial randomization procedure was followed by drawing grid cells on a map of the wards and selecting a total of 25 households from 25 grid cells using a random number table for each ward. This resulted in a sample size of 300 households from 12 wards.

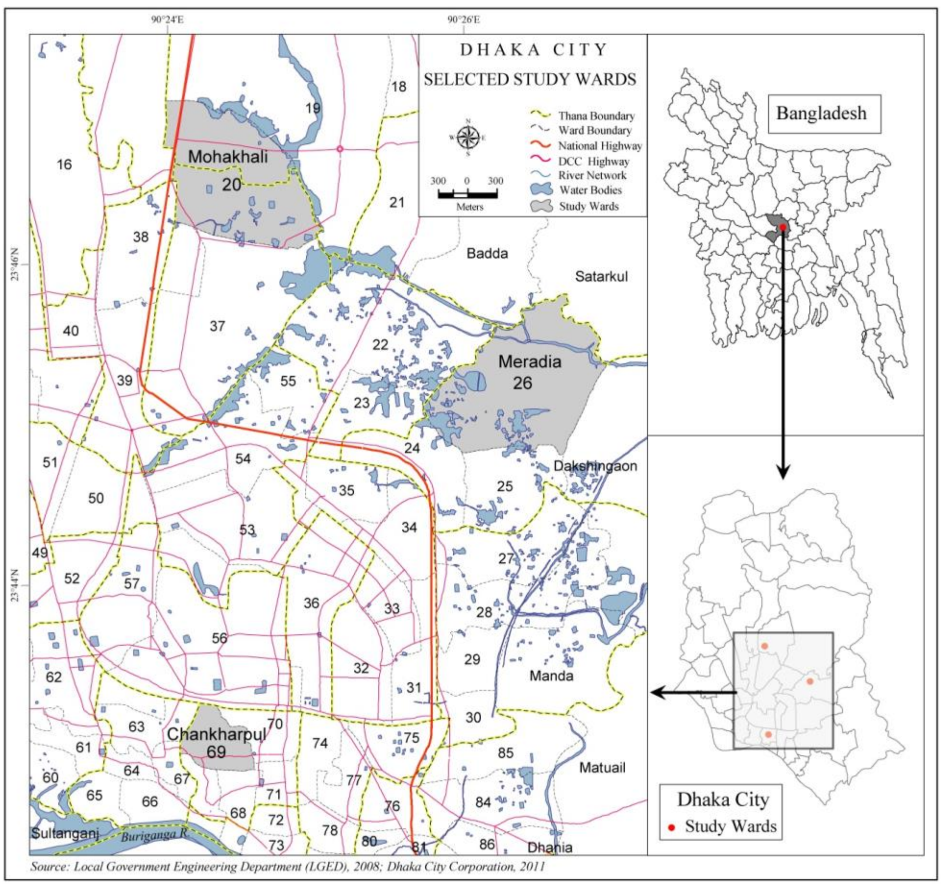


Figure 3.7: Location of three selected wards (Ward: 20, 26, 69) for in-depth study♣

♣ Source: Compiled after Dhaka City Corporation 2005, Bangladesh Bureau of Statistics 2011, Local Govt. & Engineering Dept. 2003

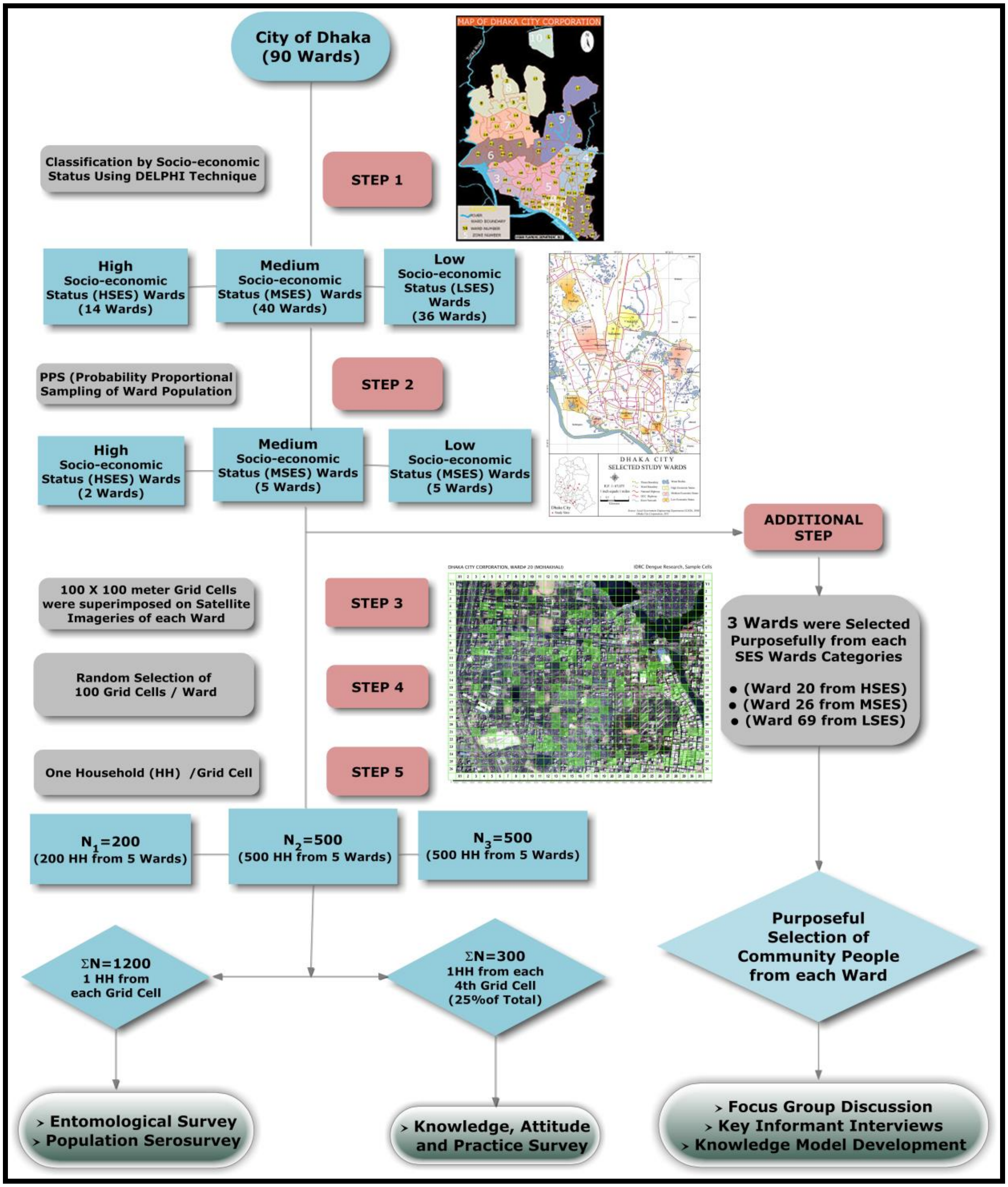


Figure 3.8: Flow diagram of field survey methodology

To identify key socio-demographic characteristics expected to affect interviewees' views with respect to dengue-disease-related risk perceptions - as well as to delineate their mental maps (knowledge models) - two discrete groups (lay citizens and experts) of participants (15 from each group; n=30) were also interviewed in this study. In addition, three purposefully selected wards were chosen (Figure 3.7) for participation in more in-depth focus group discussions (12 focus group discussions where n=107) and key informant interviews (n=18).

3.2.2 Application of the study design: entomological Survey

3.2.2.1 Survey team: Four entomological surveys during 2011 monsoon, 2012 dry season and monsoon, and 2013 monsoon were completed during the transmission season at the time of peak mosquito abundance (likely July and/or August). Monsoon entomological surveys (2011-13) were conducted with twelve entomological teams with a total of of 16 government entomological technicians (for field data collection, lab based mosquito identification and supervision) and 24 masters students from the Public Health Department of North South University (Bangladesh) who attempted to visit 1200 households (100 houses/Ward) over two weeks (Plate 3.1 and Appendix XVII; Image 3.1).

Data collected during the above stated four entomological surveys were used according to the purpose, need, and relevance of the analysis. Therefore, all survey data were not included in this thesis. Only the 2011 entomological survey data were applied in the analysis of socioeconomic and ecological factors influencing *Aedes aegypti* abundance which is presented in Chapter 4 of this thesis. Here, considerations were given to the availability of socioeconomic and demographic data at the household level only in 2011 survey outputs. Similarly, only the 2012 monsoon entomological survey data were used to perform spatial evaluation of dengue vector abundance and its association with seroconversion which is offered in Chapter 6. The limit to only 2012 entomological data analysis in this chapter was stemmed from the availability of RapidEye satellite sensor data for 2012-13. The data collected during the dry season of 2012 which was not included for analysis in this thesis as well as monsoon 2012 entomological data were summarized and presented in Appendix X and XI respectively.

Plate 3.1: Present researcher with entomological survey team in North South University, Dhaka

3.2.2.2 Identifying dry and wet containers: All selected sites were physically marked on the map and their addresses were recorded either on field data sheets or using GPS units. After gaining permission from household residents, all containers inside the household as well as within the 50-meter radius outside the surrounding household were inspected for immature mosquitoes. In the case of apartment complexes and condominiums where the 50-meter outside radius was not applicable, container samples were not collected from outside yards or other environments. If owners were not home or unwilling to give permission to search a selected household, the team approached neighboring homes until permission was granted. To find the randomly chosen neighboring HH, field investigators used dice to obtain a random number (in the 1^{st} to 6^{th} HHs range). The type and capacity of all containers in and around the houses was recorded. Any water-filled containers with water stored more than 3 days were considered as wet containers. For wet (water-holding) containers, the amount of water at the time of the survey was also recorded, and householders were asked about the source and use of their water. Information on dry containers was also collected to assist in calculating container index (CI). All wet containers were examined with flashlights to confirm the presence of immature *Aedes.*

3.2.2.3 Immature mosquito collection: Larvae and pupae from sequential dips were saved for species determination and counts of both larvae and pupae (per dip) were recorded (pupal numbers were recorded accurately but larval counts were estimated for high density sites, especially if specimens were pooled into a single vial). Contents of water-filled containers were observed on white enamel pans, and pupae manually extracted with droppers and placed into 10 ml. test tubes. For very small containers, larvae and pupae were removed using a pipette or the entire contents were emptied through a net. For larger containers such as elevator shafts, sequential samplings were performed to get a reasonable estimate of larval and pupal density (minimum of 5 dips per large container). All collected immature mosquitoes (larvae and pupae) were brought to the laboratory at North South University. Two entomological technicians identified the species according to taxonomic keys (Consoli and de-Oliveira, 1994).

3.2.2.4 Data collection from each PSU: Two survey instruments were used to collect data on abundance of immature *Aedes* positive containers and the socio-economic condition of the household. The following data were recorded for each positive container: container type, water volume (e.g. scanty, half-filled, three-quarter and full), source of container water (e.g. added by humans, rainfall), amount of exposure to sun (e.g. full, partial, none), and presence of vegetation (e.g. nearby, under, none). Recent studies in both Latin America and Asia on vector ecology and human behavior have revealed a strong correlation between water storage and dengue incidence (Caprara et al., 2009). It was therefore important to encompass these aspects of human behavior at the household level in relation to the entomological dimensions. A questionnaire was formulated to collect the socio-demographic background of all sampled household members as well as data on their water storage behavior during the first monsoon survey in 2011. For household socio-economic status (HSES) data collection, we surveyed one adult respondent (>18 year old) per household, with a focus on household income, occupation, and educational attainment. Data on water and waste management systems were also recorded for analysis.

3.2.2.5 Tracking new container types: To better track new types of containers found during the survey, each team was provided with a current list of container types. When a new container type was encountered, the next available container type number was applied to this container and the description of the new container written clearly on the front of the pupal survey form. Once back in the lab, all new container types were compiled and added to a master list.

3.2.2.6 Site Selection during pupal surveys in 2012 and 2013: When revisiting a site from 2011 (first survey) for pupal survey in 2012 and 2013, only the pupal survey form was completed and no socio-demographic data was collected. However, if a new location was visited due to out-migration of the previous household owner or a survey team failed to access the HH, then both the pupal survey and the household questionnaire were administered. Within each household, the same procedure was followed to collect immature *Aedes* specimens.

3.2.2.7 Laboratory analysis of collected samples: All collected larvae and pupae were brought to the Zoology laboratory of North South University for identification under the supervision of the head laboratory technician. Larvae were killed immediately with formaldehyde, identified (III and IV instars of *Aedes aegypti*, *Aedes albopictus,* and other species), and counted. Third and fourth instars were counted and their species identified under dissecting microscopes. To facilitate idenfication, pupae were placed into wide-necked transparent plastic bottles (Plate 3.1) covered with a mesh and sugar-filled cotton balls, with the adults' species being identified (*Aedes aegypti* or *Aedes albopictus*) once they emerged. Emerging adult mosquitoes were also sexed then killed by freezing. Counts of III/IV instars and pupae were added together to calculate the total number of immatures in each container. For samples that contained recently emerged pupae (pupae emerged during transportation time), the pupae were removed and placed in separate emergence containers for later identification. These emerged pupae were counted as larvae in the collection data.

Plate 3.2: plastic bottles covered with a mesh and sugar-filled cotton balls for adult emergence

3.2.3 Application of the study design: Population serosurvey

Blood sample collection was carried out by the serological research team members (Plate 3.2), led by the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b) in Dhaka. Seasonality in dengue incidence is an important factor, especially due to the effects of monsoon on vector abundance. In light of this, multiple population serosurveys were carried out at varying seasons: premonsoon (June-July 2012), post monsoon (November-December 2012) and another post monsoon survey (November 2013). For the purpose of examining seroprevalence and socioeconomic risk factors as well as seroconversion, only 2012 pre- and post-monsoon serosurvey data were analyzed in this thesis. Post-monsoon 2013 serosurvey data which were not included for analysis in this thesis were summarized and presented in Appendix XIV.

The participation of the community members in the serosurvey was voluntary and the collection of blood samples followed the ethical guidelines of Bangladesh Medical Association. In addition to collecting serum samples, information on demographic, socioeconomic and other relevant characteristics was collected from the selected cases using a structured socio-economic questionnaire. Special attention was paid to age, sex, place of residence, socio-economic status, medical history, migration and mobility. The serum samples were separated in icddr,b in Dhaka and sent to the National Microbiology Laboratory (NML) in Winnipeg, Canada for diagnostic testing.

The roles and responsibilities for performing diagnostic tests of the sero survey samples and the clinical samples at the National Microbiology Laboratory (NML), Public Health Agency of Canada, Winnipeg, were shared as follows:

Plate 3.3: Present researcher is performing serosurvey with the icddr,b team in Dhaka

(i) IgG and IgM ELISA diagnostic tests were performed for all pre- and post-monsoon (2012; 2013) sero survey samples by the present researcher at the National Microbiology Laboratory (NML, Public Health Agency of Canada, Winnipeg). The IgM background subtractions for the 2012 pre- and post-monsoon samples were performed by Kai Makowski [Zoonotic Disease Special Pathogens (ZDSP), NML]. (ii) PRNTs for the 2012 pre-monsoon samples were performed by the present researcher. In addition, PRNTs for randomly selected 50 samples of the 2012 post-monsoon samples were performed by the present, Antonia Dibernardo, and Nicole Barairo of ZDSP in NML.(iii) PCRs for 47 clinical samples collected during 2013 monsoon were performed by Kimberly Holloway of ZDSP at the NML.

3.2.3.1 Background knowledge on laboratory analysis of population serosamples

In most patients, suspected cases of DF are most rapidly diagnosed using serological methods. Serology testing for dengue virus-specific antibodies is useful in confirming antibodies to dengue antigen in serum as an aid to clinical laboratory diagnosis of patients with clinical symptoms. DENV IgG/IgM enzyme-linked immunosorbant assays (ELISA) are an indirect ELISA intended for the detection of IgG or IgM antibodies to DENV types 1-4. In most individuals, the IgM response to DF is strain-specific and persists for up to 90 days while IgG antibodies to dengue virus have been detected in patients as long as 60 years following infection (Halstead, 1990). Patients in the early stages of dengue fever may not have detectable IgG antibodies, as the IgG response may take several weeks to develop. Therefore, a single antibody determination should not be considered conclusive.In the absence of detectable IgG, testing with an IgM capture ELISA has become the method of choice. However, the IgG ELISA is useful as an epidemiological tool when used to establish sero-prevalence. Due to the significant cross-reactivity displayed by the IgG ELISA, additional testing is typically carried out using more specific assays such as neutralization procedures. In this case, the flavivirus-positive sera are subjected to a plaque reduction neutralization test (PRNT) to confirm the presence of dengue virus-specific antibodies.

In certain cases, a person may have been exposed to several dengue virus serotypes and PRNT testing may be inconclusive as to the infecting virus type. This is due to the immunological phenomenon of “antigenic sin”, which is a memory response that induces a mixture of antibodies to several dengue serotypes when multiple exposures have taken place in the past. The use of molecular diagnostics such as polymerase chain reaction (PCR) amplification of dengue virus genome may aid in serotype identification and complement the serological assays.

For PCR, serum samples from acute cases of possible dengue-related disease (clinic / hospital sample screening) are processed for the presence of DENV nucleic acid. A portion of the serum (e.g. 100 ul) is extracted for RNA and both a generic set of flavivirus PCR primers and dengue-specific primers are used to perform conventional one-step reverse-transcription (RT) PCR to detect the presence of dengue virus genome within the clinical sample. The resulting PCR amplicons are further studied by DNA sequencing methodology to precisely identify serotypes and determine the phylogenetic relationships of circulating DENV strains among acute cases enrolled in the clinical study.

Genetic detection and analysis of the dengue virus infections are primarily used to complement serological procedures employed on clinical samples. A subset of community-derived serum samples may be screened by PCR if evidence of a recent seroconversion is shown. The detection and characterization of viral RNA can be beneficial in the identification of infecting DENV serotypes when dealing with issues arising from “antigenic sin” or diagnostic cross-reactivity resulting from previous infection with more than one dengue virus serotype.

3.2.3.1.1 Procedure performed: IgG and IgM ELISA

Serological analysis of patient sera was performed at NML using commercially-prepared Focus Diagnostics Dengue DxSelect™ IgM and IgG ELISA kits. The IgG ELISA was used to establish previous exposure to dengue virus or as an epidemiological tool for dengue virus (DENV) sero-prevalence surveys. The IgG ELISA kit consists of polystyrene microwells that are pre-coated with equal proportions of inactivated, purified DENV types 1-4. Diluted serum samples and controls were incubated in microwells to allow dengue-specific antibodies present in the samples to react with the coating antigen. Nonspecific reactants were removed by washing, and horseradish peroxidase-conjugated anti-human IgG was added which reacted with bound DENV-specific IgG antibodies. Excess conjugate was removed by washing. Tetramethylbenzidine (TMB), a chromogenic substrate, was added for color development. Following an incubation period, the reaction was stopped by the addition of 1M sulfuric acid. The optical density (OD) was measured with a spectrophotometer (BioTek ELx808) at wavelength 450 nm.Index values were calculated for patient samples relative to the Cut-off Calibrator. Samples with index values > 1.00 were considered positive.

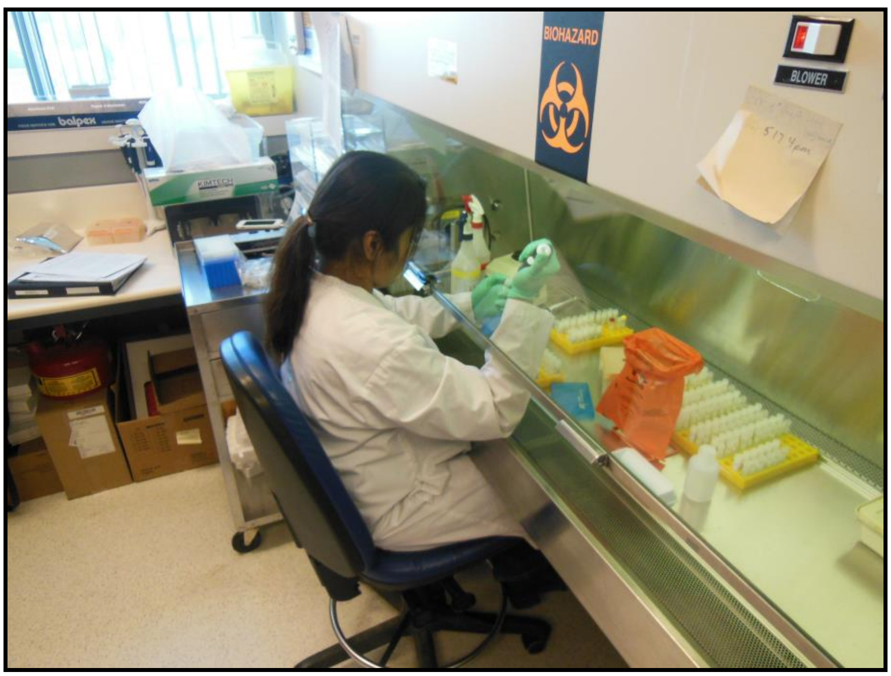


Plate 3.4: Present researcher is performing ELISA at NML in Winnipeg, Canada

The Focus Diagnostics IgM ELISA is a capture ELISA that uses polystyrene microwells coated with anti-human antibody specific for IgM (μ -chain). Diluted serum samples and controls were incubated in the wells to allow IgM present in the sample to bind to the coating anti-human antibody (IgM specific). Nonspecific reactants were removed by washing. Dengue virus (DENV) antigen was then added to the wells and incubated. Unbound DENV antigen was then removed by washing. Peroxidase-conjugated mouse anti-DENV was then added to the wells and incubated. Excess conjugate was removed by washing, and TMB added for color development. Following an incubation period, the reaction was stopped by the addition of 1M sulfuric acid. The optical density (OD) was measured with a spectrophotometer (BioTek ELx808) at wavelength 450 nm. The anti-human IgM used in the capture wells of the Focus Diagnostics Dengue Virus IgM Capture DxSelect™ kit have heterophile antibody activity, which may directly bind the reporter reagent. These false positive reactions may be mitigated through the use of the Background Subtract Procedure.

3.2.3.1.2 Dengue virus Plaque Reduction Neutralization Test (PRNT)

Flavivirus infections (including Japanese encephalitis, West Nile encephalitis and dengue fever/severe dengue) present a worldwide public health problem. Many methods have been developed for the serological diagnosis of flavivirus infections, such as haemagglutination inhibition assay, ELISA, and immunofluorescence assays. However, the specificity of these assays varies. The plaque reduction neutralizing test (PRNT) using live viruses is currently the ‘gold standard’ for the differential serodiagnosis of flavivirus infection and can be used to distinguish type-specific antibodies against flaviviruses in convalescent serum samples (Calisher et al., 1989; Johnson et al., 2009). The specificity of results obtained with PRNT exceeds that of other protocols and many laboratories apply the PRNT protocol to the differential serodiagnosis of flaviviruses.

This biological assay is based on the specific interaction between a virus and specific antibodies present in test serum. The PRNT relies on the ability of antibodies to neutralize and prevent virions from infecting cultured cells, and is believed to represent a protective antibody response. PRNT results show the inhibition of viral infectivity as a reduction of virus attachment to the cells and a subsequent reduction in plaque formation. Antibody titers are expressed as the reciprocal of serum dilutions yielding 90% reduction in the number of plaques ($PRNT_{90}$).

While the basic concept of the PRNT remains constant, this test has evolved in multiple laboratories throughout the world since its development (Russell et al., 1967), introducing variation in methods that may influence the comparability of results. The application of PRNTs in a clinical setting can be difficult for the following reasons. Firstly, it takes around 1 week to obtain results. Secondly, the test is expensive and requires highly trained staff to obtain reliable results. Thirdly, it requires a highly regulated containment laboratory when using pathogens that are classified as risk group 3 such as Japanese encephalitis virus or West Nile encephalitis virus (CDC, 2001). Recently, modified PRNT protocols have been developed based on genetically modified recombinant flaviviruses or flavivirus reporter virus particles (RVPs). These protocols offer a solution to the problems associated with classical PRNTs.

Here, sera were assayed by PRNT using WNV, JEV, and DENV-2, following standard methods (Beatty et al., 1995). In summary, serially diluted serum samples were incubated with live virus in order for antibodies, if present in the serum, to neutralize the virus. The mixture was then used for infection of a confluent Vero cell monolayer. Following infection, an agar overlay was applied to each well and the plates were incubated for 72 to 96 hours (depending on the virus) to allow for plaque formation. Once the incubation period had elapsed, a second agar overlay containing the vital stain neutral red was distributed to each well to facilitate visualization of the plaques or clearing in the cell monolayer. The number of plaques produced at each serum dilution was compared to that of the non-neutralizing controls (typically 100 and 10 PFUs virus) to determine if there was a reduction in plaque formation. The last serum dilution capable of reducing plaque formation by 90% was the reported PRNT titre for each serum sample. More specific details of the procedure are provided in the following sections.

Preparation and maintenance of cells: Vero cells (C1008, ATCC CRL-1586), derived from African green monkey kidney cells, were used for flavivirus plaque titrations and plaque reduction neutralization test (PRNT). Low passaged VERO E6 cells are kept in liquid nitrogen at -191° C. Cells for dengue PRNT and dengue virus production were maintained in cell culture medium, consisting of Dulbecco's Minimum Essential Medium (DMEM; cat. # 10313-021, Invitrogen, GIBCO), supplemented with 10% heat inactivated (at 56° C for 30 minutes) fetal bovine serum (FBS; Invitrogen) and penicillin /streptomycin / L-glutamine (Invitrogen) at 100 U/mL, 100 µg/mL and 0.29 mg/mL final concentration respectively. Vero cell cultures were grown to full monolayer in tissue culture flasks (T225

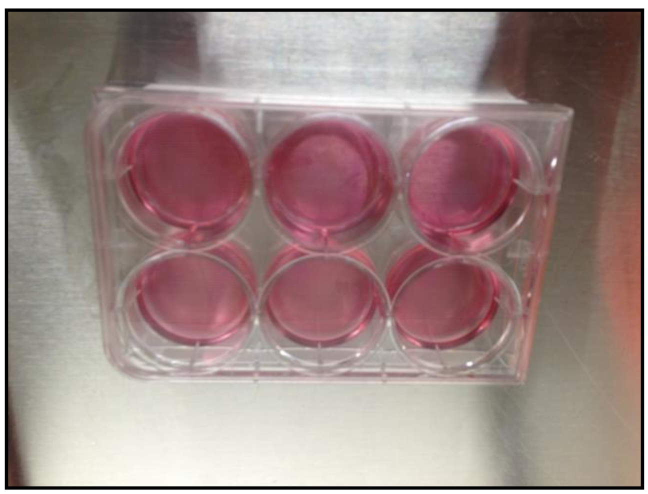


Plate 3.5: Plate with cell monolayer for PRNT

flask, Corning/Costar, Corning, NY) with 150 cm^2 surface volumes.After reaching confluence (on average 3 days), the cells were subcultured. To do so, the tissue culture medium was removed from the flask/s and the cells were incubated at 37° C with3 mL 0.25% Trypsin-EDTA solution (Invitrogen), with vigorous shaking at 3 minutes. The enzymatic activity of the trypsin was neutralized by the addition of approximately 7 mL culture medium. The disrupted cell monolayers were then either distributed to new flasks or to 6 well plates at a concentration of2x 10^6 cells/mL. New flasks or plates were placed in an incubator at 37° C with 5% CO_2. Only those plates with fully formed monolayers were used in the PRNT assays (Plate 3.4). In addition, cell banks were qualified before use and confirmed to be free of any microbial, mycoplasma and viral contaminants. All cell manipulations were performed using aseptic techniques in a biological safety cabinet.

Preparation of virus stocks: Once an 80-90% confluent monolayer of Vero cells had developed in a 150 cm^2 tissue culture flask, a 1:100 dilution of DENV-2, WNV-NY99 or JEV stock virus prepared in BA-1 diluent (1X M199, 1M Tris-HCl, 7.5% bovine serum albumin fraction V and penicillin/streptomycin) was used to infect the cells. Growth media was discarded from each flask and the monolayer was washed with 5mL of Dulbecco's Phosphate Buffered Saline (PBS) pH 7.2 (Invitrogen), followed by the addition of 2-4 ml of diluted virus. Infected cells were incubated at 37°C with of 5% CO_2. Flasks weregently rocked at 15-20 minute intervals to evenly distribute the virus. After one hour of absorption, 30 mL of growth media (DMEM with 5% FBS and penicillin/streptomycin/L-glutamine) was added to each flask. The flasks were microscopically observed daily post-infection to check for the presence of a cytopathic effect (CPE) in infected cells. Once significant CPE was observed (i.e., greater than 50 % cells infected or monolayer destroyed), the flasks were frozen at-80°C and thawed. The supernatant, also known as a cell lysate, was then used to prepare working stocks of the virus. The cell lysates were pooled and centrifuged at 1500 rpm for 15 minutes to remove cellular debris. The supernatant was transferred to another tube and heat inactivated FBS was added at a final concentration of 20%. The virus preparation was then aliquoted into Sarstedt vials in 0.25 ml volumes. Vials were labeled with virus name, passage number and date of infection and stored at -80°C for long-termstorage.

Titration of virus stocks: A plaque assay was used to determine the concentration of DENVand other viruses that were subsequently used in the $PRNT_{90}$. Six well plates (Corning, Corning, NY) seeded with 3 mL Vero cells at 2 x 10^6 cells/well,wereincubated at 37°C with 5% CO_2 for 3 days in containment level (CL)2 facilities of National Microbiology Laboratory. Once the plated cells formed a confluent monolayer, the plates were transferred to the CL3 facilities for the plaque assay. Since WNV and JEV are risk group 3 pathogens, all manipulations involving viruses were performed in CL3. This practice provided the highest level of containment required, allowed consistency in the assays using different viruses and also made it easier to schedule experiments.

Ten-fold dilutions (e.g., 10^{-1} to 10^{-8} of the virus stock/s) were prepared using BA-1 diluent in 2 mL Sarstedt vials. The tissue culture medium was aspirated from each well (leaving a residual 200 μl) and replaced with 100 μl of diluted virus dilution per well in duplicate. After rocking to ensure the monolayer was completely covered with the diluted virus preparation, the plates were incubated at 37°C with 5% CO2 for 1 hour, with gentle rocking at 15-20 minute intervals.

During this incubation period, the first nutrient agar overlay was prepared using equal volumes of solution A and solution B. Solution A consisted of 2X M199 media with Earl's salt (1:5 dilution of 10 X 199 media, Sigma), 10% FBS, 0.1% glucose, 0.15% yeast extract, 1X penicillin-streptomycin, L-glutamine and0.1% sodium bicarbonate, while Solution B consisted of 2% Noble agar. Solution A was brought to room temperature then placed in a 42° C for 15 minutes. Solution B was melted in a microwave and placed in a 43° C water bath for at least 20 minutes. Equal volumes of Solutions A and Bwere combined and incubated in a 43° C water bath for an additional 20 minutes before use.

Once the hour incubation period for infection elapsed, 3 mL of the agar overlay were added to each well of the six well plates. During addition of the first overlay, the temperature was monitored to ensure it did not exceed 42° C to avoid killing the cells. Each plate was gently swirled gently immediately following the addition of the agar overlay for uniform distribution. After 20-30 minutes the plates were inverted and placed in a 37° C incubator with of 5% CO_2 for 3 days for WNV or 5 days for DENV and JEV.

After completion of the incubation period, 2 mL of a second overlay solution containing equal volumes ofSolution A supplemented with 0.02 % Neutral Red and Solution B was added to each well. Once the agar solidified, the plates were inverted and incubated for 7-9 hours at 37° C with 5% CO_2. Plaques were counted and tabulated for results. The virus titer was calculated as PFU/ml based on the number of plaques per well and the dilution factor used.

Serum samples: Dengue antibody-positive human serum samples from children and adults were obtained from one pre-monsoon and two post-monsoon serosurvey organized by icddr,b in Dhaka. After collection of blood samples, sera were separated and 500 µl of serum from each blood sample was shipped to NML at Winnipeg. At NML, sample identifiers were removed and new sample identification numbers were issued. Serum samples were first diluted 1:5 in BA-1 (0.1 ml of the original serum to 0.4 ml of BA-1 diluent) in 2ml Sarstedt tubes, mixed by vortexing then heat inactivated for 30 minutes at 56°C to destroy non-specific neutralizing substances before use.

PRNT assay: The PRNT assay was performed on serum samples that were positive by Focus Dx Select Dengue IgG ELISA. A virus titration and back titration was also set up along with the PRNT. The virus titration was a means of monitoring the titre of the stored virus so that adjustments to the virus dilution could be made as required. The back-titration was performed using virus dilutions containing 100, 10 and 1 PFU/100 µl. These dilutions provided plaque counts against which those of serum samples were complared in order to determine the percentage inhibition of plaque formation. The back-titration also served as additional confirmation that the virus concentration was correct.

Sample preparation and virus neutralization: In a 96 well microtitre plate, serum samples were serially diluted from 1:10 to 1:640 with BA-1 diluent to produce a final volume of 110 µl. Since the last well of the serial dilution contained 220 µl, the final 110 µl was discarded. An equal volume (110 µl) of virus prepared to contain 2000 PFU/mL (or 200 PFU/100 µl) was added to all wells containing diluted sera, using a multichannel pipet. The microtitre plate was incubated at 37° C with 5% $CO_2$for 60-90 minutes. In the meantime, the 6 well plates containing confluent Vero cell monolayers were labeled with serum specimen number, serum dilution and assay date. Just prior to the end of the neutralization incubation, the majority of the tissue culture medium was aspirated from each well. Following the incubation, 100 µl of the virus-serum mixture and dilutions for virus titration or back-titration were added to the designated wells. PRNT testing and virus titration was done in duplicate wells, while an entire plate was used for each dilution of the back-titration. The plates were incubated at 37°C with 5% CO2 for 1 hour with gentle rocking at15-20 minute intervals to ensure complete coverage of the cell monolayer. Following the infection, the first and second agar overlays were performed as previously described.

Interpretation: Titres are determined as the highest dilution of the serum sample that inhibits the formation of at least 90% of the plaques as compared to the back titration control. For example, if the 100 PFU / 100 µl ml back- titration control generated 100 plaques per well, the last serum dilution that produced 10 or less PFUs would be the neutralization titre recorded for that sample. A neutralization titre of 80 or greater in a convalescent serum sample would in most cases be indicative of exposure to a specific flavivirus; however, some cross-reactivity may be observed between related flaviviruses. Therefore, a serum sample with DENV-specific antibodies should produce a DENV neutralization titre at least 4 fold or greater than PRNT titres obtained against other flaviviruses such as WNV and JEV.

3.2.4 Field data collection: Socioeconomic survey and social research methods

In consideration of the scope of the present study, three levels of socio-economic and behavioral entities have been considered to collect information in these areas: i) a household level KAP questionnaire survey of 300 PSUs from 12 wards; ii) 12 focus group discussions

(FGDs; n=107) from three purposely-selected wards; iii) 18 key informant interviews (KII) among these three wards; and iv) two knowledge model development sessions involving experts and lay persons from these three wards.

In social science research, interviewing respondents representing the PSU is a common method of data collection and is used effectively in analyzing societal variables. Although types of interview may range from informal to highly-structured, social research usually emphasize on one or two types dominant interview methods. In this context, Bernard’s (2012) classification of four types of interviews is worth elaborating: informal interview (absence of structure or control), unstructured interview (minimal control but with a clear plan), semi-structured interview (using an interview guide) and structured interview (using an identical set of questions for all interviewees).

In order to ensure high-quality data on the societal dimensions of the present research, both semi-structured and structured interviews were used. However, it should be noted that informal discussions with the respondents were carried out prior to the semi-structured or structured surveys. Following Lindzey and Aronson (1968) and Moser and Kalton (1971), special attention was paid to *accessibility* (availability of the required information to the respondent), *cognition* (understanding by the respondent of what was required of her/him), *motivation* (decision to cooperate), and *interaction* (social process involving the interviewer and respondent) to ascertain successful interview outcomes.

Both local community members and other stakeholders have directly participated and contributed to delineate the research agenda, needs, knowledge and action in multiple stages of implementation of this research. In order to provide ‘space’ and voices of the local communities, the present researcher took direct part in the daily life activities in three selected communities for the duration of four month period (January 2012-April 2012). Such involvement provided an opportunity to the researcher to become 'one of them' as well as to the community members to become part of the research team and agenda setting members.

As engaging local community members in academic and action research demands particular attention to both personal situational factors as well as social-structural issues, I have attempted to closely observed and get directly involved with such community and personal issues wherever they were permissible.

3.2.4.1 KAP questionnaire survey

In order to understand how local community members understand dengue transmission, and how their socioeconomic and demographic characteristics as well as cultural and social norms might influence these views, the socio-economic questionnaire survey was conducted among 300 PSUs. The above mentioned spatial randomization procedure was followed by drawing grid cells on a map of each wards and selecting a total of 25 households in each ward using a random number table. This resulted in a sample size of 300 households. The survey questions were designed to elicit peoples' knowledge of dengue and its vector, disease severity, mosquito habitat, community members' attitudes towards dengue prevention and control, age and gender differentials in these perceptions, and general health and occupational status factors. With administrative, human resource, and other logistical support from the Department of Public Health at the North South University (NSU) in Dhaka, six teams (2 research fellows from NSU) conducted the survey for 10 days during the months of July-August 2011.

Plate 3.6: Present researcher is conducting Knowledge, Attitute, and Practice (KAP) survey in Dhaka, Bangladesh

3.2.4.2 Focus Groups Discussions (FGDs)

Three purposely-selected wards were chosen for participation in more in-depth focus group discussions (Figure 1). Ward 69 (Chankharpul) has a history of more than four centuries and contains many densely-populated older settlements. Representing a newer and mixed land-use area, ward 20 (Mohakhali) is located near the city-center, with a considerable concentration of high-value residential and commercial buildings. Situated along the eastern fringe of Dhaka, ward 26 (Meradia) is undergoing a rapid transformation from a rural to urban landscape (see table 3.2 for more details).

The FDGs were organized with the help of the Population Services and Training Center (PSTC), a non-governmental organization in Bangladesh (Appendix XVII; Image 3.4). A total of 12 FGDs, each with 7-10 participants, were organized (4 from each ward) during the months of March-August 2012. Each session lasted approximately 90-120 minutes to ensure that all views could be shared. As focus group conversations can be influenced by a number of factors such as gender (Bangladeshi women are less comfortable voicing their opinions in front of men); occupation (people working in low-skilled and transient positions might be less comfortable sharing ideas in groups with people in higher-paid professional positions); and positionality within a community (deference might be given to the opinions of health professionals or local leaders); focus groups were stratified into four different groups per ward, based on gender and local role in decision-making. These included groups that consisted of men only (Appendix XVII; Image 3.2), women only (Appendix XVII; Image 3.2), a mix of men and women health professionals (Appendix XVII; Images 3.5 and 3.6), and a gender mix of local community leaders (Appendix XVII; Image 3.7).

The interviews were conducted in the local language of Bengali. Translations were done by of the two lead authors of the present study, who are also fluent in Bengali and are capable of fully interpreting local meanings. All participants provided their informed consent to participate and most interviews were audio recorded and transcribed verbatim. In situations when participants did not want to be audio-recorded, but nonetheless consented to the interview process, detailed notes were taken by two individuals and were synthesized for analysis by the researchers.

3.2.4.3 Key Informant Interviews (KIIs)

As part of triangulation attempts to validate the obtained neighborhood socio-economic and environmental data, selected key informant interviews were carried out in the 3 sampled wards. A maximum of three key informants in each ward were interviewed, this parameter being selected to limit the number of total interviewees. Key informant interviews involved directly interviewing a select group of individuals most likely to provide required information, ideas, and insights on a particular subject. The technique of key informant interviews has originated in cultural anthropology and presently is widely used in various public health and social science fields. Among the many advantages of the technique, as Marshall (1996) has noted, is that it allows procurement of high-quality data in a relatively short period of time. Second, only a small number of informants are interviewed. Key informants are selected according to their local knowledge and close familiarity with the community and the ideas that can be solicited by the investigator. Considering the fact that the present study concerns certain types of mosquito as a disease vector, the elected ward members and local-level health service providers (Appendix XVII; Image 3.8) were treated as the key informants for the neighborhood component of the study. A semi-structured questionnaire was used to obtain information on population characteristics of the ward, evolution of land use changes, changes in vegetation and urban services, and provisions for water supply and waste management.

A total of 18 face-to-face interviews were conducted following a semi-structured interview guide, with interview lasting between 30 and 40 minutes. The technique also allowed the investigator to access various groups of a community where they are constrained by various ethnic, religious and other cultural factors (Green et al., 1993). Five selection criteria of eligibility (role in community, knowledge, willingness, communicability and impartiality), formulated by Tremblay (1957), were applied to recruit KIs. Local-level health service providers and health professionals, political leaders, and housewives were regarded as most appropriate for this study. All participants provided their informed consent to participate and, with consent, most interviews were audio recorded and transcribed verbatim.

Table 3.2: Demographic and health infrastructural characteristics of the 3 selected wards, representing different Socio-Economic Status (SES) zone

Name of City Ward	Ward No.	Area (in Sq. km)	Population	House Hold	Household Size (total # family members)	Total Literacy Rate	#of Health services center	W.S.P	L.S.O
Chankharpul	**69**	4.3	150,000	18,496	4	68.37	04	01	07
Mohakhali	**20**	3.5	300,000	15,366	5	71.10	12	06	04
Meradia	**26**	3.6	127,000	11,636	5	67.13	07	03	No
Total		**11.4**	**577,000**	**45,498**	**4.67**	**68.87**	**23**	**10**	**11**

WSP= Water Supply Point; LSO=Locally Social Organization;
Source: Ward City Corporation Office, Bangladesh Bureau of Statistics

3.2.4.4 Mental Model development

Understanding key risk perceptions related to dengue requires the assessment of many beliefs related to the problem, its causes, and solutions. Knowledge of the problem itself affects individuals' understanding of whether and how much they and other members of their community may be at risk. It is also important to understand what individuals know about the underlying causes of these diseases. In order to evaluate the level and types of knowledge among the concerned groups, a mixed method borrowed from the Mental Model framework (Morgan, 2002) was adopted. This method is a multi-step method for creating and testing risk messages in a way that is faithful to the sciences of risk and communication. The evolution of the Mental Model is rooted in the recognition of the need for a establishing a two-way risk communication strategy characterized by mutual understanding and equal and fair participation rather than the exertion of power. It focuses on understanding people's mental models (e.g. their knowledge, beliefs, and perceptions) in order to craft effective risk communication messages that can help them understand complex or unfamiliar phenomena. Bier (2001) further suggests that risk communication messages using the mental model therefore are more effective at conveying both general knowledge and information about risk reduction strategies.

The process I pursued can be distinguished from the original Carnegie Mellon University methodology for mental models, which applies the expert influence diagram as a structural template to steer the community member content analysis in order to make comparative analyses. Methodologically, Mental Models are captured through drawing 'influence diagrams' which are basically directed networks, illustrated via arrows or 'influences' connecting related 'nodes' (Morgan, 2002). They illustrate the relationship of complex variables, with factors influencing each other in direct and indirect ways. Based on the Idea Generating Strategy (IGS) (Linstone and Turoff 1975; Needham and de Loe 1990) of the Delphi process, I attempted to preserve a strong contextual element, in which the lay persons' mental model was based primarily on community members' own understandings and concerns. Development of the lay citizen's and expert's knowledge models were the key objective of the process. The 'lay citizen knowledge model' is the representation of a broad range of public beliefs regarding the risk of dengue in relation to its causes, symptoms, and severity; while the 'expert knowledge model' is the representation of the particular state of knowledge and perception of health scientists, researchers, medical practitioners regarding dengue disease and its associated risks (i.e. technical risk perception) and problems in the city of Dhaka. In our study, influence diagrams were developed in four stages: i) undertaking a review of the literature; ii) performing a content analysis of the state of risk contained in the literature; iii) conducting focus group discussions with experts; and iv) validation of the consolidated influence diagram by a group of external experts, who possessed authority in the scientific as well as policy domains.

Plate 3.7: Present researcher is conducting meeting with Population Services Training Centre (PSTC) staff in Dhaka, Bangladesh

In the selection of the study communities, a total of three wards representing diverse socioeconomic and urban ecological settings were chosen to attain the goals of the study. With the help of Population Services and Training Center (PSTC), an NGO in Dhaka, local leaders and key persons were contacted to facilitate the required meetings (Plate 3.6). In order to gather insights into community members' perspectives on dengue, I developed a semi-structured questionnaire with researchers familiar with dengue disease issues in the City. I used the standard qualitative methods to identify key socio-demographic characteristics expected to affect interviewees' views with respect to dengue-disease-related risk perceptions (Becker, 1996). Two discrete groups of participants were involved in this study: the lay citizens representing the public at the local community level, and the experts representing specialists in infectious diseases like dengue and malaria, health practitioners, and health program managers.

The development of the ‘lay person knowledge model’ involved a total of 65 respondents from the selected wards representing various socio-economic and demographic groups (age range: 19–74 years), who were were directly interviewed with semi-structured survey instruments (Appendix XVII; Image 3.10). A systematic random sampling procedure was employed to select respondents from the lists of ward members. The second sample of participants in this study was a group of 15 experts representing specialists in infectious diseases, health practitioners, and health program managers. A list of experts was prepared by contacting the office of the Director General Health Services, Government of Bangladesh. Selection of the participating experts was then based on the specialist’s willingness to participate. Formulation of the expert knowledge model was achieved through a day-long meeting for Focus Group Discussion to construct ‘influence diagrams’ capturing the current state of knowledge and the pooled beliefs of the participants (Appendix XVII; Image 3.9).

Along with Bernard (1988), gender and socioeconomic status are important variables affecting disease-related risk perceptions; therefore I aimed at interviewing lay citizens in terms of their gender, occupation and level of income (Bernard, 2011). Participants were approached in public areas such as community centers, plazas, local NGO offices, and club meeting rooms. All discussions and interviews were conducted in Bengali, tape recorded, transcribed verbatim, and translated. All participants provided their informed consent to participate, and in situations when participants did not want to be audio-recorded, but nonetheless consented to the process, detailed notes were taken by two individuals and were synthesized for analysis by the researchers.

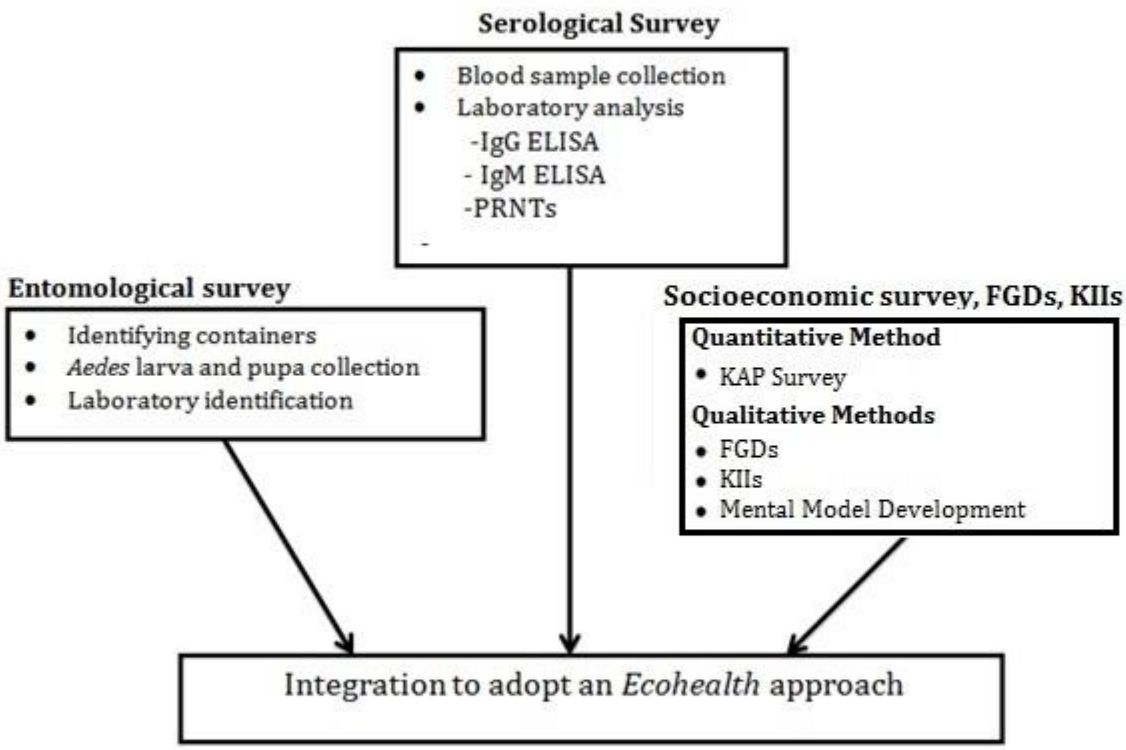


Figure 3.9: Overview of field and laboratory methods of the research

3.3 Data Analysis

The present study involved analysis of both quantitative and qualitative data, consistent with its mixed-method research design. The quantitative data were obtained from entomological, community population serosurvey, and socio-economic surveys. The compiled data were entered into an SPSS statistical software program (IBM SPSS Inc. version 22; August 2013) for data processing and synthesis. In order to synthesize the data, descriptive statistics were calculated for each variable of interest. Both parametric and non-parametric tests (i.e. chi-quare test, student t-test, Kruskal-Wallis k-sample test) were used to evaluate homogeneity, independence, and relationships among various groups or variables. For complex relational analysis among the response and explanatory variables, I employed a two-step framework: univariate analysis using descriptive statistics followed by multivariable analysis using logistic and nominal regression analysis. In order to facilitate interpretation, the stepwise selection method was chosen to identify important explanatory variables, which provided odd ratio estimates. The Hosmer-Lemeshow goodness-of-fit test was used to assess the validity of the final regression models.

Qualitative data analysis was a constituent feature of my research design. The qualitative data were coded and synthesized using NVivo software (QSR international 2007). The data gathered during the course of this research were analyzed progressively during and after the data gathering seasons. During the field seasons I made field notes and analyzed them in the field so that an iterative process could be established. Written textual material was initially analyzed for its surface, descriptive content, and then analyzed more interpretively for thematic content. Data analysis was carried out using the Bengali transcriptions, while quotes presented in this chapter have been translated into English. The transcripts were imported into QSR International NVivo® (version 10) software for analysis. Written textual material was initially analyzed for its surface descriptive content, and then analyzed more interpretively for thematic content. As part of an ongoing engagement process, many participants and communities were debriefed of findings to assess their congruency as well as to involve participants in subsequent phases of the research. Detailed descriptions of data analysis are presented within each chapter of this research.

3.4 Ethical Consideration

The University of Manitoba (UM) ethical research guideline (approved by UM Joint Faculty Research Ethics Board) was strictly followed for i) KAP survey, ii) FGDs, iii) KIIs, and iv) knowledge model components during the conduct of the field research. The informed consent document (ICD, approved by UM Joint Faculty Research Ethics Board) was first read to participants before they signed it (Appendix I). The confidentiality of all participants was maintained throughout the study. Participants representing local community members in general, stakeholders, government officials, civil society organization personnel, community leaders, and other beneficiaries took part in this research voluntarily. Requests for participants' time were backed up by explaining the significance, scope, and benefits of this research. Disagreement to participate had no negative consequences, and participants were told they were free to withdraw from the study at any time, and/or refrain from answering, without prejudice or consequence.

For FGDs and KII, I met the participants at convenient times in their schedules, taking a minimum amount of time to complete the discussions. In addition, mobilization of research participants within three different wards was facilitated by relevant consultations between PSTC and its beneficiaries for optimum use of the participants' time. As a researcher, my involvement in any consultation was impartial. Information provided by the participants and stakeholders was kept confidential and their personal identies were never disclosed. Only the principal researcher had access to the completed survey forms, which were securely stored in the Natural Resources Institute, University of Manitoba (UM) (Room # 305; Sinnott Building). Any other documents bearing the participants' names were stored separately from survey responses, which were coded with an arbitrary number. These anonymous data were stored in paper form for up to five years post-publication of the results. Photographs of any participants or group discussions were taken or used with their consent.

Bangladesh Medical Research Council (BMRC) ethical guidelines were firmly followed for household entomological surveys during 2011-2013. If the head of household or respondent was interested in participating entomological survey, the informed consent document (ICD) was shown to them during the first survey (2011) and consent of willingness for participation was taken for next entomological surveys (2012-2013). All household socio-demographic and laboratory data on each entomological sample were entered into a database (i.e., JAVA JAR file) as a unique identification number.

International Center for Diarrheal Disease and Research, Bangladesh (icddr,b) Ethical Review Committee (ERC) and Research Review Committee (RRC) ethical guidelines for population serosurvey and collection of human blood samples were strictly followed throughout the field research process during 2012-2013. The risks of infection with venipuncture sampling were minimized by using only trained personnel from icddr,b. To perform the venipuncture procedures only sterile, single use needles were used. In the reporting of the laboratory results, names were used, but the information was only provided to the head of the household. All demographic, clinical, epidemiological, and laboratory data for each sample were entered into a database by a unique global identification number.

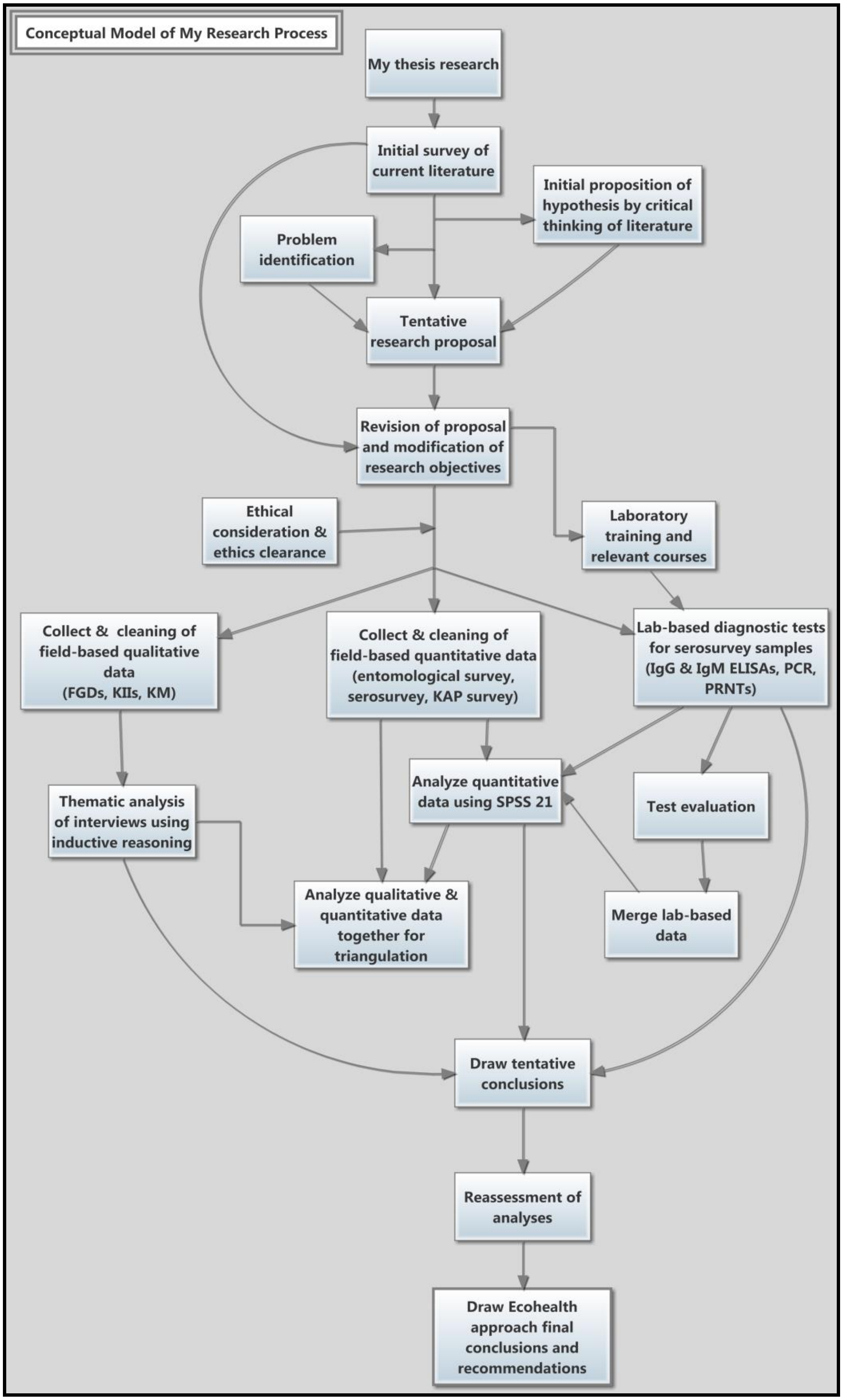


Figure 3.10: Schematic diagram of the research process

References

Albrecht, G., Higginbotham, N., Connor, L. (Ed.). (2001). *Transdisciplinary thinking in health social science research: definition, rationale, and procedures. In: Health Social Science: a Transdisciplinary and Complexity Perspective*. South Melbourne: Oxford University Press.

Bangladesh Bureau of Statistics. (2001). *Area, Population and Literacy Rate by Paurashava*. doi:http://web.archive.org/web/20080625052740/http://www.bbs.gov.bd/dataindex/census/municip.pdf.

Bangladesh Bureau of Statistics. (2010). *Statistical pocket book Bangladesh* Dhaka: Government of Bangladesh.

Beaty, B.J., Calisher, C.H., Shope, R.E. (Ed.). (1995). *Diagnostic procedures for viral, rickettsial, and chlamydial infections* [Arboviruses, Lennette, EH, Lennete, DA, Lennete ET, (eds)] (7th edition ed.). Washington, D.C.: American Public Health Association.

Becker, H. S. (1996). The epistemology of qualitative research. *Ethnography and Human Development: Context and Meaning in Social Inquiry, ,* 53-71.

Bernard, H. R., & Bernard, H. R. (2012). *Social research methods: Qualitative and quantitative approaches* Sage.

Bernard, H. R. (2011). *Research methods in anthropology* Rowman Altamira.

Bernard, H. R. (1988). *Research Methods in Cultural Anthropology* Sage Publications.

Bier, V. (2001). On the state of the art: risk communication to the public. *Reliability Engineering & System Safety, 71*(2), 139-150.

Breilh, J. (2003). Epidemiologı´a Crı´tica: Ciencia Emancipadora e Interculturalida. *Buenos Aires: Lugar Editorial,*

Calisher, C. H., Karabatsos, N., Dalrymple, J. M., Shope, R. E., Porterfield, J. S., Westaway, E. G., & Brandt, W. E. (1989). Antigenic relationships between flaviviruses as determined by cross-neutralization tests with polyclonal antisera. *The Journal of General Virology, 70 (Pt 1)*(Pt 1), 37-43.

Caprara, A., Lima, J. W. O., Marinho, A. C. P. et al. (2009). Irregular Water Supply, household usage and dengue: a bio-social study in the Brazilian Northeast. *Cad. Saude Publica, 25*(Sup 1), S125-S136.

Caracelli, V. J., Riggin, L.J.C. (1994). Mixed-method evaluation: Developing quality criteria through concept mapping : Mixed-Method Collaboration. *Evaluation Practice, 15*(2), 139-152.

Casebeer, A. L. & Verhoef, M. J. (1997). Combining qualitative and quantitative research methods: considering the possibilities for enhancing the study of chronic diseases. *Chronic Diseases in Canada, 18,* 130-135.

Centers for Disease Control and Prevention (2001). West Nile Virus activity--United States, 2001. *MMWR.Morbidity and Mortality Weekly Report*, *51*(23), 497-501.

Charron, D. F. (Ed.). (2012). *Ecohealth research in practice: Innovative Applications of an Ecosystem Approach to Health*. Ottawa, Canada: Springer.

Consoli, R. A., & de Oliveira, R. L. (1994). *Principais mosquitos de importância sanitária no Brasil* Editora Fiocruz.

Creswell, J. W., & Clark, V. L. P. (2007). *Designing and conducting mixed methods research* Wiley Online Library.

Creswell, J. W. (2009). *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*. Los Angeles, London, New Delhi,Singapore: Sage.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches* Sage.

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process* Sage.

Despres, C., Brais, N., Avellan, S. (2004). Collaborative planning for retrofitting suburbs: transdisciplinarity and intersubjectivity in action. *Futures, 36.*

Dhaka Metropolitan Development Plan (DMDP). (1997). *Dhaka Metropolitan Development Plan (1997-2015),Dhaka,* (No. I & II).Rajdhani Unnayan Kartripakha (RAJUK).

Green, E. C., Jurg, A., Dgede, A. (1993). Sexually transmitted diseases, AIDS and traditional healers in Mozambique. *Medical Anthropology, 15,*261-281.

Guba, E. G., Lincoln,Y. S. (Ed.). (1994). *Competing paradigm in qualitative research*. California: Thousand Oaks, Sage.

Halstead, S. B. (1990). Global epidemiology of dengue hemorrhagic fever. *The Southeast Asian Journal of Tropical Medicine and Public Health, 21*(4), 636-641.

Haque, M. A., Yamamoto, S. S., Malik, A. A., & Sauerborn, R. (2012). Households' perception of climate change and human health risks: a community perspective. *Environmental Health : A Global Access Science Source, 11*(1), 1-1.

Hashizume, M., Dewan, A. M., Sunahara, T., Rahman, M. Z., & Yamamoto, T. (2012). Hydroclimatological variability and dengue transmission in Dhaka, Bangladesh: a time-series study. *BMC Infectious Diseases*, *12*, 98-98.

Hoshmand, L. T. (2003). Can lessons of history and logical analysis ensure progress in phychological science? *Theory and Psychology, 13*, 39-44.

Johnson, R.B., Onwuegbuzie, A. J. (2004). Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher, 33*(7), 14-26.

Johnson, B. W., Kosoy, O., Hunsperger, E., Beltran, M., Delorey, M., Guirakhoo, F., & Monath, T. (2009). Evaluation of chimeric Japanese encephalitis and dengue viruses for use in diagnostic plaque reduction neutralization tests. *Clinical and Vaccine Immunology : CVI, 16*(7), 1052-1059.

Karim, M. N., Munshi, S. U., Anwar, N., & Alam, M. S. (2012). Climatic factors influencing dengue cases in Dhaka city: a model for dengue prediction. *The Indian Journal of Medical Research, 136*(1), 32.

Kearney, M. (1984). *World View*. Novato, CA: Chandler and Sharp.

Klein, J. T. (1990). *Interdisciplinarity: history, theory, and practice*. Detroit, Michigan: Wayne State University Press.

Klein, J. T. (2004). Prospects of transdisciplinarity. *Futures, 36*, 515-526.

Krieger, N. (1994). Epidemiology and the Web of Causation: HAs anyone seen the Spider? *Social Science and Medicine, 39*(7), 887-903.

Krieger, N. (2001). Theories for social epidemiology in the 21st century: an ecosocial perspective. *International Journal of Epidemiology, 30*(4), 668-77.

Leathard, A. (1994). *Going inter-prefessional:Working together for health and welfare*. London: Routeledge.

Lebel, J. (2003). *Health: an Ecosystem Approach*. Ottawa: International Development Research Centre.

Lindzey, G. E., & Aronson, E. E. (1968). The handbook of social psychology .

Linstone, H. A., & Turoff, M. (1975). The Delphi method: Techniques and applications.

Marshall, M. N. (1996). The key informant technique. *Family Practice, 13*(1), 92-97.

McDonell, G. (2000). Disciplines as cultures: Towards reflection and understanding. *Transdisciplinarity: Recreating Integrated Knowledge.EOLSS Publishers, Oxford, UK,*

McMichael, A. J. (1999). Prisoners of the proximate: Loosening the constraints on epidemiology in an age of change. *American Journal of Epidemiology, 149*(10), 887-897.

Morgan, M. G. (2002). *Risk communication: A mental models approach* Cambridge University Press.

Morgan, D. L. (1998). Practical strategies for combining qualitative and quantitative methods: Application to health research. *Qualitative Health Research, 3*, 362-376.

Moser, C., Kalton, G. (1977). *Survey methods in social investigation*. London: Heinemann Educational Books Limited.

Moser, C. A., & Kalton, G. (1971). Survey methods in social investigation. *Survey Methods in Social Investigation.*, (2nd Edition)

Needham, R.D., de Loe, R. C. (1990). The policy Delphy: Purpose, Structure and Application. *The Canadian Geographer*, *34*(2), 133-142.

O'Cathain, A., Murphy, E., Nicholl, J. (2007). Integration and publications as indicators of "yield" from mixed methods studies. *Journal of Mixed Methods Research, 1*, 48-76.

Onwuegbuzie, A. J. (2000). Validity and qualitative research: An oxymoron? *Annual Meeting of the Association for the Advancement of Educational Research (AAER),* Ponte Vedra, Florida.

Perkes, M. W., Bienen, L., Breilh, J. et al. (2005). All hands on deck: Transdisciplinary approaches to emerging infectious disease. *Ecohealth, 2*, 258-272.

Rosenfield, P. L. (1992). The potential of transdisciplinary research for sustaining and extending linkages between the health and social sciences. *Social Science Medicine, 35,* 1343-1357.

Russell, P. K., Nisalak, A., Sukhavachana, P., & Vivona, S. (1967). A plaque reduction test for dengue virus neutralizing antibodies. *Journal of Immunology (Baltimore, Md.: 1950), 99*(2), 285-290.

Shamsuddoha, M., & Hossain, M. (2011). Unpublished manuscript, Dhaka, Bangladesh.

Tashakkori, A., Teddlie,C. (1998). *Mixed methodology: Combining qualitative and quantitative approaches*. London: Sage.

Tremblay, M. (1957). The Key Informant Technique: A nonethnographic application . *American Anthropologist, 59*(4), 688-701.

Tudge, J. (2000). Theory, method, and analysis in research on the relations between peer collaboration and cognitive development. *The Journal of Experimental Education, 69*(1), 98-112.

United Nations. Department of Economic. (2008). *The Millennium Development Goals Report 2008* United Nations Publications.

Waltner-toews, D., & Kay, J. (2005). The Evolution of an Ecosystem Approach : the Diamond Schematic and an Adaptive Methodology for Ecosystem Sustainability and Health.*10*(1)

Whittemore, A. S., & Halpern, J. (1997). Multi- stage sampling in genetic epidemiology. *Statistics in Medicine, 16*(2), 153-167.

Wilcox, B. A., & Colwell, R. R. (2005). Emerging and Reemerging Infectious Diseases: Biocomplexity as an Interdisciplinary Paradigm. *Ecohealth, 2*(4), 244-257.

Wilcox, B. A., Gubler, D. J., & Pizer, H. F. (1996). Urbanization and the social ecology of emerging infectious diseases.

World Bank. (2010). *Country Assistance Strategy for the People's Republic of Bangladesh.* (No. 4).

World Health Organization. (2007). Guidelines for plaque reduction neutralization testing of human antibodies to dengue viruses.

World Health Organization and UNICEF. (2012). *Joint monitoring programme for water supply and sanitation: Estimates for the use of improved sanitation facilities*.

CHAPTER FOUR

SOCIOECONOMIC AND ECOLOGICAL FACTORS INFLUENCING *AEDES AEGYPTI* ABUNDANCE*

Abstract

This chapter examines the socioeconomically and spatially-differentiated household risk factors associated with immature *Aedes* abundance and distribution, and their association with socioeconomic and ecological factors at both the urban zonal and household levels in the city of Dhaka, Bangladesh. Entomological surveys to detect larvae and/or pupae of *Aedes* mosquitoes and a socioeconomic questionnaire were conducted during the 2011 monsoon season. All administrative Wards (N=90) of the City were classified into three Socio-Economic Status (SES) zones using the Delphi method, and 826 households in 12 randomly selected Wards were surveyed for vector mosquitoes. The results revealed that the abundance and distribution of immature *Aedes aegypti* and *Aedes albopictus,* as well as pupae per person indices (PPI), did not vary significantly among urban zones with varying SES. Of 35 different types of identified wet containers, 23 types were found to be infested, and nine were determined to be 'most productive' for pupae of vector mosquitoes. Refrigerator trays had the most pupae among all positive containers, followed by sealable plastic barrels, plastic buckets, and disposable plastic containers. When the function of the containers was assessed, ornamental, discarded, and household repair and reconstruction-related container categories were found to be significantly associated with the number of pupae in the households. The purpose of storing water and annual income variables were significant predictors of container-type possession by householders.

* Parts of this chapter have been accepted by *Ecohealth* journal: authors: Dhar-Chowdhury, P., Haque, C.E., Lindsay, R., Hossain, S.; title: Socioeconomic and ecological factors influencing *Aedesaegypti* abundance and distribution in Dhaka, Bangladesh.

4.1 Background

In the absence of a dengue vaccine or other antiviral drugs, the only way to combat dengue is to control dengue vector mosquitoes (*Aedes aegypti* and *Aedes albopictus*), either by limiting larval habitats or area spraying to reduce adult population densities - or a combination of both (Gubler, 1998; Reiter et al., 1997). The entomological indices commonly used in dengue vector surveillance efforts were developed originally for yellow fever control (the *Stegomyia* indices) and focus on immature populations. The initial *Stegomyia* indices, described in 1923, included the House Index (HI) - referring to the percentage of houses infested with larvae and/or pupae - and the Container Index (CI), referring to the percentage of water-holding containers infested with active immature forms. Thirty years later, the Breteau Index (BI), the number of positive containers per 100 houses, became a common measure (Sanchez et al., 2006; WHO, 2009). BI is considered to be one of the better risk indicators for dengue outbreaks, as it combines infestation data for both containers and houses (Seng et al., 2009; Tun-Lin et al., 1995). The CI is likely the weakest measure as it reflects only the proportion of positive containers in a certain area and does not take into account the number of containers per area, house, or person. The HI is better, but also fails to indicate the number of positive containers per positive house.

The application of these indices has been attempted in a number of regions. For example, in 1922, Connor and Monroe, developers of the HI and CI, observed that a CI of 10% in urban areas of Central and northern South America constituted a safety zone with regards to yellow fever transmission; they inferred similar conclusions regarding dengue without much further evidence. Soper gave a prophylactic level for the same topical areas to be an HI of < 5% (Sanchez et al., 2006). The Pan American Health Organization defines three levels of risk for dengue transmission: low (HI<0.1%), medium (HI 0.1%–5%), and high (HI>5%) with little actual data to back up these delineations (Sanchez et al., 2006).

However, several investigators have argued that the traditional *Stegomyia* indices should be abandoned as epidemiologic indicators of dengue transmission on account of several serious shortcomings (Focks et al., 2000). For example, dengue outbreaks occurred in Singapore when the national overall HI was <1% (Ooi et al., 2006). In contrast, researchers from Fortaleza, Brazil, found that dengue outbreaks never occurred when HI was <1% (Caprara et al., 2009). Different geographic levels were also used to calculate the indices by in each study, and the appropriate level for entomologic indices is in itself an area of much debate. In Cuba, the traditional *Stegomyia* indices, calculated from the results of routine larval surveillance, have not proven effective as an early warning system, with transmission occurring despite House and Breteau indices of <5 (Bisset et al., 2006).

In the late l960s, the World Health Organization began promoting the worldwide surveillance of *Ae. aegypti*. To facilitate the dissemination of this information on maps, they developed their own statistical measure, the Density Figure or Index (DI), then derived empirical relationships between this measure and the *Stegomyia* indices. A number of analysts have suggested that these indices may have useful epidemiologic significance. A. W. A. Brown, the WHO developer of the DI, noted that transmission in the 1965 yellow fever epidemic in Diourbel, Senegal occurred where CIs were > 30 and BIs were > 50 (DIs > 5) and not where the BIs were < 5 (DI l).Brown also mentioned, regarding dengue in Singapore, that dengue hemorrhagic fever (DHF) was most prevalent where HIs were > 15, corresponding to DI > 3. Notably, several studies have shown that these indices may not always be useful in predicting dengue transmission risk in light of the complex and multifactorial nature of dengue transmission (Focks, 2003) and the fact that larval populations do not necessarily translate directly into adult populations (Alexander et al., 2006; Focks & Barrera, 2007).

In the 1990s pupal indices were developed by Focks et al. (2000) to identify potential larval development sites and to better reflect dengue transmission risks (Strickman and Kittayapong, 2003). Given low mortality in the pupal stage and knowledge of the approximate time from pupation to adult emergence, pupal counts can serve as a useful proxy for the number of emerging adults. As *Ae. aegypti* tends to stay in or near human dwellings, and most often develop in water-filled containers, the identification of the most productive container habitats may facilitate the development of a more cost effective, targeted strategies for controlling vector populations (Alexander et al., 2006; Barrera et al., 2006; Lenhart et al., 2006).

Traditional *Stegomyia* indices do not provide a complete picture of 'key' containers used by *Ae. aegypti* as developmenta sites. Therefore, a methodology for *Ae. aegypti* pupal/demographic survey was recently developed to identify the 'key' types of container (i.e., the subset of container types from which a large proportion of the relevant adult mosquitoes emerge) and facilitate the estimation of transmission risk in a given setting (Arredondo-Jiménez and Valdez-Delgado, 2006; Focks, 2003). Once the key container types in a given setting are identified, resources may be concentrated on eliminating these types rather than wasted on all containers (Alexander et al., 2006; Focks & Chadee, 1997). This method involves estimating the (minimum) sample size required to identify those container types which together hold a certain percentage (e.g. 70%) of the relevant pupae. Field observations by Southwood and others (1972) have revealed that for a temple area in

Bangkok, Thailand an approximately 23-fold difference existed between the most and the least productive types of containers. A six-fold difference was seen in Honduras. Today, for reasons of cost-effectiveness, most dengue control efforts aim for the suppression rather than the elimination of *Ae. aegypti* (Lenhart et al., 2006; Focks 2003). These programs emphasize reducing *Ae. aegypti* pupal populations to levels that prevent or slow virus transmission, with the ultimate objective of decreasing the incidence of disease. This goal is aided by localized measures that target the most adult-productive *Ae. aegypti* habitats, and ultimately to improve the measurement and forecasting of transmission risk.

These types of interventions are especially applicable to urban areas where complex and interactive socio-ecological factors ultimately determine mosquito production and abundance, species composition, and potential pathogen exposure. Environmental conditions are very important for *Ae. aegypti* development, both in terms of micro-environments (Gubler, 1998) and climate (Peterson et al., 2005), which determine larval development abundance and productivity (Maciel-de-Freitas et al., 2011). The number of adults emerging from the immature stage is regulated by biotic (e.g., predation, parasitism, competition, abundance of food) and abiotic (e.g. rainfall, temperature, and evaporation) factors along with container type and local ecological factors (e.g., amount of shade or direct sunlight, presence or extent of vegetation, water type within container, and water temperature) (Midega et al., 2006). Container capacity, water temperature, source of water, and container location, all of which can vary seasonally, have been cited as important ecological factors affecting production of adult *Ae. Aegypti* (Aldstadt et al., 2011; Barrera et al., 2006). This is reflected in a number of studies which have found that *Ae. aegypti* abundance is not homogeneous among households, with disproportionate numbers of immature and adult mosquitoes clustered around key premises.

Moreover, the number and types of mosquito-infested containers in and around households are affected by the socio-economic status (SES) of the residents, along with their behavior and container management (Dowling et al., 2013; Mondini and Neto, 2008; Brunkard et al., 2007). Within urban areas, SES has been associated with immature mosquito infestation and mosquito-borne diseases (Reisen et al., 1990, Braks et al., 2003, Rios et al., 2006, Reisen et al., 2009, Harrigan et al., 2010, Unlu et al., 2011). Differences in larval microhabitat abundance, type, and quality can all contribute to differences in the production of adult *Aedes* mosquitoes (Kuno, 1995; Tun-Lin et al., 1995). Empirical evidence suggests that in the United States, higher abundance of key vector mosquitoes (e.g., Reisen et al., 1990, Unlu et al., 2011) and prevalence of West Nile virus (WNV) and Saint Louis encephalitis viruses (e.g., Rios et al., 2006, Reisen et al., 2009, Harrigan et al., 2010) are all associated with socioeconomic status. In addition, studies have shown that larger numbers of mosquitoes are produced in low-income neighborhoods compared to high SES neighborhoods (LaDeau et al., 2013).

Ae. aegypti exploits a wide variety of domestic containers as larval development sites, ranging in size from bottles and cans to large water storage tanks. Uncontrolled urban growth, which is often accompanied by unreliable water supplies (thus promoting water storage), and the proliferation of non-degradable trash containers combine to provide an ample supply of larval development sites within domestic settings. From the bio-ecological perspective, the presence of *Ae. aegypti* and the quantity of mosquito developmentsites are the most important factors driving dengue occurrence. This study therefore examined both larval and pupal stages in domestic containers, located inside or outside of household premises.

There are few studies examining how ecological factors regulate the occurance of positive containers. To address this gap, entomological surveys for immature *Aedes* mosquitoes were conducted within randomly selected households accross the city of Dhaka. We also measured a variety of ecological factors within each household and determined the SES of each household. In addition, we investigated the socio-economic factors that determined certain households possessed containers that were more frequently infested with *Aedes* mosquitoes as this would provide important context to why mosquito abundance may not be uniform across households. As in other metropolitan areas of the developing world, Dhaka is a highly heterogeneous city, with slums and luxurious houses often in close proximity to one another. The objective of this chapter is to examine *Aedes* mosquito abundance with relation to the surrounding ecology and household SES in three socioeconomically distinct zones in order to test the hypothesis that residents in different neighborhoods within a city exhibit different levels of exposure to dengue vectors. To this end, entomological surveys were conducted indoors as well as within 50 meters surrounding each sampled household.

4.2 Data Analysis

All data were compiled and analyzed using IBM SPSS version 22 (IBM Corp., Armonk, NY, USA). The Chi-Square test was used to compare the distribution of pupae from different container types. The Kruskal-Wallis test was used to independently evaluate differences in the distribution of the most productive containers among the various SES zones of the City. The strength of the relationships between container abundance and pupal productivity was determined by applying Spearman's correlation. Descriptive statistics were applied to summarize the data, and confidence limits including mean ± SE were calculated.

A two-step cluster analysis was used to classify positive containers based on the following six social-ecological variables: i) source of water in container, ii) volume of water, iii) exposure to sun, v) collection of rain water, and vi) presence or absence of vegetation nearby. Following the formulation of two 'natural groupings' or 'clusters' of containers, statistics of *Ae. aegypti* pupae per container for each cluster were identified, and a two tailed t-test was performed to compare mean pupae across the cluster .

A logistic regression model was applied to determine the influence of social-ecological explanatory variables (e.g. level of education of the household head, occupational status of the household head, annual household income, water supply provisions, waste disposal provisions, and purpose of storing water in the household) upon the possession of containers (by functional categories) at the positive household premises. Considering the diversity of types of containers, five different *functional categories* of containers based on their use at household level were recognized: category A (household chores), category B (ornamental; Appendix XVII; Image 4.4), category C (amenities), category D (discarded; Appendix XVII; Image 4.3), and category E (for household repairing and reconstruction purposes). The functional categorization of containers is necessary for the purpose of minimizing the number of categories to analyse the data in specific terms. Following Barrera et al. (2006), the criteria of human activities relating to livelihoods and day-to-day *functional* activities were adopted. In the context of Dhaka, Bangladesh five functional container categories appear to be most appropriate. Odd ratios (OR) with 95% confidence intervals are reported to account for the influences. To assess the causal relationship between the functional categories (FC) of containers and the pupal productivity (PP), (that is, PP ~ FC), a Poison regression model was applied. The GENLIN-procedure of the SPSS-system was used to fit this model.

4.3 Results

4.3.1 Distribution of immature *Aedes species*

During the first entomological survey (2011), 12 randomly selected Dhaka city wards were surveyed (Appendix XVII; Image 4.1) and all (100%) were found to harbor the immature stages of *Ae. aegypti*. The vast majority (86.4%) of the larvae collected were subsequently identified as *Ae. aegypti (Ae. albopictus* accounting for only 13.6%; Appendix XVII; Image 4.2). In all 12 wards, 826 household premises were inspected (total population 4,870) and 221 (26.7%) were found positive for *Ae. aegypti* larvae and/or pupae (Appendix XVII; Image 4.7). At the time of the survey during the monsoon of 2011, 85.7% of containers (1,286 containers of 1,501 inspected) held water, revealing that many more containers had potential to be larval habitats. A total of 4,217 immature *Ae*. *aegypti* mosquitoes (3,667 III and IV instars and 550 pupae) were counted in 1,501 containers inspected. Traditional *Stegomyia* indices for the study area were a House Index (HI) of 26.7% (221 positive household premises of 826 sampled), a Container Index (CI) of 32.8% (493 positive containers of 1,501 sampled), and a Breteau Index (BI) of 59.6% (493 positive containers of 826 household premises inspected). *Ae. aegypti* pupae (550; 205 males (37.3%) and 345 females (62.7%)) were present in 134 (10.4%) of 1,286 containers containing water (Appendix XVII; Image 4.5).

Table 4.1 shows the HI, CI, and BI for high, medium, and low SES wards. The null hypothesis stating that there was no significant difference in terms of HI and CI [(HI: χ^2=3.591, df=2, p-value=0.166) and (CI:χ^2=1.302, df=2, p-value=0.521)] among different socioeconomic status wards was accepted. Similar conclusions were drawn for the Breteau Index as this index is a combination of HI and CI. There is no significant difference in terms of positive houses (possessing at least one container with either *Aedes aegypti* larva and pupa) in different socio-economic wards (χ^2= 21.8386, df = 2, p-value <0.00001) and the number of pupa collected from these different SES wards (χ^2= 74.6332, df = 2, p-value< 0.00001).

Table 4.1: Distribution of *Stegomyia* indices with 95% Confidence Interval in different SES wards

SES wards	HI (%)	95% CI	CI (%)	95% CI	BI (%)	95% CI
HSES	18.6	(11.0-26.2)	28.8	(19.9-37.7)	63.4	(53.9-72.8)
MSES	20.6	(12.6-28.5)	31.2	(22.1-40.3)	52.0	(42.2-61.7)
LSES	25.3	(16.8-33.8)	38.7	(28.1-47.1)	64.8	(53.4-72.4)

4.3.2 Distribution of positive and most productive containers

Ae. aegypti immatures were found in 493 containers of 35 different types. In contrast, *Ae. Aegypti* pupae were found in only 23 different container types. Out of 493 positive containers, high socio-economic status (HSES) wards had a total of 85 positive containers, followed by 165 in medium socio-economic status (MSES) wards and 236 in low socio-economic status (LSES) wards. Seven positive containers were from seven households where no holding numbers or addresses were found. These seven houses were from LSES wards and were not accounted in the data analyses. A Kruskal-Wallis test was performed to determine whether there was a significant difference among different socio-economic wards and number of positive containers. It was found that there was no significant difference among the high, medium, and low SES wards possessing positive containers ($\chi 2$= 0.38, df =2, p-value=0.8) (Figure 4.1a).

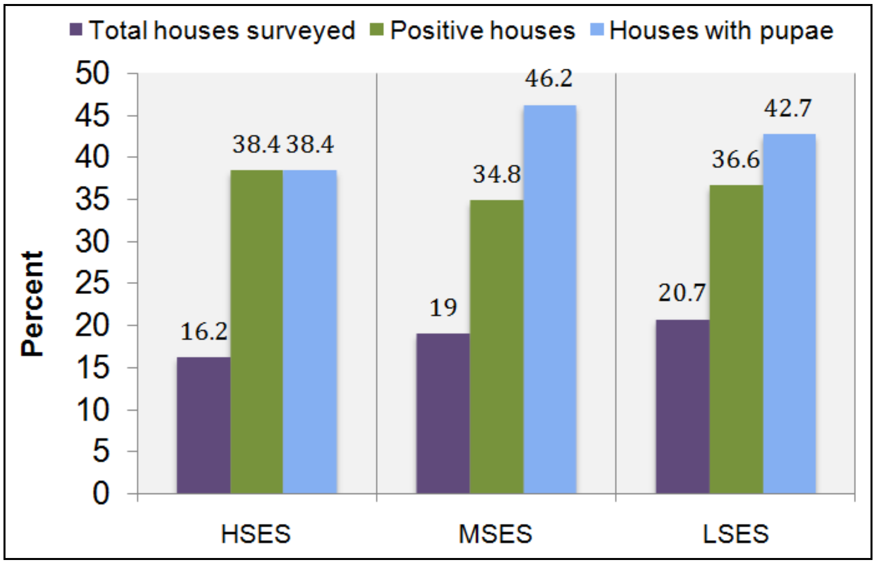


Figure 4.1.a: Distribution of householdsby different Socio-Economic Status (SES) zone

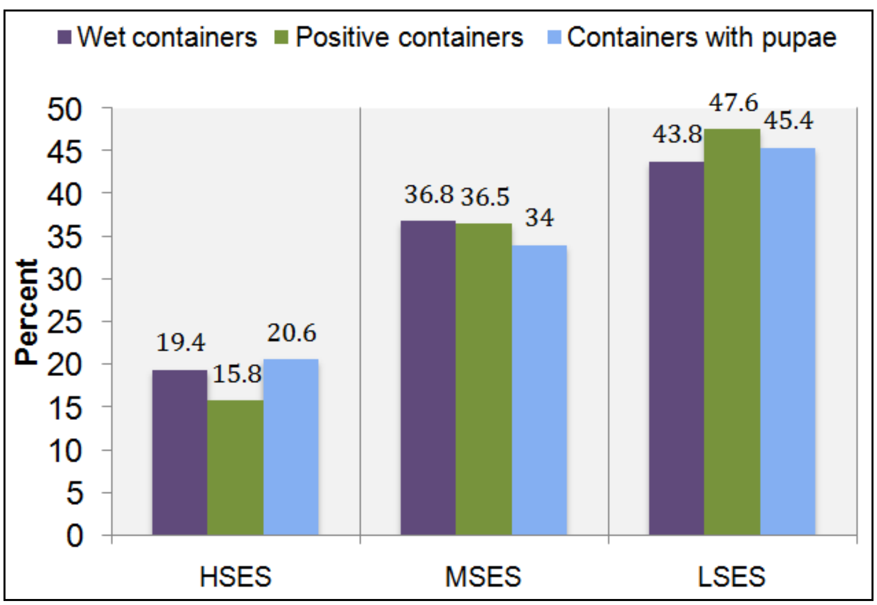


Figure 4.1.b: Distribution of containers by different Socio-Economic Status (SES) zone

Water supply (either piped, tap, or hand driven or deep tube well) was available to the residents of 81.5% of the total households sampled, while 18.4 % of the households didn't have any water supply services in their premises. Regardless of SES, the vast majority of the containers recorded were of 9 main types: flower tubs and trays (11.8%), plastic buckets (9.8%), sealable plastic drums (9.6%), disposable plastic containers (8.9%), plastic bottles (8.3%), clay pots (8.1%), refrigerator trays (7.5%), tires (6.9%), and water tanks (4.3%). These containers accounted for more than 75.2% of all positive containers (371 out of 493 positive containers from 221 premises) and 72.8% (397 of 550 pupae) of all *Ae. aegypti* pupae. In HSES zone, the most productive positive container was tires (20%), in MSES it was flower tubs and trays (22.4%), and in LSES it was 5 different types (53.4%) of containers (Figure 4.2). Statistically, however, there was no significant difference among the distributions of the most productive containers (MPCs) among the three SES wards ($\chi 2$= 3.5, df =2, p-value=0.17; Kruskal-Wallis test).

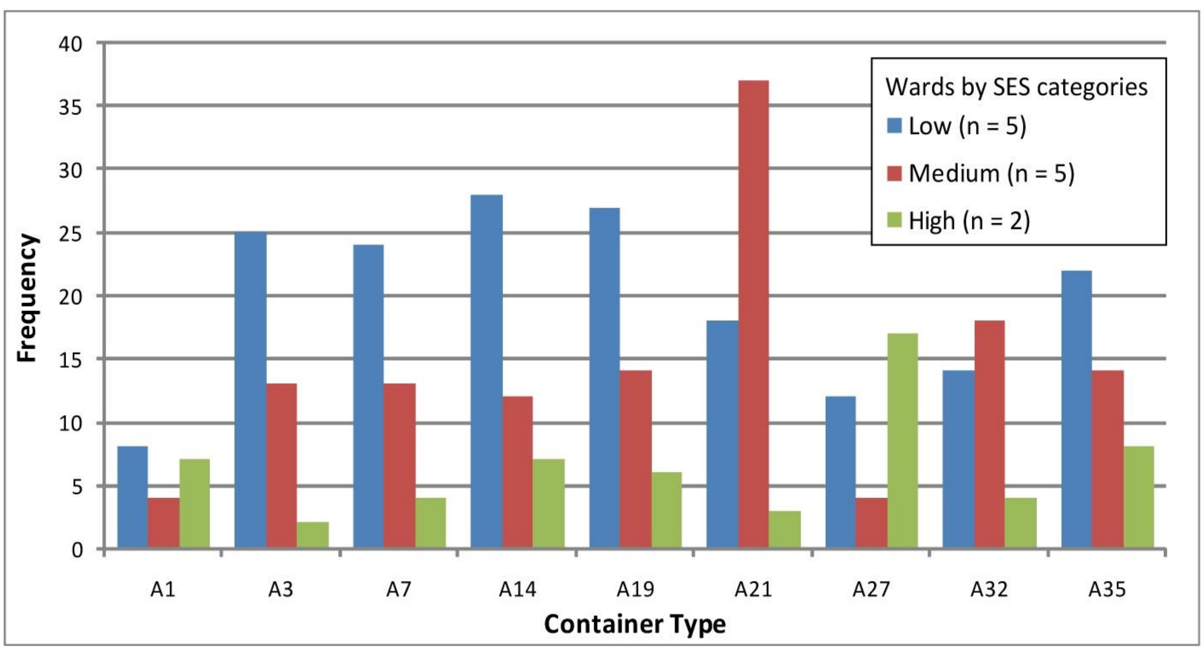


Figure 4.2: Distribution of most frequent containers by different Socio-Economic Status (SES) zone

[A1= water tank, A3= clay pot, A7= plastic bottle, A14= plastic bucket, A19= sealable plastic drums, A21=flower tub and tray, A27=tyre, A32= disposable plastic containers,A35=refrigerator tray]

4.3.2.1 Aedes aegypti pupae per type of container

All of the above 9 different types of most productive containers (flower tub and tray, clay pot, plastic buckets, sealable plastics drums, disposable plastic containers, refrigerator tray, tires, water tank; Figure 4.3) held 72.2 % (397 /550) of all pupae, reflecting the positive correlation between container abundance and pupal productivity.

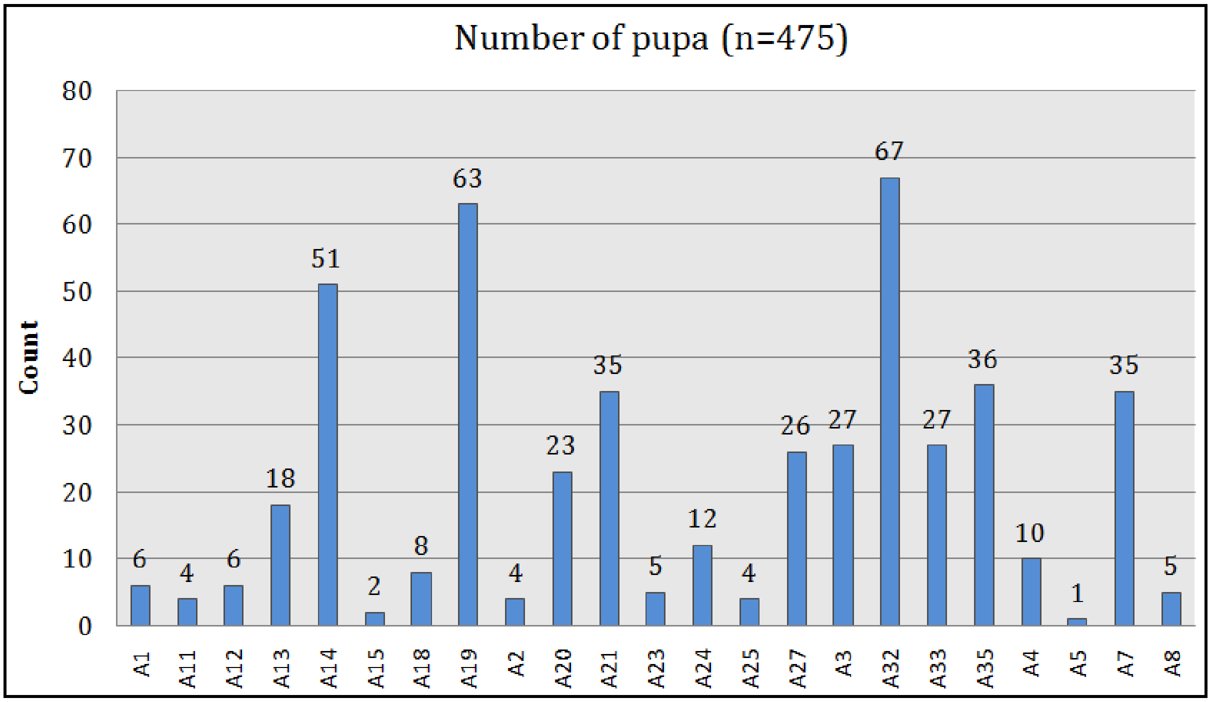


Figure 4.3: Frequency distribution of pupal count among different household containers

[A1= water tank, A3= clay pot, A7= plastic bottle, A14= plastic bucket, A19= sealable plastic drums, A21=flower tub and tray, A27=tyre, A32=disposable plastic containers, A33= plastic sheets used to cover large objects, A35= refrigerator tray]

It was noted that disposable plastic containers held the most pupae (14.1%), followed by sealable plastic drums (13.3%), plastic buckets (10.7%), and refrigerator trays (7.6%). These four types of positive containers yielded 45.5% of all pupae and represented approximately 35.8% of all containers surveyed (Figure 4.3). A Spearman correlation test between the rank orders of container abundance and pupal productivity was positive and significant ($n = 23$; $r_s = 0.817$, p-value < 0.01), confirming that the MPCs were abundant and common. The mean ± SE percentage of containers accounting for 70-80% of all pupae across the 9 most abundant types was 39 ±10 (%), or 371 (28.9%) of 1,286 containers with water in our study area.

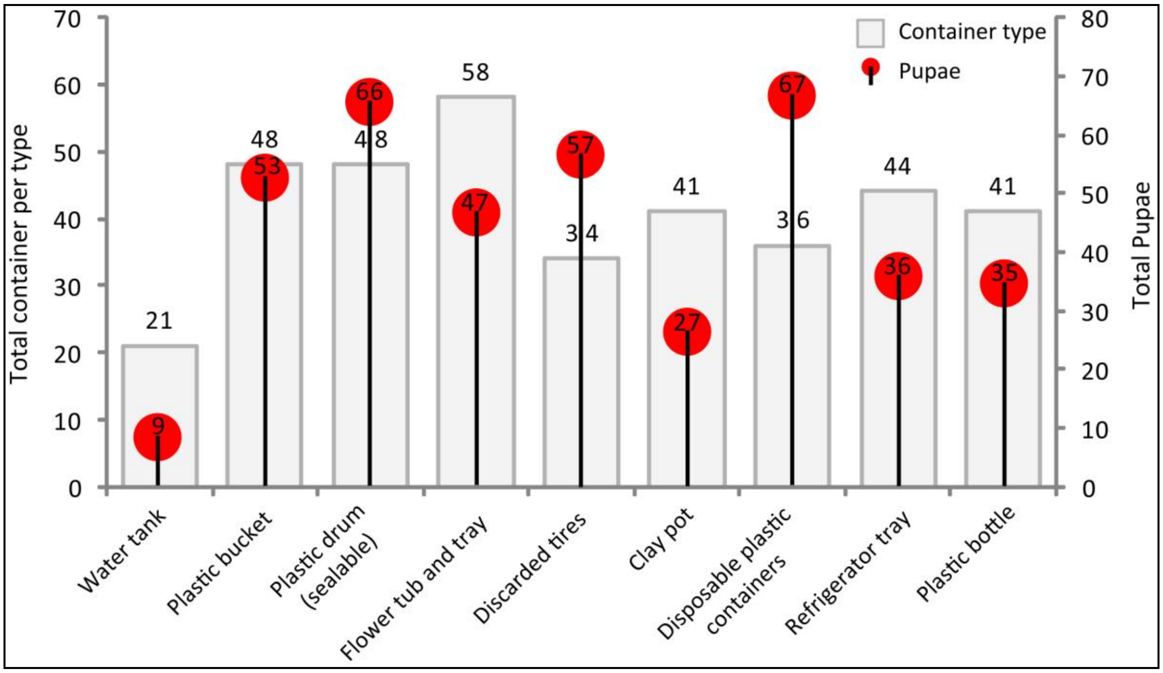


Figure 4.4: Frequency distribution of Most Productive Containers (MPCs) and their corresponding pupal counts

The pupae per household index was calculated, which revealed 2.38 pupae per household in LSES zone, 2.45 in MSES zone, and 2.68 in HSES zone. Therefore, the relative homogeneity in the distribution of pupae among the SES wards was reflected in the minimal variation in pupae per household, ranging between 2.38 and 2.68. The mean pupae-per-person (PPI) was 0.58 in the sampled 12 Wards. The distribution by SES zone, they were 0.53 in LSESZ, 0.55 in MSESZ, and 0.62 in HSESZ.

Table 4.2: Pupae-per-Person Index among different Socio-Economic Status (SES) ward

Urban Socio-Economic Status (SES) wards/zones	Number of households inspected	Number of people in households	Number of collected pupae	Pupae-per-Person Index (PPI)
LSES	375	200	107	0.53
MSES	317	302	169	0.55
HSES	134	432	271	0.62
Total	826	934	547	0.58

The details of the distribution of selected entomological data by SES zone can be seen in Appendix IX. Although the total number of pupae collected from different SES wards varied significantly ($\chi^2 = 74.6$, df =2, p-value <0.00001), there was no noticeable difference in pupae per person among these three SES wards (Table 4.1b). Moreover, this study showed that female *Ae. aegypti* pupae per container (mean ± SE = 0.87 ± 0.24) were more abundant than male pupae (0.48 ± 0.15; $t = 2.68$; df = 44, p-value <0.005). By analyzing the statistical distributions and variance: mean ratios per type of container, the hypothesis that a few containers within each type held most of the pupae was tested. For each type of container, the null hypothesis of a Poisson distribution (variance/mean = 1) was assessed (Chi-square goodness-of-fit test). The outcomes revealed that the variance ratio was significantly different ($\chi^2 = 72.5$, df =10, p-value<0.0001) for each type of container (variance: mean ratios = 0.6-17.4), and that the pupae distribution by container type is not homogeneous.

4.3.3 Ecological factors in *Aedes aegypti* pupal productivity

To investigate the effects of ecological factors on immature *Aedes aegypti* (P.) productivity, the hypothesis was explored that ecological factors at the micro-level (i.e., ecological factors surrounding containers) and household level (i.e., ecological factors at household level) play a significant role in pupal productivity.

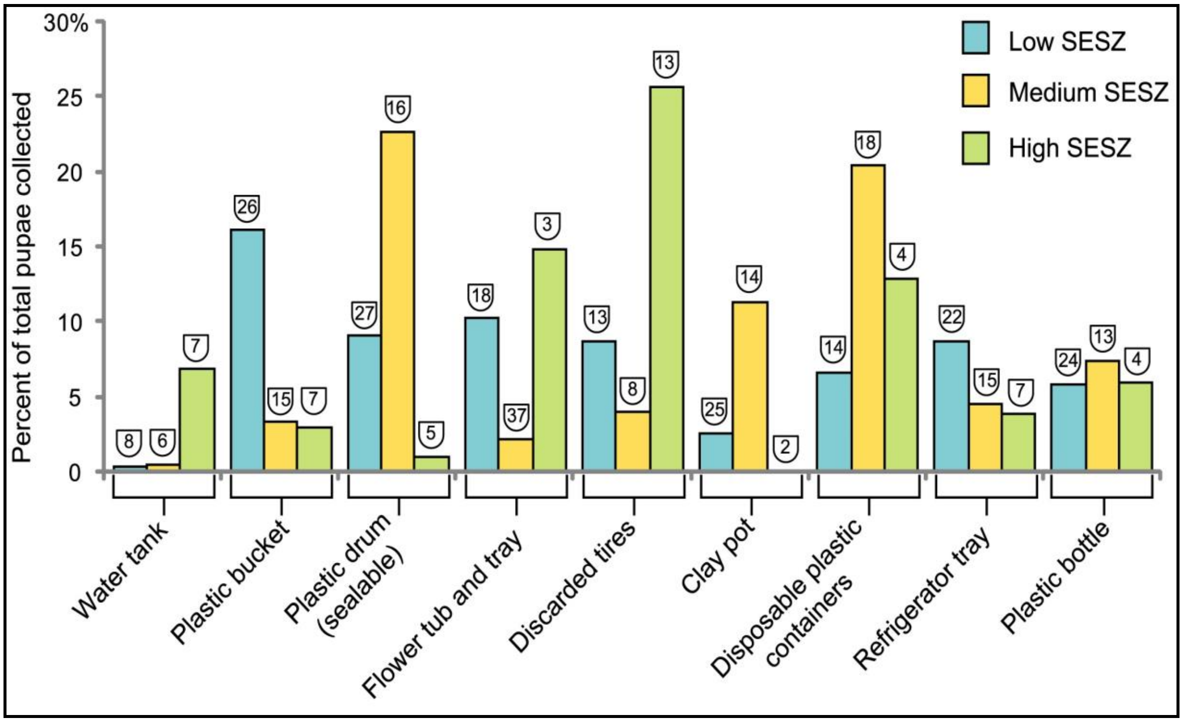


Figure 4.5: Percentage distribution of pupae by MPCs among different SES zones

4.3.3.1 Cluster analysis of positive containers

The two-step cluster analysis produced two groups of containers (Table 4.4). In Cluster-1 (41.7% of samples) most of the containers consisted of A21 (flower tubs & tray 18.5%) followed by A27 (t), A3 (clay pots), and A35 (discarded plastic containers). Cluster-1 had 192 (34.9%) immature *Ae. aegypti* pupae (mean pupae per container: 0.94 ±0.20), representing 34.9% of total pupa (Table 4.4). Most containers in Cluster-1 were under shade (90.8%), filled with mainly tap water (87.3%), and with scanty water volume inside the containers (76.1%). No vegetation (56.7%) was present near containers in this cluster.

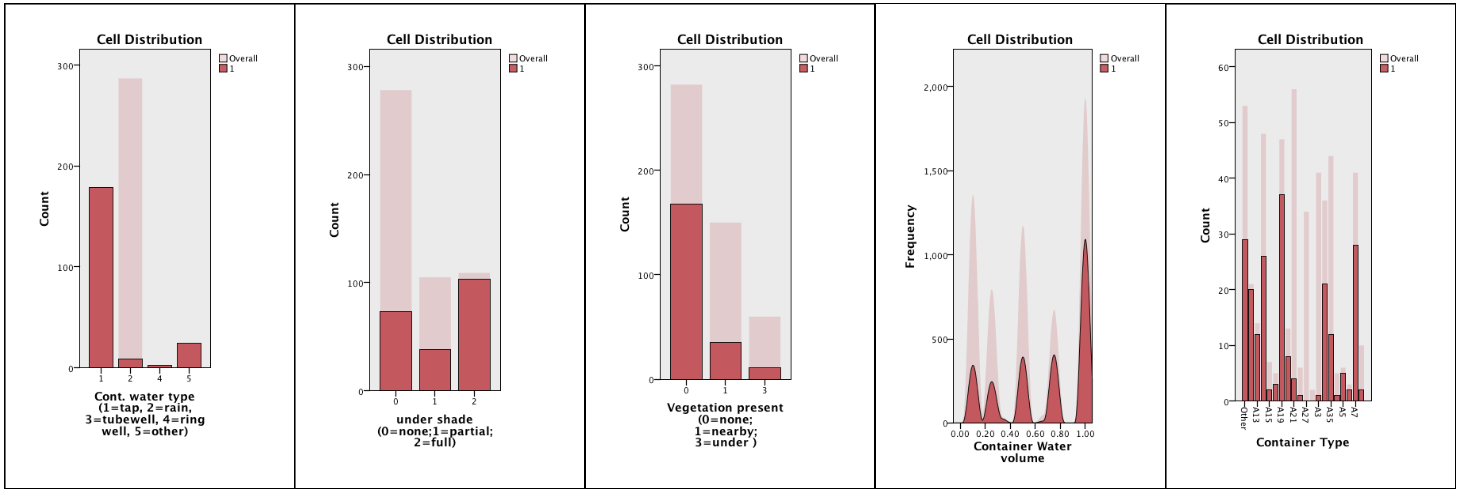
Cluster 2 (58.3% of samples) included A19 (sealable plastic drum; 17.6%) - the most productive container (22%) - followed by A32 (refrigerator trays), A7 (plastic bottles), A4 (ceramic pots), A1 (water tanks), and A20 (money plant tubs). The mean number of pupae was 1.25 ± 0.19 for Cluster-2 (total pupae 358, or 65.09%; Table 4.4). Most containers in

Cluster-2 were under sun (74.1%), filled with rain water (100%), and had vegetation present nearby (81.7%), and were full (70.3%).

Table 4.3: Percentage distribution of pupae by Most Productive Containers (MPCs) among different Socio-Economic Status (SES) zones

Derived ecological clusters of positive containers	Cluster 1	Cluster 2
Containers per cluster (%)	41.7	58.3
Containers exposed to sun (%)	25.9	74.1
Containers under full shade (%)	90.8	9.2
Containers with vegetation presence (%)	18.3	81.7
Containers without vegetation (%)	56.7	43.3
Containers with rain water (%)	0.0	100.0
Containers with tap water (%)	87.3	12.6
Containers with scanty water volume (%)	76.1	23.9
Containers with full water volume (%)	29.7	70.3
Water volume per container (Mean±SE)	0.68±0.02	0.48±0.02
Number of pupaeper container (Mean±SE)	0.94 ±0.20	1.25 ± 0.19
Total number of pupae per cluster (%)	192 (34.9)	358 (65.1)

Cluster 1



Cluster 2

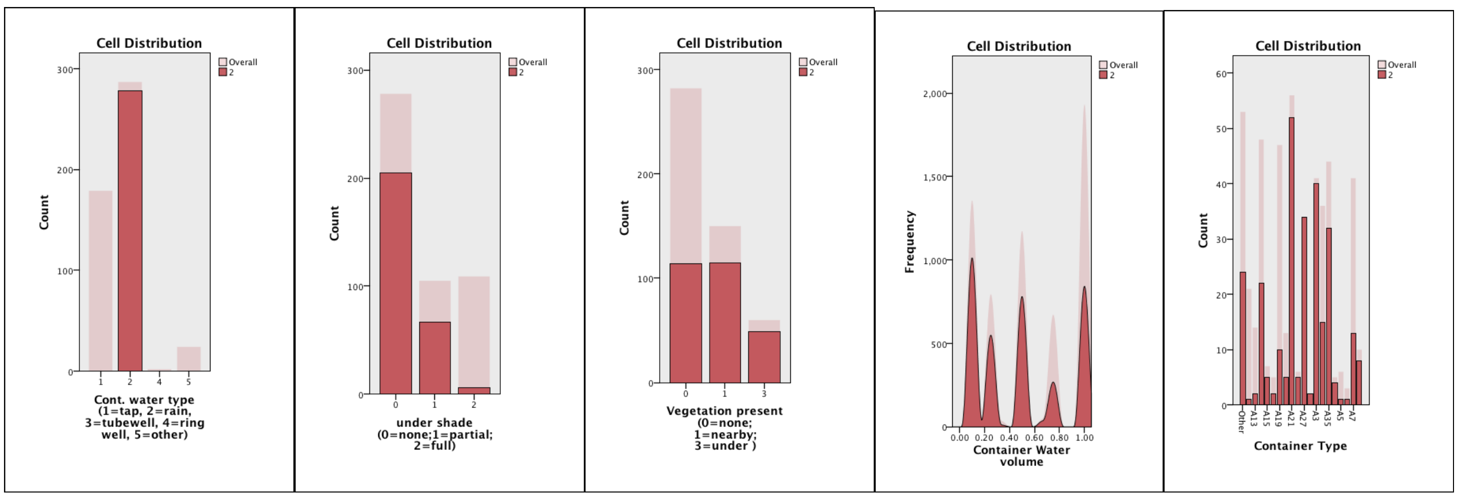


Figure 4.6: Comperative graphic representation of two derived ecological clusters relative to overall distribution

4.3.3.2 Cluster analysis of household premises

Mean ±SE pupae of *Aedes aegypti* per type of residence were: i) one-storied houses = 1.46±0.38 (18.3%), ii) multi-storied buildings = 1.80±0.37 (30.4%), and iii) High-rise apartments= 4.78±0.98 (51.3%). Three clusters were derived from this data. The first cluster (93 premises) contained 95.7% multi-storey buildings. Cluster II (69 premises) contained 98.6% one-storey buildings and Cluster III (59 premises) contained both multi-storied (49.2) and single-storey (42.4) buildings almost in equal proportion.

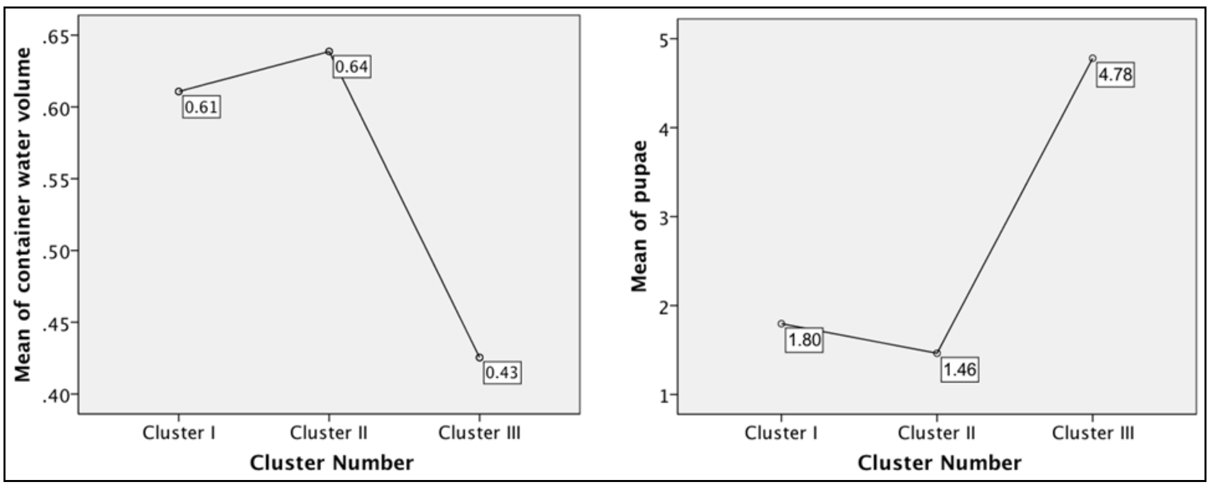


Figure 4.7: Mean plot of container water volume and pupae in household premises by derived clusters

The most *Aedes aegypti* pupae were present in the premises of Cluster III (51.3%). This cluster of premises featured little green space attached to the households (66.1%). Green space consisted mostly of grass (88.9%) and ponds were the predominant water bodies (Table 4.5). Within Cluster II, 91.3% premises had no open/green space. The most common open space consisted of bare soil. The houses in this cluster had least amount of water bodies near houses. Cluster III had mostly shrubs (77.8%) for green space and rivers or canal for nearby water bodies. All three clusters had piped water supplies, although Cluster III had

37.6% tube wells. As most frequent container types producing the most pupae, Cluster I had flower tubs and trays, Cluster II had sealable plastic drums, and Cluster III had refrigerator trays playing such role (Table 4.5). A significant difference was observed among these three clusters in terms of pupae productivity (range=1.82-3.15; $F=9.09$, $P<0.0001$, by ANOVA) and container water volume (range=0.51-0.62; $F=6.02$, $P<0.002$, by ANOVA) among these three clusters. Interestingly the mean plot (Figure 4.7) reveals that most of the pupae in Cluster III were produced by containers with the lowest water volume.

4.3.4 Socioeconomic and behavioral factors of possession of container types by household

I have analyzed the association between socioeconomic, infrastructural, and behavioral variables, and possession of container types per household. From the household socio-economic and demographic questionnaire, six variables - level of education, type of occupation, level of income, water storage practices in household, waste disposal practices in household, and water supply provisions by the Dhaka City Corporation and local government to household - were defined (Table 4.5). These variables were selected based on the following criteria: scale or dichotomous items; items for which more than 95% of all the records have meaningful values; and items for which duplicated independent translations of the questionnaire were consistent; items for which all the records are within a meaningful range. A total of 35 different container types were recognized as positive containers during entomological survey that had immature *Aedes*.

Table 4.4: Percentage distribution of the variables used in the classification, and mean number of container water volume, pupae, and immature *Aedes aegypti*

Household premises characteris	**Cluster I**	**Cluster II**	**Cluster III**
Building types (%)	Multi-storied (95.7)	One-storied (98.6)	Mix of multi-storied (49.2) and one-storied (42.4)
Presence of different water bodies near household premises (within 100 meters) (%)	River/canal (60)	Ditch, lake, abandone water bodies (38.9)	Ponds (90.9%)
Absence of green space (%)	86.4	91.3	33.9
If green space present, then type of green space in the household premises (%)	Shrubs (77.8)	Bare soil (40)	Grass covered (88.9)
Water supply in the household (%)	Piped water to house (86.4)	Piped water to house (75.4)	Piped water to house (62.4) & tube wells (37.6)
Main container type	Flower tubs and tray	Sealable plastic drum	Refrigerator tray
Water volume (Mean±SE) of containers with pupae	0.61±0.04	0.63±0.04	0.42±0.04
Total Pupae (%)	167 (30.4)	101 (18.3)	282 (51.3)
Pupae (Mean±SE)	1.80±0.37	1.46±0.38	4.78±0.98
Mean±SE of immature *Aedes aegypti* (larvae & pupae)	19.41±1.54	16.33±1.55	21.78±1.89

A univariate analysis (dependent variable was container class) was performed among these 5 types of container categories and the socioeconomic and behavioral factors in the positive households. Of 221 positive household premises, only 163 household responders provided full information regarding their socioeconomic conditions. Here, using proxy data for socioeconomic variables was intentionally avoided as this may contaminate the linkage between socioeconomic and behavioral factors. From univariate analysis, it was concluded that at household level, there was a significant (p-value= 0.05) positive correlation between income (p-value= 0.04) and the purpose of storing water (p-value= 0.021) (Table 4.6). To allow robust and extensive interpretable multivariate analysis, all variables as well as pre-select significant (p=0.05) variables from univariate analysis were analyzed. Multivariable logistic regression of all variables as well as pre-selected variables from univariate analysis both confirmed that income (χ^2 =15.62, df = 8, p-value= 0.0481) and the purpose of storing water (χ^2=11.82, df=4, p-value=0.0187) were found, statistically, to be significantly associated with possession of different categories containers (Table 4.7).

4.3.5 Association between *Aedes aegypti* pupae and container category

To evaluate the association between *Ae. aegypti* pupae and different container categories, a Poisson regression model was used (by GENLIN command in SPSS) to model the relationships between the container types (i.e., household chores, ornamental, amenities, discarded and household repair and reconstruction purposes containers) and the number of pupae per household. As the number of reported pupae was small relative to the total population of pupa, distribution of pupae per household was assumed to follow the Poisson distribution. Hence, the fitted model is:

$$\log (PC)= 1.71+0.72*I(O)+0.16*I(A)+0.24* I(D)+0.48*(OT)$$

where I(A)= 1, if A belongs to container category and 0, otherwise.The household chore was assumed as a reference category. [PC=pupal count; O=ornamental; A=amenities; D=discarded; OT=household repairs and reconstruction purposes containers]

Table 4.5: Socioeconomic and demographic variables of households among different SES wards

Socioeconomic and demographic variables	LSES	MSES	HSES	Overall
	Number (%)	Number (%)	Number (%)	Number (%)
Sex				
Male	87 (85.29)	59 (76.62)	38 (90.48)	184 (83.26)
Female	15 (14.71)	18 (23.38)	4 (9.52)	37 (16.74)
Age				
< 25	5 (4.90)	1 (1.30)	1 (2.38)	7 (3.17)
25-44	35 (34.31)	20 (25.97)	10 (23.81)	65 (29.41)
45-60	42 (41.18)	31 (40.26)	14 (33.33)	87 (39.37)
60+	10 (9.80)	15 (19.48)	4 (9.52)	29 (13.12)
Non Response	10 (9.80)	10 (12.99)	13 (30.95)	33 (14.93)
Level of Education of Household Head				
Illiterate	12 (11.76)	23 (29.87)	10 (23.81)	45 (20.36)
Primary	38 (37.25)	22 (28.57)	7 (16.67)	67 (30.32)
Secondary	13 (12.75)	10 (12.99)	7 (16.67)	30 (13.57)
Higher Secondary	17 (16.67)	15 (19.48)	6 (14.29)	38 (17.19)
Graduate	16 (15.69)	6 (7.79)	7 (16.67)	29 (13.12)
Postgraduate	6 (5.88)	1 (1.30)	5 (11.90)	12 (5.43)
Occupational Status of Household Head				
Service	4 (3.92)	6 (7.79)	5 (11.90)	15 (6.79)
Housewife/Student	22 (21.57)	6 (7.79)	5 (11.90)	33 (14.93)
Business	41 (40.20)	25 (32.47)	14 (33.33)	80 (36.20)
Others	23 (22.55)	22 (28.57)	14 (33.33)	59 (26.70)
Non Response	12 (11.76)	18 (23.38)	4 (9.52)	34 (15.38)
Annual Household Income (in Bangladeshi Taka)				
< 5,000	9 (8.82)	5 (6.49)	10 (23.81)	24 (10.86)
5,000-9,999	16 (15.69)	9 (11.69)	12 (28.57)	37 (16.74)
10,000-24,999	40 (39.22)	16 (20.78)	8 (19.05)	64 (28.96)
25,000-49,999	20 (19.61)	18 (23.38)	3 (7.14)	41 (18.55)
50,000-99,999	8 (7.84)	9 (11.69)	1 (2.38)	18 (8.14)
> 99,999	2 (1.96)	5 (6.49)	5 (11.90)	12 (5.43)
Non Response	7 (6.86)	15 (19.48)	3 (7.14)	25 (11.31)
Housing Materials (Wall)				
Masonry	100 (98.04)	64 (83.12)	30 (71.43)	194 (87.78)
Corrugated Iron Sheet	0 (0.00)	6 (7.79)	4 (9.52)	10 (4.52)
Thatch	2 (1.96)	7 (9.09)	8 (19.05)	17 (7.69)
Sources of water supply to house				
Piped water to house	69 (67.65)	61 (79.22)	31 (73.81)	161 (72.85)
Piped water to community	33 (32.35)	15 (19.48)	9 (21.43)	57 (25.79)
Tube well	0 (0.00)	1 (1.30)	2 (4.76)	3 (1.36)

Socioeconomic and demographic variables	LSES	MSES	HSES	Overall
	Number (%)	Number (%)	Number (%)	Number (%)
Waste disposal provision to house				
Municipal/Private pickup	82 (80.39)	71 (92.21)	36 (85.71)	189 (85.52)
Disposalat specific location	20 (19.61)	6 (7.79)	3 (7.14)	29 (13.12)
Others	0 (0.00)	0 (0.00)	3 (7.14)	3 (1.36)

Table 4.8 shows that the container categories ornamental, discarded, and repairs and reconstruction purposes containers are significantly associated to the number of pupae counted in the households (ornamental vs. household chore: risk ratio=2.06; 95% CI: 1.59 - 2.67; p-value<0.0001; discarded vs. household chore: risk ratio= 1.28; 95% CI: (0.99, 1.64); p-value=0.061, and household repairs and reconstruction purposes vs. household chore: risk ratio= 1.62; 95% CI: (1.17, 2.24); p-value=0.0035. These findings reveal that the above container categories are primarily responsible for the development of pupae in the inspected households. To interpret the risk ratio, it was clear that more than twice as many pupae were found on average in ornamental category compared with the household chore category after adjusting for all other container types.

Table 4.8: Poisson regression models for the container categories and pupal productivity

Container type	Adjusted risk ratio (95% CI)	p-value
A (Household chores, reference)	1.00	
B (Ornamental)	2.06 (1.59, 2.67)	<0.0001
C (Amenities)	0.86 (0.53, 1.37)	0.514
D (Discarded)	1.28 (0.99, 1.64)	0.061
E (repairing and reconstruction purposes)	1.62 (1.17, 2.24)	0.0035

Table 4.6: Descriptive and bivariate χ2 analyses of selected Socio-Economic Status (SES) variables in householdsby container categories (based on functional type

Socio-Economic Variable	Total pupae-positive containers n (%) n = 163	Containers category based on functional types [n (%)] Household chores (A) n = 73	Ornamental (B) n = 20	Amenities (C) n = 22	Discarded (D) n = 37	Reconstruction (E) n =11	p-value
1. Educational status (household head)							
Primary	73 (44.79)	27 (36.99)	10 (50.00)	10 (45.45)	21 (56.76)	5 (45.45)	
Secondary	57 (34.97)	26 (35.62)	6 (30.00)	9 (40.91)	11 (29.73)	5 (45.45)	0.575
Graduate	33 (20.25)	20 (27.40)	4 (20.00)	3 (13.64)	5 (13.51)	1 (9.09)	
2. Occupation (household head)							
Housewife/unemployed	54 (33.13)	27 (36.99)	7 (35.00)	3 (13.64)	12 (32.43)	5 (45.45)	
Business	43 (26.38)	18 (24.66)	3 (15.00)	9 (40.91)	10 (27.03)	3 (27.27)	0.47
Service	66 (40.49)	28 (38.36)	10 (50.00)	10 (45.45)	15 (40.54)	3 (27.27)	
3. Income (annual household)							
High (>70K Taka)	54 (33.96)	17 (23.29)	8 (40.00)	8 (36.36)	13 (39.39)	8 (72.73)	
Medium (30K-70K Taka)	54 (33.96)	22 (30.14)	6 (30.00)	9 (40.91)	15 (45.45)	2 (18.18)	0.04*
Low (<30K Taka)	51 (32.08)	34 (46.58)	6 (30.00)	5 (22.73)	5 (15.15)	1 (9.09)	
4. Water supply (provisions to household)							
Piped water	123 (75.46)	53 (72.60)	16 (80.00)	16 (72.73)	28 (75.68)	10 (90.91)	0.79
Tube wells & others	40 (24.54)	20 (27.40)	4 (20.00)	6 (27.27)	9 (24.32)	1 (9.09)	
5. Waste disposal provisions							
Municipal/private pick up	143 (87.73)	62 (84.93)	18 (90.00)	19 (86.36)	34 (91.89)	10 (90.91)	0.899
Open disposal	20 (12.27)	11 (15.07)	2 (10.00)	3 (13.64)	3 (8.11)	1 (9.09)	
6. Purpose of storing water in household							
Drinking & cooking	70 (42.94)	42 (57.53)	6 (30.00)	7 (31.82)	11 (29.73)	4 (36.36)	0.021*
Cleaning, washing, showers	93 (57.06)	31 (42.47)	14 (70.00)	15 (68.18)	26 (70.27)	7 (63.64)	

*Significant at $P < 0.05$ level

Table 4.7 Multivariate logistic regression model of Socio-Economic Status (SES) explanatory factors associated with container categories

Variable	Container category***	Estimates	S.E.	p-value	OR (95%CI)
Constant	B	-1.46	0.57	0.106	
	C	-1.44	0.56	0.009	
	D	-1.03	0.47	0.030	
	E	-1.23	0.61	0.043	
Income of the household*					
2 vs 1	B vs. A	-0.40	0.64	0.530	0.66 (0.19-2.35)
2 vs 1	C vs. A	0.01	0.59	0.990	1.00 (0.31-3.22)
2 vs 1	D vs. A	0.04	0.52	0.944	1.04 (0.38-2.84)
2 vs 1	E vs. A	-1.54	0.86	0.073	0.22 (0.04-1.16)
3 vs 1	B vs. A	-1.02	0.63	0.105	0.36 (0.11-1.14)
3 vs 1	C vs. A	-1.20	0.65	0.067	0.30 (0.08-1.09)
3 vs 1	D vs. A	-1.09	0.54	0.042	0.33 (0.12-0.96)
3 vs 1	E vs. A	-2.80	1.11	0.011	0.06 (0.01-0.53)
Purpose of storing water**					
2 vs 1	B vs. A	1.19	0.55	0.030	3.29 (1.11-9.71)
2 vs 1	C vs. A	1.17	0.53	0.027	3.22 (1.14-9.10)
2 vs 1	D vs. A	1.27	0.44	0.004	3.55 (1.48-8.49)
2 vs 1	E vs. A	0.86	0.70	0.220	2.37 (0.60-9.34)

*1 = High (>70K Taka); 2 = Medium (30K-70K Taka); 3 = Low (<30K Taka)
**1 = drinking and cooking; 2 = cleaning, washing and showring
***A = Household chores; B = Ornamental; C = Amenities; D = Discarded; E = Reconstruction

*overall chi-square value= 15.62, df=8, p-value=0.0481
**overall chi-square value= 11.82, df=4, p-value=0.018

4.4 Discussion

The main aim of this research is to test the association between different socio-economic and ecological variables in the city of Dhaka with dengue vector (*Aedes* sp.) productivity. To attain this, I assessed *Aedes* mosquito larval and pupal microhabitats in three different socio-economically zones by abundance, ecological clusters, and relevant socio-economic variables at the household level. To estimate abundance and gain a better understanding of dengue vector mosquito populations in Dhaka, immature (larva and pupa) *Aedes* were investigated and expressed in terms of *Stegomyia* indices. The House, Container and Breteau indices measured during the 2011 survey were similar to those measured during the 2000 dengue epidemic (Yunus et al., 2001). In general, the indices were quite high but varied considerably from year to year. For example, the BI varied between 11.4 in 2001 and 59.6 in 2011. These findings are supported by the various literature on dengue, which demonstrate that the abundance of *Ae. aegypti* populations varies markedly at different spatial scales, particularly the household level (i.e., vector density will vary from low to high even in houses in close proximity to each other, Aldstadt et al., 2011; Goh et al., 1987). For example, two similar studies in Thailand and Cuba which directly examined larval growth in household inspections and used structured questionnaires to determine socio-ecological risks enable us to put forward some comparative perspectives (Thammapalo et al., 2005; Spiegel et al., 2007). The Breteau Index was found to be 154.8 in Thailand, and between 0.11 to 1.32 in Central Havana, Cuba. In our study, the BI in Dhaka, Bangladesh ranged between 52.0 and 63.4 among different SES wards/zones. Also, the *Stegomyia* indices and number of positive houses exhibited no significant differences between SES wards. This appears logical, as Dhaka city is a highly heterogeneous city, with slums and luxurious houses often in close proximity.

As traditional *Stegomyia* indices are poor surrogates of vector abundance (Focks & Chadee, 1997), traditional entomological surveillance techniques based on *Stegomyia* indices have largely been replaced by targeted vector control strategies with a focus on container productivity (PAHO, 1994). It is obvious that some types of containers are more significant than others in producing adult vectors and targeting the most productive container types is needed to optimize labor efficiency and minimize costs while maximizing vector population reduction (Focks and Chadee, 1997; Focks et al., 2000; Focks, 2003). As indicated by Focks and Chadee (1997) in Trinidad, the nature of a container influenced immature *Aedes* productivity, in this study, container analysis was performed to evaluate the productivity. We used a container-type classification with 35 types, but the number of different container types could have been much larger. The record of the presence or absence of *Aedes* immatures among these 35 different container types, had shown that 9 major types of containers accounted for 75.2% of all infested containers. While HSES had tire and MSES had flower tubs and trays, LSES had five different types of containers as most productive. Recent studies in central Havana and Thailand showed significant association between flower vases and immature *Aedes* due to religious practices (Spigel et al., 2007; Thammapalo et al., 2005). A study in Northern Queensland, Australia, identified tires as the most common and highly productive habitats in developed societies (Tun-Lin et al., 1995). In LSES, it was expected to see higher number of different types of productive containers as they use different containers for storing water due to frequent water supply problem, and to reduce frequency of cleaning of the household containers. In general, plastic containers for domestic water requirements and disposed were more consistently available than other containers. The present study using complete counts of pupae produced a similar conclusion to the most productive containers.

While exploring whether most abundant containers were most productive, it was noticed that the hypothesis is true and refrigerator tray and sealable plastic drums had most pupae (27.4%) among the above mentioned 9 containers. The most conspicuous finding is the link between water supply interruptions and resultant water storage. We found a statistically significant increase in *Ae. aegypti* in household premises where water was stored to cope with uncertainty in power and water supply services. This is noteworthy as despite almost every household (81.5%) having piped water supply, the reliability of this water supply is questionable due to frequent power cuts. At the ward level, budgets are controlled through the DCC (Dhaka City Corporation), which struggles to get the necessary funds from taxes and central government transfers (Banks, 2008). As half of the total pupae (45.5%) were produced from domestic water holding plastic containers, it is clear that water storage in the household is a common practice in Dhaka. The use of electric appliances (e.g., refrigerators, air conditioners) by the emerging middle class, without adequate awareness of the effect of accumulated water droplets due to both condensation and the effects of power cuts into the refrigerator and A.C. trays are found to be linked with pupal production. These findings imply a positive correlation of *Aedes* pupal productivity vis-à-vis dengue transmission with inadequate urban services in Dhaka.

A recent study revealed that most urban poor in Dhaka have limited access to potable water. Due to the increasing prevalence of informal settlements in the city, informal dwellers spend Tk. 1.00 for 18 L. of water; while others, who are linked to the piped water system directly, receive 220 L. for Tk.1.00 (Akbar et al., 2007). Another reason to elicit why these domestic containers had most pupae, can be explained by our knowledge, attitude, and practice (KAP) survey data which showed that majority of residents (82.7%) do not clean water holding containers at least once per week (Dhar-Chowdhury et al., 2014).

The quantitative approach followed in the research to classify the positive containers (two-step cluster analysis) based on ecological variables surrounding containers (volume of water, exposure to sun, presence of vegetation, source of water in container) showed that most pupae found in the study area were in unattended, rain-filled containers outdoors. The most productive containers were those in the direct exposure to sunand not under the shade that received rainfall directly and had scanty water volume in the containers. The rest of pupae were in containers used for the residents mainly to store water or decorating flower plants or ornamental plants. From this classification system, we concluded that a significant reduction in the *Ae. aegypti* population could be achieved by household management actions, such as removing discarded containers and placing essential receptacles under a roof or upside-down to prevent rainwater accumulation.

Using the same multivariate technique, we classified the premises in the study areas using several structural variables of the premises (type of building, whether or not the building has green space, water supply to the building, presence of different water bodies near building) and containers (volume of water, total pupae). Among all three derived clusters it was prominent that presence of green space surrounding premises had lowest predictor importance in terms of producing immature *Aedes*. An analysis of spatio-temporal green space dynamics revealed that the green spaces of Dhaka are rapidly decreasing; in the last 30 years a total loss of 8,617 ha was observed in comparison to the baseline year of 1975 due to an increase of total population of 400% over this period (Byomkesh et al., 2012). Cluster III had most of the *Aedes* pupae (comprised only 26.7% of all premises) and was characterized by possessing the least amount of green space and both multi-storied and independent one-storied buildings. This finding is in contrast to a study in Puerto Rico, where the most pupae were found in clusters with more green trees (Barrera et al., 2006). Similar results were obtained in Queensland, Australia where a small percentage of premises contained a large percentage of positive containers and were 2.5 times more likely to be positive for *Ae. aegypti* immature forms (Tun-Lin et al., 1995).

The association between household socioeconomic status and pupal productivity has generally been viewed as a direct and linear relationship (Banerjee et al., 2013; Focks and Alexander, 2006). To our knowledge, no study has yet disaggregated this association by sequential causal relationships i.e. the association of containers with SES, followed by pupal productivity with container type. In this regard, our study is the first attempt to apply such a causal framework. From the results, it was found that there was a strong correlation between household socioeconomic status and use of containers for different purposes in the household. To evaluate what socioeconomic factors at the household level influence the possession of different container types, a multivariable regression analysis between different container functional categories (household chore, ornamental, amenities, discarded, reconstruction purposes) and household socioeconomic variables was performed. From the result, it was clear that income and purpose of storing water had a significant relationship with possession of different container types.

The City of Dhaka is a fastest growing megalopolis and primate city in the world where about 35.4% of the total urban population is poor (Banks, 2008; Nahiduzzaman, 2006). Slum and squatter settlements are found in almost all functional land use zones of the city (Nahiduzzaman, 2006). As every ward of the City contains pockets of informal settlements, socioeconomic variables were chosen at the individual house scale instead of different SES zone/wards. To the extent of my knowledge, ours is the first study to explore such relationships.

Most economic models assume that expenditure within the household depends on total income (non-labor and labor) (Thomas, 1993). In Bangladesh, low-income households mostly spend their earnings to fulfill their basic needs (food and shelter), with very little being spent on household goods and other amenities (Hossain, 2005). As our results revealed no significant difference in the number of positive containers between different socioeconomic status wards, it was important to explore the household income within each SES zone and positive container category. Low-income households possessed more discarded containers while middle and high-income household had more ornamental categoties (i.e., flower tubs and trays). The literature reveales that discarded ground-level containers are the most significant larval producers (Lenhart et al., 2006; Morrison et al., 2006; Bisset et al., 2006; Seng et al., 2008; Kearney et al., 2009), which is consistent with our results that low-SES zones produced more immature *Aedes*. Many studies have demonstrated the relationship between container types and *Aedes* productivity, but this is the first study to successfully reveal that possession of productive container categories is significantly associated with household income.

In this study, a multivariable logistic regression analysis showed that in a household having different positive container categories depends on its purpose of storing water. Existing literature suggests that half of the people living in the large cities of developing countries live in informal settlements and thus household connections to a piped water supply are often available to only an elite minority of the population (Kyessi, 2005; McIntosh, 2003).

However, in the city of Dhaka, the majority of population have piped water supply (81.6% in this research area). The main problem in Dhaka is that most urban dwellers do not have reliable access to potable water (Akbar et al., 2007). Locally known as “load-shedding” (Banks, 2008), intermittent interruptions of power supply everyday have been a common phenomenon for the last few decades. This, in turn, has resulted in serious disruptions in water supply to households. All socioeconomic groups in the city of Dhaka are affected by load-shedding, though the financial ability and enriched physical assets of higher-income groups allow them to store water in different types of containers (e.g. cement or metal tanks, andsealable plastic barrels) than the poor. Poor people in the slums have a strong tendency to store water in smaller containers in their household for maximum use of potable water or for the purposes of daily household chores (Appendix XVII; Image 4.8). Similar findings were revealed in a study of dengue in Fortaleza, Brazil, where people in low socioeconomic neighborhood stored water due to irregular supply (Caprara et al., 2009). The need to store water (for drinking, taking baths, doing household chores, and other necessary work) in containers of various sizes created a very conducive environment for vector development, especially during monsoon seasons (Ehsan et al., 2012).

People with high incomes depend on either the DCC or DWASA for regular water supply. However, their capacity to give bribes to authorities or officials does not solve the problem, as the local elected commissioner is provided with little in the way of resources or power and have only three staff members at their disposal (Banks, 2008). Consequently, storing water for washing, cleaning, and other household chores, has also become a common practice among high-income groups (Appendix XVII; Image 4.6). Improvement in water supply provisions and income subsidies through the distribution of leaded containers to the low socioeconomic groups would help reduce the number of open water containers in the city. Further research should be undertaken to validate the influence of more explanatory socioeconomic variables on the possession of different type of containers.

The specific policy implications of this study can be categorized into 3 main areas: 1) 9 specific types of containers were found to be more productive for dengue vector breeding than all others. Targeting these container types would be among the most cost and labour-effective strategies for controlling vector populations (Focks and Chadee, 1997; Focks et al., 2000; Focks, 2003). 2) Improving regular electricity and water supply has the potential to reduce dengue risk in Dhaka and in other urban centres of Bangladesh. Nonetheless, a study in Vietnam revealed that improvement in water infrastructure did not change household water storage practices or *Ae. aegypti* larval indices (Tran et al., 2012). It is therefore, recommend that urban infrastructure development should be combined with social communication campaigns aimed at changing householders' water storage behaviours.

3) This research has highlighted the ubiquity of *Aedes* larval development across all SES zones of the city of Dhaka and the unfeasibility of targeting all potential vector habitats via centralized insecticidal interventions. A two-pronged approach, involving intersectoral (power and water supply, municipal waste management, and infrastructure) authorities from multi-level governments (national, city corporation, and local) as well as community-based organizations, to control dengue outbreak in Dhaka would be the best option. The evidence for the efficacy of community-based programs is still limited (Heintze et al., 2007), and there is an urgent need for further research and development in this area.

4.5 Limitations

The scope of the present study is limited by three factors. First, we only examined the entomological data at a single time point and not over the course of several seasons. Since this study is the first *Aedes* pupal productivity study in Dhaka, future research endeavors can fill in these gaps in the research. Second, considering the socio-demographic, economic and infrastructural heterogeneity among the Wards, generalization of data at the City level must be made cautiously. Finally, this study focused mainly on household containers and surroundings to assess *Aedes* habitats and left out other *Aedes* habitats in the urban environment. To capture *Aedes* dynamics fully, future studies will need to cover non-household habitats of *Aedes* mosquitoes.

References

Akbar, H., Minnery, J. R., van Horen, B., & Smith, P. (2007). Community water supply for the urban poor in developing countries: the case of Dhaka, Bangladesh. *Habitat International, 31*(1), 24-35.

Aldstadt, J., Koenraadt, C. J., Fansiri, T., Kijchalao, U., Richardson, J., Jones, J. W., & Scott, T. W. (2011). Ecological modeling of Aedes aegypti (L.) pupal production in rural Kamphaeng Phet, Thailand. *PLoS Neglected Tropical Diseases, 5*(1), e940.

Alexander, N., Lenhart, A. E., Romero-Vivas, C. M. E., Barbazan, P., Morrison, A. C., Barrera, R., . . . Focks, D. A. (2006). Sample sizes for identifying the key types of container occupied by dengue-vector pupae: The use of entropy in analyses of compositional data. *Annals of Tropical Medicine and Parasitology, 100*(SUPPL. 1), S5-S16.

Arredondo-Jiménez, J., & Valdez-Delgado, K. (2006). Aedes aegypti pupal/demographic surveys in southern Mexico: consistency and practicality. *Annals of Tropical Medicine & Parasitology, 100*(Supplement-1), 17-32.

Banerjee, S., Aditya, G., & Saha, G. K. (2013). Household disposables as breeding habitats of dengue vectors: Linking wastes and public health. *Waste Management (New York, N.Y.), 33*(1), 233-239. doi:http://dx.doi.org/10.1016/j.wasman.2012.09.013

Banks, N. (2008). A tale of two wards: political participation and the urban poor in Dhaka city. *Environment and Urbanization, 20*(2), 361-376.

Barrera, R., Amador, M., & Clark, G. G. (2006). Use of the pupal survey technique for measuring Aedes aegypti (Diptera: Culicidae) productivity in Puerto Rico. *The American Journal of Tropical Medicine and Hygiene, 74*(2), 290-302.

Bisset, J., Marquetti, M., Suarez, S., Rodríguez, M., & Padmanabha, H. (2006). Application of the pupal/demographic-survey methodology in an area of Havana, Cuba, with low densities of Aedes aegypti (L.). *Annals of Tropical Medicine & Parasitology, 100*(Supplement-1), 45-51.

Braks, M. A., Honório, N. A., Lourenço-De-Oliveira, R., Juliano, S. A., & Lounibos, L. P. (2003). Convergent habitat segregation of Aedes aegypti and Aedes albopictus (Diptera: Culicidae) in southeastern Brazil and Florida. *Journal of Medical Entomology, 40*(6), 785-794.

Brunkard, J. M., Robles L'opez Jose Luis, Ramirez, J., Cifuentes, E., Rothenberg, S. J., Hunsperger, E. a., . . . Haddad, B. M. (2007). Dengue fever seroprevalence and risk factors, Texas-Mexico border, 2004. *Emerging Infectious Diseases, 13*(10), 1477-1483. doi:10.3201/eid1310.061586

Byomkesh, T., Nakagoshi, N., & Dewan, A. M. (2012). Urbanization and green space dynamics in Greater Dhaka, Bangladesh. *Landscape and Ecological Engineering, 8*(1), 45-58.

Caprara, A., Lima J. W. O.,Marinho, A. C. P. et al. (2009). Irregular Water Supply, household usage and dengue: a bio-social study in the Brazilian Northeast. *Cad. Saude Publica, 25*(Sup 1), S125-S136.

Dhar-Chowdhury, P., Emdad Haque, C., Michelle Driedger, S., & Hossain, S. (2014). Community perspectives on dengue transmission in the city of Dhaka, Bangladesh. *International Health,* doi:10.1093/inthealth/ihu032

Dowling, Z., Ladeau, S. L., Armbruster, P., Biehler, D., & Leisnham, P. T. (2013). Socioeconomic Status Affects Mosquito (Diptera : Culicidae) Larval Habitat Type Availability and Infestation Level.*50*(4), 764-772.

Ehsan, M., Ovy, E., Shariar, K. F., & Ferdous, S. M. (2012). A novel approach of electrification of the high rise buildings at Dhaka city during load shedding hours. *International Journal of Renewable Energy Research (IJRER), 2*(1), 123-130.

Focks, D. A., & Chadee, D. D. (1997). Pupal survey: an epidemiologically significant surveillance method for Aedes aegypti: an example using data from Trinidad. *The American Journal of Tropical Medicine and Hygiene, 56*(2), 159-167.

Focks, D., & Barrera, R. (2007). Dengue transmission dynamics: assessment and implications for control. Scientific Working Group, Report on Dengue, 1–5 October 2006, Geneva: World Health Organization. *Switzerland, Copyright World Health Organization on Behalf of the Special Programme for Research and Training in Tropical Diseases,*

Focks, D. A. (2003). A review of entomological sampling methods and indicators for dengue vectors. *Geneva: WHO,*

Focks, D. A., Brenner, R. J., Hayes, J., & Daniels, E. (2000). Transmission thresholds for dengue in terms of Aedes aegypti pupae per person with discussion of their utility in source reduction efforts. *The American Journal of Tropical Medicine and Hygiene, 62*(1), 11-18.

Focks, D. A., & Alexander, N. (2007). Multicountry study of Aedes aegypti pupal productivity survey methodology : Findings and recommendations. *Dengue Bulletin, 31*

Goh, K. T., Ng, S. K., Chan, Y. C., Lim, S. J., & Chua, E. C. (1987). Epidemiological aspects of an outbreak of dengue fever/dengue haemorrhagic fever in Singapore. *The Southeast Asian Journal of Tropical Medicine and Public Health, 18*(3), 295-302.

Gubler, D. J. (1998). Dengue and dengue hemorrhagic fever. *Clinical Microbiology Reviews, 11*(3), 480-496.

Harrigan, R. J., Thomassen, H. A., Buermann, W., Cummings, R. F., Kahn, M. E., & Smith, T. B. (2010). Economic conditions predict prevalence of West Nile virus. *PloS One, 5*(11), e15437.

Heintze, C., Garrido, M. V., &Kroeger, A. (2007). What do community-based dengue control programmesachieve ? A systematic review of published evaluations. *Trans R Soc Trop Med Hyg*101(4): 317-25.

Hossain, S. (2005). Poverty, household strategies and coping with urban life: Examining 'livelihood framework'in Dhaka city, Bangladesh. *Bangladesh e-Journal of Sociology, 2*(1), 1-8.

Kearney, M., Porter, W. P., Williams, C., Ritchie, S., & Hoffmann, A. A. (2009). Integrating biophysical models and evolutionary theory to predict climatic impacts on species' ranges: the dengue mosquito Aedes aegypti in Australia. *Functional Ecology, 23*(3), 528-538.

Kuno, G. (1995). Review of the factors modulating dengue transmission. *Epidemiologic Reviews, 17*(2), 321-335.

Kyessi, A. G. (2005). Community-based urban water management in fringe neighbourhoods: the case of Dar es Salaam, Tanzania. *Habitat International, 29*(1), 1-25.

LaDeau, S. L., Leisnham, P. T., Biehler, D., & Bodner, D. (2013). Higher Mosquito Production in Low-Income Neighborhoods of Baltimore and Washington, DC: Understanding Ecological Drivers and Mosquito-Borne Disease Risk in Temperate Cities. *International Journal of Environmental Research and Public Health, 10*(4), 1505-1526.

Lenhart, a. E., Castillo, C. E., Oviedo, M., & Villegas, E. (2006). Use of the pupal/demographic-survey technique to identify the epidemiologically important types of containers producing Aedes aegypti (L.) in a dengue-endemic area of Venezuela. *Annals of Tropical Medicine and Parasitology, 100 Suppl*(1), S53-S59.

Maciel-de-Freitas, R., & Lourencco-de-Oliveira, R. (2011). Does targeting key-containers effectively reduce Aedes aegypti population density? *Tropical Medicine \& International Health : TM \& IH, 16*(8), 965-973.

McIntosh, A. C. (2003). *Asian water supplie*. IWA publishing.

Midega, J. T., Nzovu, J., Kahindi, S., Sang, R. C., & Mbogo, C. (2006). Application of the pupal/demographic-survey methodology to identify the key container habitats of Aedes aegypti (L.) in Malindi district, Kenya. *Annals of Tropical Medicine and Parasitology, 100 Suppl*(1), S61-S72.

Mondini, A., & Chiaravalloti-Neto, F. (2008). Spatial correlation of incidence of dengue with socioeconomic, demographic and environmental variables in a Brazilian city. *The Science of the Total Environment*, *393*(2-3), 241-248.

Morrison, A. C., Sihuincha, M., Stancil, J. D., Zamora, E., Astete, H., Olson, J. G., . . . Scott, T. W. (2006). Aedes aegypti (Diptera: Culicidae) production from non-residential sites in the Amazonian city of Iquitos, Peru. *Annals of Tropical Medicine and Parasitology, 100 Suppl*(1), S73-S86.

Nahiduzzaman, K. (2006). Housing the Urban Poor: Planning, Business and Politics: A Case Study of Duaripara Slum, Dhaka city, Bangladesh.

Ooi, E., Goh, K., & Gubler, D. J. (2006). Dengue prevention and 35 years of vector control in Singapore. *Emerging Infectious Diseases, 12*(6), 887-93.

PAHO. (1994). *Dengue and dengue hemorrhagic fever in the Americas: Guidelines for prevention and control.* (No. 548).

Peterson, A. T., Martínez-Campos, C., Nakazawa, Y., & Martínez-Meyer, E. (2005). Time-specific ecological niche modeling predicts spatial dynamics of vector insects and human dengue cases. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 99*(9), 647-655.

Reisen, W. K., Carroll, B. D., Takahashi, R., Fang, Y., Garcia, S., Martinez, V. M., & Quiring, R. (2009). Repeated West Nile virus epidemic transmission in Kern County, California, 2004–2007. *Journal of Medical Entomology, 46*(1), 139.

Reisen, W., Meyer, R., Tempelis, C., & Spoehel, J. (1990). Mosquito abundance and bionomics in residential communities in Orange and Los Angeles Counties, California. *Journal of Medical Entomology, 27*(3), 356-367.

Reiter, P., Gubler, D. J., Gubler, D., & Kuno, G. (1997). Surveillance and control of urban dengue vectors. *Dengue and Dengue Hemorrhagic Fever.CAB International, New York, ,* 425-462.

Rios, J., Hacker, C. S., Hailey, C. A., & Parsons, R. E. (2006). Demographic and spatial analysis of West Nile virus and St. Louis encephalitis in Houston, Texas. *Journal of the American Mosquito Control Association, 22*(2), 254-263.

Sanchez, L., Vanlerberghe, V., Alfonso, L., Marquetti, M. d. C., Guadalupe Guzman, M., Bisset, J., & Van Der Stuyft, P. (2006). Aedes aegypti larval indices and risk for dengue epidemics. *Emerging Infectious Diseases, 12*(5)

Seng, C. M., Setha, T., Nealon, J., Socheat, D., Chantha, N., & Nathan, M. B. (2008). Community-based use of the larvivorous fish Poecilia reticulata to control the dengue vector Aedes aegypti in domestic water storage containers in rural Cambodia. *Journal of Vector Ecology, 33*(1), 139-144.

Seng, C. M., Setha, T., Nealon, J., & Socheat, D. (2009). Pupal sampling for Aedes aegypti (L.) surveillance and potential stratification of dengue high-risk areas in Cambodia. *Tropical Medicine & International Health : TM IH, 14*(10), 1233-1240.

Southwood, T. R., Murdie, G., Yasuno, M., Tonn, R. J., & Reader, P. M. (1972). Studies on the life budget of Aedes aegypti in Wat Samphaya, Bangkok, Thailand. *Bulletin of the World Health Organization, 46*(2), 211-226.

Spiegel, J. M., Bonet, M., Ibarra, A., Pagliccia, N., Ouellette, V., & Yassi, A. (2007). Social and environmental determinants of Aedes aegypti infestation in Central Havana: results of a case–control study nested in an integrated dengue surveillance programme in Cuba. *Tropical Medicine & International Health, 12*(4), 503-510.

Strickman, D., & Kittayapong, P. (2003). Dengue and its vectors in Thailand: calculated transmission risk from total pupal counts of Aedes aegypti and association of wing-length measurements with aspects of the larval habitat. *The American Journal of Tropical Medicine and Hygiene, 68*(2), 209-217.

Thammapalo, S., Chongsuwiwatwong, V., McNeil, D., & Geater, A. (2005). The climatic factors influencing the occurrence of dengue hemorrhagic fever in Thailand.

Thomas, D. (1993). The distribution of income and expenditure within the household. *Annales d'Economie Et De Statistique,* 109-135.

Tran, H. P., Huynh, T. T., Nguyen, Y. T., Kutcher, S., O'Rourke, P., Marquart, L., . . . Kay, B. H. (2012). Low entomological impact of new water supply infrastructure in southern Vietnam, with reference to dengue vectors. *The American Journal of Tropical Medicine and Hygiene, 87*(4), 631-639.

Tun-Lin, W., Kay, B., & Barnes, A. (1995). Understanding productivity, a key to Aedes Aegypto surveillance. *The American Journal of Tropical Medicine and Hygiene, 53*(6), 595-601.

Unlu, I., Farajollahi, A., Healy, S. P., Crepeau, T., Bartlett- Healy, K., Williges, E., . . . Fonseca, D. M. (2011). Area wide management of Aedes albopictus: choice of study sites based on geospatial characteristics, socioeconomic factors and mosquito populations. *Pest Management Science, 67*(8), 965-974.

World Health Organization. (2009). Regional guidelines on Dengue/DHF, prevention and control. *Regional Publication, 29*

Yunus, E. B., Bangali, A. M., Mahmood, M. A. H., Rahman, M. M., Chowdhury, A., & Talukder, K. (2001). Dengue outbreak 2000 in Bangladesh: from speculation to reality and exercises. *Dengue Bulletin, 25*, 15-20.

CHAPTER FIVE

SEROEPIDEMIOLOGY AND SOCIOECONOMIC RISK FACTORS

Abstract

This chapter examines the socioeconomically and spatially-differentiated household risk factors related to dengue seroprevalence and seroincidence, and their association with socioeconomic factors at both the urban zonal and household levels in the city of Dhaka, Bangladesh. Serological surveys to collect population serum samples and a socioeconomic questionnaire were conducted during the 2012 pre- and post-monsoon seasons. All administrative Wards (N=90) of the City were classified into three Socio-Economic Status (SES) zones using the Delphi method, and 1125 households during the pre-monsoon and 1068 households during post-monsoon 2012 season in 12 randomly selected Wards were surveyed. Based on IgG ELISA, the results revealed a seroprevalence rate of 79.9% (pre-monsoon, 2012) and 88.2% (post-monsoon, 2012). 95 individuals were seroconverted during post-monsoon season of 2012. Seroconversions were calculated based on negative to positive OD/CO results from both IgG and IgM ELISA. Examination of prevalence of IgG reaction to DENV among the subjects in each group revealed that seropositivity was strongly associated with age. Seroconversion was high among children, with 15.8% being seroconverted. From univariate analysis at the household and neighborhood level, the number of indoor potted plants, different types of mosquito control measures, and febrile illness in family members during past six months were found to be statistically significant variables linked to seroprevalence. Multivariate logistic regression of all variables as well as pre-selected variables from univariate analysis both confirmed that age and number of indoor potted plants were significantly associated with seroprevalence and seroincidence.

1 Background

The increased incidence and rapid geographic spread of dengue across the tropical and sub-tropical world has been profoundly influenced by recent large-scale phenomena including, population growth, rapid urbanization, inadequate basic housing, climate change, and increasing air travel (Banu et al., 2011; Gubler, 2002; Guha-Sapir and Schimmer, 2005; Guzmán and Kouri, 2002). During last eight years, incidence of dengue has grown in its endemic regions including the Americas. However, fatality rates have increased most alarmingly in the Southeast Asia and Western Pacific regions (Guzmán and Kouri, 2002). The reasons for the spread of the disease are not fully understood, but are primarily related to geographical and societal changes, as well as the heterogeneity of dengue incidence in time and space, which reflects the complexity of risk factors related to the transmission of the disease (World Health Organization, 2012). In the 1960s and 1970s, epidemics were mainly confined to the major urban centers of Southeast Asian countries. In the past 25 years; however, the epidemics have spread to new geographic locations, with reports of many thousands of cases. In most countries of the region, epidemics occur in cycles of three to five years, as illustrated in data from Thailand, Vietnam and Indonesia, (which have good long-term surveillance programs). During this period, epidemic dengue fever and DHF have spread progressively throughout these countries. Demographic and societal changes over the past 50 years have been responsible for the dramatic global spread of dengue viruses and the mosquitoes that transmit them. The result has been the cocirculation of multiple virus serotypes (hyperendemicity) in most large cities in the tropics, where the dengue viruses are maintained during inter-epidemic periods. Based on the emergence and spread of epidemic DEN-3 in Indonesia in the 1970s, it was speculated that new genetic variants of viruses, with greater epidemic potential and virulence (epidemic strains), emerge in this urban environment and then spread to new areas (Gubler, 2004).

Many studies using GIS tools have been performed to assess and identify possible risk factors involved in dengue transmission (Siqueira et al., 2004; Van Benthem et al., 2005). Moreover, studies have identified that the transmission of this disease does not occur uniformly throughout all the regions in a city (Mondini and Chiaravalloti-Neto, 2008). With the increased incidence and rapid geographic spread of dengue disease, much more research on disease risk factors is needed to explain the above observation (Braga et al., 2010; Guzmán and Kouri, 2002; Hayes et al., 2006; Heukelbach et al., 2001).

Identified dengue risk factors vary greatly depending on the location of the investigation, the circulating virus serotypes, human population density, and previous exposure to specific serotypes (Hayes et al., 2003). Low income is one of the most dominant risk factors for both recent and past dengue infection (Brunkard et al., 2007). Population growth, rural-urban migration, inadequacy of basic urban infrastructure, and exponential growth of consumerism are other important risk factors (Hayes et al., 2003). Among other possible individual and household risk factors for dengue are greater age, low socio-economic status (Siqueira et al., 2004), lower education levels (Teixeira et al., 2008), and household characteristics such as window screens or the presence of air-conditioning (Reiter et al., 2003). Cobelens et al. (2002) found that in Southeast Asia, dengue outbreaks have been reported outside the rainy season (Kuno, 1995), which may explain why the proportion of travellers returning from endemic areas with antibodies to dengue infection is much higher than would be expected from incidences of clinical dengue (Cobelens et al., 2002). Similar studies have shown that the risk of dengue to travellers is over 100-fold higher than the available risk estimates for typhoid and 3 to10-fold higher than for hepatitis A - both of which travelers are routinely vaccinated against (Ratnam et al., 2012). The risk of dengue is higher as no vaccine is yet available. Significant positive correlation between seroprevalence and education, head-of-household income, and personal and family history of dengue have been found in several studies (Brunkard et al., 2007; Siqueira et al., 2004; Thai et al., 2005). However, a household survey of a Northeastern Brazilian city found dengue seroprevalence risk to be inversely associated with socio-economic status (Braga et al., 2010). In addition, this study revealed that apartment dwellers had much lower seroprevalence than individual householders in affluent areas despite the higher entomological indices in the former dwelling types. This is explained by the presences of private water wells in apartments, reducing the need to store water in containers. In Vietnam, sanitary facilities and age were also significantly associated with the prevalence dengue IgG antibodies (Thai et al., 2005).

In Bangladesh, the Government of Bangladesh Health Services registered 23,872 cases of dengue, with 233 fatal cases, between 2000 and 2009 (Banu et al., 2011). However, before 2000, Bangladesh was thought to be dengue-free except some sporadic reports dating back to 1965 (Yunus et al., 2001). As a result, the people, the medical establishment, and disease control programs were not well-acquainted with the diagnosis, management, prevention and control of the disease (Yunus et al., 2001). After the 2000 outbreak, in the face of the continued risk of dengue transmission among the urban population of Dhaka, research was carried out only to confirm the presence of dengue. Few studies have identified the circulating serotypes in Bangladesh (Karim et al., 2012; Islam et al., 2006; Pervin et al., 2004; Rahman et al., 2002). Despite the increasing circulation of dengue virus, population-based prevalence data are not available in this region. To our knowledge, research has not yet been done to identify the dengue risk factors in the City of Dhaka.

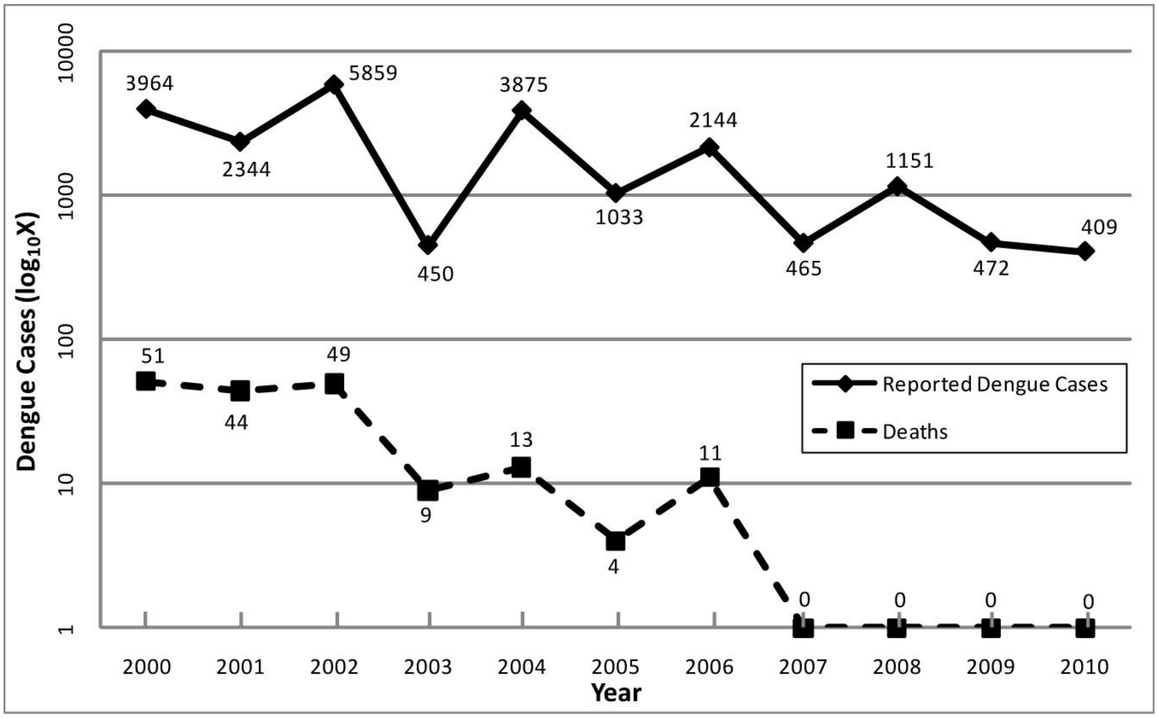


Figure 5.1: Trend in dengue cases and fatalities in Dhaka city, Bangladesh, 2000-2010

5.2 Data Analysis

To define risk factors and seroprevalence in the City of Dhaka, a large-scale household serosurvey during the pre- and post-monsoon periods of 2012 were carried out to assess the extent of previous exposure to dengue virus. Two serosurveys (pre and post-monsoon) were completed during the year 2012 (Appendix XVII; Image 5.2). The purpose of conducting pre-monsoon and post-monsoon serosurveys was to complete a baseline seroprevalence study and a seroconversion study in the city of Dhaka. The pre-monsoon 2012 survey or baseline seroprevalence study as well as post-monsoon 2012 survey or seroconversion study were used interchangeably in this chapter. Using a standardized questionnaire, household heads were interviewed to collect information at the individual level associated with viral infection.

Potential individual risk factors were collected by a structured questionnaire that included aspects of education, income, gender, age, occupation, frequency of presence in public gatherings, number of standing water containers inside and outside the house, and history of travel and febrile illness in the past 6 months (Table 5.1; Appendix XVII; Image 5.1). Differences in Odds ratios seropositivity during the pre- and post-monsoon periods of 2012 and other risk factors were calculated by chi-square tests, with a p-value < 0.05 being considered statistically significant. Logistic regression was applied to identify risk factors for seropositivity. (ORs) and their 95% confidence intervals (95% CIs) were calculated. Factors associated (p-value< 0.05) with seropositivity in univariate analyses were selected for multivariate analyses. In multivariate analyses, I tested statistically significant (p-value< 0.05) interactions between determinants. All statistical analyses were performed using SPSS software (SPSS Inc., Chicago, IL).

5.3 Results

During the 2012 pre-monsoon period (June-July), a total of 1125 serum samples were collected from 12 wards of the Dhaka City Corporation (DCC). These serum samples were collected from a total of 635 households. The target was to collect only one serum sample per household. However, because multiple members of each household often insisted in participating, I was forced to adjust my methodology. Therefore, samples were collected and tested from more than one volunteer from each household. From a cost-effectiveness perspective, it was redundant to analyze all samples; however, we tested all anyway to examine the intensity of DENV exposure in the population.

During 2012 post-monsoon period (November-December), a total of 1068 serum samples were collected from 743 households. Of these households, 386 had been previously sampled during the pre-monsoon survey. In order to meet the same target sample size as the 2012 pre-monsoon study (n=1125), additional households (n=357) were sampled from 12 wards, providing an additional 500 serum samples. The percentage of positive IgG and IgM ELISA during both seasons along with different socioeconomic status (SES) wards is presented in Table 5.1a and 5.1b.

Table 5.1: Serosurvey Results of Pre-monsoon and Post-Monsoon in the City of Dhaka, 2012

Serological Results	**Pre-monsoon 2012**				**Post-Monsoon 2012**			
	IgG		**IgM**		**IgG**		**IgM**	
	N	(%)	N	(%)	N	(%)	N	(%)
Positive	899	79.9	23	2.1	942	88.2	88	8.2
Negative	226	19.1	1102	97.9	126	11.8	980	91.8
Total	1125	100	1125	100	1068	100	1068	100

5.3.1 Serologic interpretation of the results from ELISA

Seroprevalence is defined as the presence of IgG (OD/CO>=1) in serum samples. Seroconversion is defined as where IgM and IgG results changed from OD/CO<=1 to OD/CO>=1 during post-monsoon 2012 in paired sample. The terms *Seroincidence* and *seroconversion* (during post-monsoon 2012) were used interchangeably in this study.

5.3.2 Findings on baseline seroprevalence survey (2012 pre-monsoon)

The age of survey participants ranged from 1 to 97 years. Mean ages for participants were 31.9 (95%CI: 29.0-31.0). 122 children (10.8% of the total; age range, 1-11 years) had their sera tested for DENV IgG and IgM antibodies, and 54.9% (67/122) were positive for IgG and 0.8% (1/122) for IgM. The IgG prevalence increased with age and by the age of 9 years, 77% (94 of 122) children became IgG seropositive. There is no significant (p-value=0.05) gender difference for prevalence of IgG (p-value=0.372; Table 3a).

Among youth, adults, and the aged, 1005 subjects (89.2% of total; age range, 12-77 years) had their sera tested for DENV IgG and IgM antibodies and 74.2% (835 of 1125) were positive for IgG and 1.95% (22 of 1125) for IgM. The male to female ratio of the subjects was 1: 1.3. The prevalence of IgG among male and female subjects was 81.1% (396 of 488) and 79.2% (506 of 639) respectively. The examination of prevalence of IgG reaction to DENV among the subjects in each group revealed that seropositivity was strongly positively correlated with age (Figure 5.2). The population characteristics of baseline seroprevalence survey were presented in Table 5.2.

5.3.3 Risk factors assessment of seroprevalence

Of 24 variables in the questionnaire, 12 variables (Table 5.3a and 5.3b) were selected to assess the risk factors for seroprevalence based on the following criteria: scale or dichotomous items; items for which more than 95% of all the records have meaningful values; items for which duplicated independent translations of the questionnaire were consistent; and items for which all the records are within a meaningful range. From univariate analysis (dependent variables were seropositivity and seronegativity) it was clear that at individual level, there was a significant (p-value=0.05) positive correlation between seroprevalence and age (p-value=0.0001) and mean hours spent outside home per week due to occupational requirement (p-value= 0.0002). Likewise, significant positive correlation was found between IgG seroprevalence and all different age groups (CI: 2.70-5.90; p-value= 0.0001). Individual income and sex were not statistically related with dengue seropositivity (Table 5.3a).

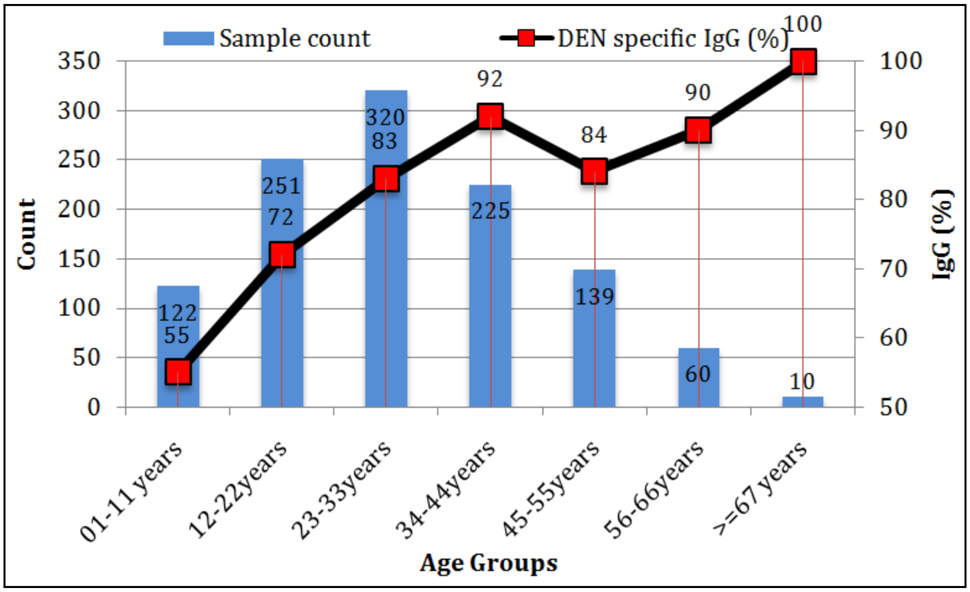


Figure 5.2**:** Dengue (DEN) specific IgG seroprevalence during pre-monsoon 2012 by age groups in Dhaka

At the household and neighborhood level, number of indoor potted plants (CI: 0.34-0.77; p-value = 0.0011), different types of mosquito control measures (p-value= 0.016), and febrile illness in any family members during past six months (CI: 1.00-1.81; p= 0.0441) were found to be statistically significant variables driving seroprevalence. Number of stored water vessels inside the household, number of uncovered water tank outside house, presence in public gathering places, travel outside Dhaka within last 6 months, and whether mosquito control measures were taken were not significantly associated with DENV seroprevalence (Table 5.3b). To allow robust and extensive interpretable multivariate analysis, all variables as well as pre-select significant (p-value =0.05) variables from univariate analysis were analyzed. Multivariate logistic regression of all variables as well as pre-selected variables from univariate analysis both confirmed that age, number of indoor potted plants, and type of mosquito control measures undertaken were significantly associated with seroprevalence. Notably, type of mosquito control measures variable is significant overall (p value = 0.048); (Table 5.4).

Table 5.2: Population characteristics of pre-monsoon 2012 serosurvey participants

Population characteristics	Count	%
Age (years)		
01-11	122	10.8
12-22	251	22.7
23-33	320	28.4
34-44	225	20
45-55	139	12.3
56-66	60	5.3
67-77	10	0.9
Sex		
Male	488	43.3
Female	639	56.7
Income (Bangladeshi Taka)		
0-14,9999	441	39.2
15000-24,999	226	19.9
≥25, 000	453	40.3
Education		
No Education	122	10.8
Primary	352	31.2
Secondary	293	26
Higher Secondary	140	12.4
Undergraduate	135	12
Graduate	81	7.2
Occupation		
Service/professional	44	3.9
Business	124	11
Labor/menial workers	135	12
Student	221	19.6
Housewife	383	34
Others	116	10.3

Table 5.3a: Univariate association between seroprevalence (IgG) of dengue and selected individual variables, pre-monsoon 2012

Variable	Seropositive n (%)	Seronegative n (%)	OR (95% CI)	p
Age, years, mean	31.94	22.56		0.0001★
Age, years, (categorized)				
<=11 (children)	67 (7.4)	55 (24.3)	1	
12-77 years (adults)	833 (92.6)	171 (75.7)	4.00 (2.70-5.90)	<0.0001★
Income in household				
0-14,9999	341 (38.0)	100 (44.8)	1	0.0827
15000-24,999	179 (20.0)	47 (21.1)	1.10 (0.76-1.65)	
>=25,000	377 (42.0)	76 (34.1)	1.46 (1.04-2.03)	
Sex				
Female	505 (56)	134 (59.3)	1	
Male	396 (44)	92(40.7)	1.14 (0.85-1.54)	0.3720
Hours per week spent outside home due to occupation (mean hours)	15.5	9.27		0.0002★

★**Significant variables at p=0.05 level**

Table 5.3b: Univariate association between seroprevalence (IgG) of dengue and selected household and neighborhood variables, pre-monsoon 2012

Variable	Seropositive n (%)	Seronegative n (%)	OR (95% CI)	p
Number of stored water vessels inside household				
0	317 (35.2)	82 (36.3)	1	0.853
1	112 (12.5)	26 (11.5)	1.11 (0.68-1.82)	
2	147 (16.4)	32 (14.2)	1.19 (0.76-1.87)	
3	151 (16.8)	37 (16.3)	1.06 (0.68-1.63)	
≥4	172 (19.1)	49 (21.7)	0.91 (0.61-1.35)	
Number of uncovered water tank outside house				
1	474 (52.8)	125 (55.3)	1	
≥1	423 (47.2)	101 (44.7)	1.10 (0.82-1.48)	0.506
Number of indoor potted plants				
≥1	218 (24.3)	32 (14.2)	1	
None	681 (75.7)	194 (85.8)	0.52 (0.34-0.77)	0.001★
Mosquito control measures				

Variable	Seropositive n (%)	Seronegative n (%)	OR (95% CI)	p
Yes	740 (82.3)	197 (87.2)	1	
No	159 (17.7)	29 (12.8)	1.46 (0.95-2.23)	0.081
Presence in public gathering places				
No appearance	249 (27.7)	76 (33.6)	1	
School	211 (23.4)	54 (23.9)	1.19 (0.80-1.77)	0.256
Mosque/religious places	145 (16.1)	29 (12.8)	1.53 (0.95-2.45)	
Entertainment places	295 (32.8)	67 (29.7)	1.34 (0.93-1.94)	
Types of mosquito control measures				
Bed net	243 (33.2)	62 (31.8)	1	
Mosquito coil	323 (44.1)	105 (53.8)	0.79 (0.55-1.12)	0.016★
Spray and others	166 (22.7)	28 (14.4)	1.51 (0.93-2.93)	
Travel outside Dhaka within last 6 months				
Yes	535 (59.6)	144 (63.7)	1	
No	363 (40.4)	82 (36.3)	1.19 (0.88-1.61)	0.26
Any family member suffers from fever within last 6 months				
Yes	446 (49.6)	129 (57.1)	1	
No	453 (50.4)	97 (42.9)	1.35 (1.00-1.81)	0.044★

★Significant variables at p=0.05 level

Table 5.4: Estimated odds ratios (OR) for the multilevel analysis of the association between seroprevalence of dengue and selected variables

Variable	Estimates (St. error)	OR (95% CI)	p-value
Age			0.05
Intercept	0.59 (0.30)		
0-11		1	
12-44	1.42 (0.23)	4.13 (2.65-6.42)	<0.0001
45 and over	1.78 (0.30)	5.90 (3.26-10.68)	<0.0001
No. of indoor potted plant			
One and more		1	
None	-0.63 (0.22)	0.53 (0.34-0.81)	0.004
Type of mosquito control measure			
Type 1		1	
Type 2 vs. 1	-0.22 (0.19)	0.80 (0.56-1.16)	
Type 3 vs. 1	0.36 (0.26)	1.44 (0.87-2.39)	0.04

OR= Odds ratio; CI=Confidence interval
Hosmer- Lemeshow goodness-of-fit test= 2.86; p=0.8261
ϴ This variable is overall significant (p-value=0.048)

5.3.4 Findings on seroconversion study (2012 post-monsoon)

All households were revisited during the post-monsoon period (i.e. November-December 2012). Of 1125 subjects enrolled at baseline, 600 (53.24%) still lived in the previous location and were eligible for a second blood sample draw. The 600 study participants with paired serum samples tested for DENV antibodies with ELISA (Age range, 01–77 years) comprised the population sample of the seroconversion study. 95 individuals (83 households) were seroconverted during the 2012 post-monsoon season. Seroconversions were calculated based on negative to positive OD/CO results from both IgG and IgM ELISA. Seroconversion was high among children, with 15.8% being seroconverted. Among pre-monsoon IgG positive samples, I looked into the index value and found 6 with OD/CO>=4, which may be assumed to be secondary infection. Besides these 95 samples of 600 paired sera, another 18 samples had OD/CO value >= 4 which I purposefully did not include in further statistical analysis (as Focus dengue ELISA has no instruction to define these samples as secondary infection). Seroconversion was higher among female (61.1%) participants than male (38.9%).

5.3.5 Risk factors assessment for seroconverted samples

Of 24 variables in the questionnaire, 12 variables (Table 5.5a and 5.5b) were selected to assess the risk factors for seroprevalence based on the following criteria: scale or dichotomous items; items for which more than 95% of all the records have meaningful values; items for which duplicated independent translations of the questionnaire were consistent; items for which all the records are within a meaningful range. From univariate analysis (dependent variables were seropositivity and seronegativity), it was clear that at individual level, there was a significant (p-value=0.05) positive correlation between seroincidence (i.e., seroconversion/ person/ season) and age (p-value=0.0001) and education (p-value= 0.022). Individual income, occupation, mean hours spent outside home per week due to occupation, and sex were not statistically related with dengue seropositivity (Table 5.5a).

At the household and neighborhood level, multivariate logistic regression of all variables as well as pre-selected variables from univariate analysis (Table 5.5b) both revealed that age and number of indoor potted plants were statistically significantly associated with seroincidence (Table 5.6; Appendix XVII, Image 5.3). In Dhaka, it is a common cultural practice to have a Money Plant in one's house. These plants grow without soil, it is believed locally that keeping them will bring prosperity and financial growth to the family. An image of this plant (*Epipremnum aureum*) is shown in Appendix XVII, Image 5.4.

5.3.6 PRNT results

Excellent correlation was found between the Focus Dx Select Dengue IgG kit and the DENV PRNT assay. A total of 150 randomly selected samples (100 sera from pre-monsoon and 50 sera from post-monsoon) were tested for PRNT. Of the 150 IgG ELISA-positive samples tested by PRNT, 96% of the pre-monsoon and 94% of the post-monsoon samples were shown to have significant titres to DENV-2. Further testing of these samples in the JEV and WNV PRNT yielded negative results. This outcome confirms that the neutralizing antibodies present in the test sera were specific for dengue virus. A PRNT titre $\geq$ 80 is considered significant. Samples tested in the dengue PRNT produced titres ranging from 40 to 640.

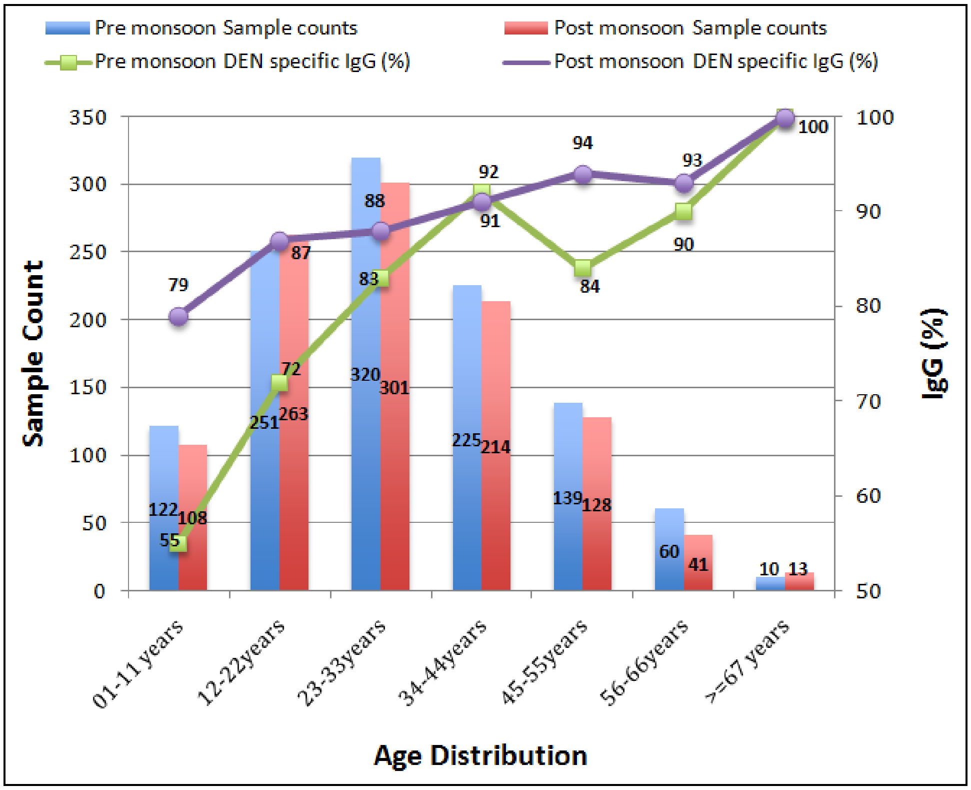


Figure 5.3: Dengue (DEN) specific IgG distribution during pre- and post- monsoon 2012 by age groups

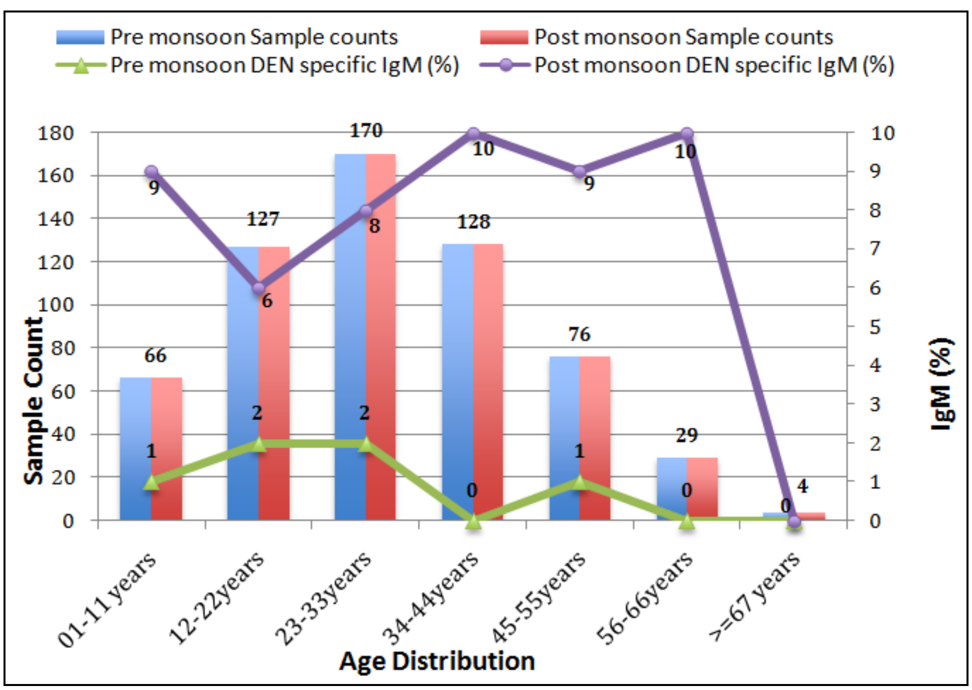


Figure 5.4: Dengue (DEN) specific IgM distribution during pre- and post-monsoon 2012 by age groups

Table 5.5a: Univariate association between seroconversion of dengue and selected individual variable in Dhaka, Bangladesh, Post-monsoon 2012

Variables	Seroconversion n (%)	Seroprevalence n (%)	OR (95% CI)	CI	p-value
Age, years, mean	31.4	21			<0.0001★
Age, years, (categorized)					
<=11 (children)	15 (15.8)	51 (10.1)	1		
12-77 years (adults)	80 (84.2)	454 (89.9)	0.6	(0.32-1.12)	0.104
Income in household					
0-14,9999	40 (42.1)	190 (37.6)	1		
15000-24,999	19 (20.0)	102 (20.2)	0.89	(0.49-1.61)	
>=25,000	36 (37.9)	213 (42.2)	0.8	(0.49-1.31)	0.68
Sex					
Male	37 (38.9)	206 (40.8)	1		
Female	(58 (61.1)	299 (59.2)	0.92	(0.59-1.45)	0.736
Education					
0	11 (11.6)	39 (7.7)	1		
1	31 (32.6)	159 (31.5)	0.69	(0.32-1.50)	
2	21 (22.1)	152 (30.1)	0.49	(0.22-1.10)	0.022★
3	19 (20.0)	51 (10.1)	1.32	(0.56-3.09)	
4	13 (13.7)	104 (20.6)	0.44	(0.18-1.07)	
Hours per week spent outside home due to occupation (mean hours)	14.31	10.67			0.1376
Occupation					
1	7 (8.0)	23 (5.0)	1		
2	7 (8.0)	50 (10.8)	0.46	(0.14-1.46)	
3	9 (10.2)	56 (12.1)	0.53	(0.18-1.58)	0.812
4	21 (23.9)	114 (24.7)	0.61	(0.23 -1.59)	
5	35 (39.7)	179 (38.7)	0.64	(0.26 -1.61)	
6	9 (20.2)	40 (8.66)	0.74	(0.24-2.25)	

★Significant variables at p=0.05 level

Table 5.5b: Univariate association between seroconversionof dengue and selected household and neighborhood variables in Dhaka, Bangladesh, Post-monsoon 2012

Variables	Seropositive n (%)	Seronegative n (%)	OR (95% CI)	CI	p-value
Number of stored water vessels inside household					
0	28 (29.5)	192 (38.0)	1		
1	12 (12.6)	61 (12.1)	1.35	(0.64-2.81)	
2	13 (13.7)	70 (12.9)	1.27	(0.63-2.59)	0.32
3	16 (16.8)	88 (17.4)	1.25	(0.64-2.42)	
≥4	26 (27.4)	94 (18.6)	1.9	(1.05-3.42)	
Number of uncovered water tank outside house					
1	57 (60.0)	277 (55.1)	1		
≥ 1	38 (40.0)	226 (44.9)	0.82	(0.52-1.28)	0.375
Number of indoor potted plants					
None	76 (80.0)	374 (74.1)	1		
≥1	19 (20.0)	131 (25.9)	0.71	(0.42-1.23)	0.22
Mosquito control measures					
Yes	84 (88.4)	414 (82.0)	1		
No	11 (11.6)	91 (18.0)	0.6	(0.31-1.16)	0.125
Public gathering place					
No appearance	28 (29.5)	143 (28.3)	1		
School	20 (21.0)	133 (26.3)	0.77	(0.41-1.43)	
Mosque/religious places	15 (15.8)	68 (13.5)	1.13	(0.57-2.25)	
Entertainment places	32 (33.7)	161 (31.9)	1.02	(0.58-1.77)	0.728
Types of mosquito control measures					
Bed net	32 (39.0)	140 (34.0)	1		
Mosquito coil	35 (42.7)	188 (45.6)	0.81	(0.48-1.38)	
Spray and others	15 (18.3)	84 (20.4)	0.78	(0.4-1.52)	0.677
Travel outside Dhaka within last 6 months					
Yes	63 (66.3)	305 (60.4)	1		
No	32 (33.7)	200 (39.6)	0.77	(0.49-1.23)	0.278

Variables	Seropositive n (%)	Seronegative n (%)	OR (95% CI)	CI	p-value
Any family member suffers from fever within last 6 months					
Yes	43 (45.3)	245 (48.5)	1		
No	52 (54.7)	260 (51.5)	1.14	(0.73-1.76)	0.561

★Significant variables at p=0.05 level

Table 5.6: Estimated odds ratios (OR) for the multilevel analysis of the association between seroincidence/seroconversion of dengue and selected variables

Variable	Estimate (st. error)	OR (95% CI)	p-value
Intercept	-0.57 (0.49)		0.25
Age (new categorization)			
0-11		1	
12-44	-0.84 (0.39)	0.43 (0.20-0.92)	
45 and over	-0.23 (0.42)	0.80 (0.35-1.83)	0.031★
Number of indoor potted plant			
One and more		1	
None	-0.64 (0.32)	0.53 (0.28-0.98)	0.043★

★Significant variables at p=0.05 level

5.4 Discussion

Dhaka, the 9th largest city in the world (The Document of the World Bank, 2010), has been a DEN-endemic region since 1964 when a laboratory test confirmed an outbreak of DEN-virus (Aziz et al., 1967). While dengue viruses were likely responsible for what was called *Dhaka fever* in 1964, sporadic cases and small outbreaks of dengue fever in Bangladesh went unreported until the major outbreaks 2000 (5,555 cases and 93 deaths), 2001 (2,430 cases and 44 deaths), and 2002 (6,104 cases and 58 deaths) (Khan et al., 2009). Very few reports have been published on the magnitude of virus circulation in Dhaka, and to my knowledge, no city wide serosurvey has yet been completed before this study. Considering these gaps, the objectives of the current chapter were to determine the seroprevalence of DEN virus-specific IgG among the Dhaka population, and the seroconversion of DEN during the peak season of 2012, through which the extent of transmission and related risk factors of DEN virus among population can be estimated.

This first population-based study of DENV infection among the population of the City of Dhaka, Bangladesh, revealed a high baseline DENV seropositivity rate (IgG positive results was 82%) over the monsoon season. These findings are indicative of the circulation of DENV in the city for a considerable period of time, with the occurrence of periodic DENV outbreaks during 2000-2012. With ELISA tests, cross-reactions with antibodies to other flaviviruses may occur. Although none of the participants were vaccinated against JEV or YF and not a single case of WNV has been reported so far in Bangladesh, we nonetheless confirmed my serology results with DENV PRNT with other two flaviviruses (i.e. JEV and WNV). In PRNTs, plaques generated by test sera at various dilutions confirmed the presence of virus-specific neutralizing antibodies present in the serum of sample individuals. The risk for JEV in Dhaka is very low; however, we did not eliminate it entirely as JEV was detected in Dhaka, Mymensingh, and Rajshahi in Bangladesh (Hossain et al., 2010). As a result, I found serological cross-reactivity during PRNT screening at 1:20 dilution. At the lowest dilution factor (i.e., 1:20) cross-reactivity can be found in flavivirus infections because antibodies elicited against conserved epitopes on the immunogenic envelope protein may cross-react with other flaviviral antigens, which can cause false-positive results. The PRNT results confirmed the absence of JEV antibodies. Hence, the seroprevalence in this study can be regarded as 'confirmed dengue infections'.

Because this is the first population-based DENV seroprevalence study in Bangladesh, I am unable to compare my findings with other seroprevalence data. A high rate of seropositivity comparable to my findings has been observed during outbreaks; for example, a serological study of dengue cases reported in hospitals in Delhi, India during 2004 outbreak revealed a seroprevalence rate of 87% (n=141).

The IgM-capture ELISA is a suitable tool for identifying recent dengue infections (Kuno et al., 1995) and the test used here has shown high specificity and sensitivity ((specificity: 97% (95% CI: 94.1%-98.4%) and sensitivity: 96% (95% CI: 89.9%-99.9%)) by Dengue Virus IgM Capture Dx Select™ kit). The serosurvey to estimate the rate of DENV seroconversion was conducted during the post-monsoon period and revealed a sizable seroconversion (15.8 persons/100 person-season at risk or 15.8 X 600/100=94.8 person-season). The conversion rate of DENV infection during the follow-up in Dhaka was higher than that recently estimated for regions with stable transmission in South East Asia, such as Southern Vietnam (11.7 cases/100 person-years), Northern Thailand (8.5 cases/100 person-years); and the Americas, such as Nicaragua (6.0-12.0 cases/100 person-years), and Brazilian

Amazonia (3.67 cases/100 person-years) (Thai et al., 2007; Endy et al., 2002; Morrison et al., 2010). Since in Bangladesh the peak dengue season occurs in July and August, it is more likely that the reported seroconversions in the findings are correlated with the 2012 monsoon season.

This study reaffirmed classic linear association between age and increasing IgG antibody prevalence in Dhaka, which is characterized by an endemic flavivirus transmission. The pattern of prevalence of dengue infection with increased age is indicative of cumulative DENV exposure in Dhaka, and similar to the findings of comparable studies in central Brazil (Siquieira et al., 2004). Research findings of seroprevalence among children in both Asian and Latin American cities have revealed similarly strong associations between seropositivity and the age of children (Yamashiro et al., 2004). For example, in Bangkok (Thailand) 53% of the children were found to have DENV antibodies by the age of 9 (Burke et al., 1988). In the case of Santo Domingo (Dominican Republic) Yamashiro et al. (2004) observed an increase of the prevalence of DENV-specific IgG with age except in children under one year. Children in Dhaka may also be more vulnerable to dengue infection due to vertical transmission of the disease (Fatimil et al., 2003) as well as their exposure to infected mosquitoes as they spend most of their times outdoors (e.g. playground) or in crowded places (e.g. schools, parks, recreational areas etc.). The relative vulnerability of children compared to adults is still a subject of considerable debate (Miagostovich et al., 1993; Cunha et al., 1999; Vasconscelos et al., 1998).

Men and women in Dhaka are similarly exposed viral infection, as in other regions of the world (Siqueira et al., 2004; Teixeira et al., 2009; van Benthem, 2005). This trend more likely reflects gender-based human behavioral patterns rather than mosquito biting behavior does not play any significant role in enhancing gender-differentiated risk. Population-based studies in various parts of the tropical world have generally found no significant association between sex and seropositivity (Braga et al., 2010; Rahman et al., 2007), while most hospital-based studies have found significant male-female differences in infection rates and severity of dengue disease (Wali et al., 1999; Ray et al., 1999; Sekhar and Huat, 1992; Rasul et al., 2002). For example, the Bangladesh Ministry of Health recorded a hospital patient DF/DHF male-to-female ratio of 1.5:1 during an outbreak in the City of Chittagong, Bangladesh, reflecting male predominance in hospitalization as well as social bias toward male members in family dynamics.

While in Brazilian epidemics attack rates were found to be higher in females (Cunha et al., 1999; Vasconscelos et al., 1999) in Puerto Rico, Waterman et al. (1985) registered no significant sex differences during dengue epidemics. Nonetheless, a population-based investigation comparing DENV infection rates according to sex in Mexico recorded increased risk for women (Kaplan et al., 1980). It nonetheless remains inconclusive whether there is an association between sex and DENV infection rate and disease severity; therefore, further research in this area should be pursued.

In Dhaka, the socioeconomic background of individual citizens, reflected in their educational attainment and income status, has not been found to be a significant risk factor for susceptibility to dengue. This finding conforms to the results of a Brazilian study by Vasconcelos et al. (1998). However, in this study, it has been registered that although an individual's only socioeconomic status per se may not be an important independent risk factor, poverty at a larger scale (such as local community level) and a low socio-economic status of a zone or region have been found to be important risk factors (Brunkard et al., 2007;

Guha-Sapir and Schimmer 2005). In a comparative study between Texas, USA and Matamoros, Mexico, Brunkard et al. (2007) inferred that poverty is a proxy indicator for numerous risk factors. They reported that the protective effect of air conditioning in the more developed, well-off areas was profound in risk exposure. In Taiwan, Ko (1989) recorded that patients who resided near markets and/or open sewage or ditches had a risk of contracting infectious diseases 1.8 times higher than those who did not. Further multi-scale investigations encompassing both individual and aggregate/neighborhood level socioeconomic status as risk factors will fill in this gap in the understanding.

Of the household-level risk factors evaluated in this research, the number of indoor potted plants was the only variable found to be significantly associated with seroprevalence, confirming that individuals who not only lived in the household but also remained in close proximity of *Aedes aegypti* foci are most at risk of becoming infected. There have been nominal studies on household level risk factors worldwide; however, findings of a few significant studies are noteworthy here to compare my results. Teixeira et al. 2009 examined the association of premise index (PI) - indicating the proportion of household in which recipients with immature forms of *Aedes aegypti* were found to be positively correlated with the total number of households inspected - with the incidence of DENV infection. In a study in southern Vietnam, Thai et al. (2005) found a positive association between some peri-domestic risk factors including discarded cans and pit latrines and a high prevalence of dengue antibodies. They further explained that uncovered water containers used for flushing pit latrines might be the actual source of larval production, rather than the latrines themselves.

In the case of Bangladesh, keeping potted ornamental plants indoors has become the norm in recent years. This trend has become more prevalent among the middle and upper middle socio-economic classes, which was reflected in the high proportion of dengue cases among this demographic during the 2000 epidemic (Rahman et al., 2002).

Results of follow-up study suggest that overall, 15.8% of baseline population were seroconverted during the course of the study in 2012. Although serotype identification was beyond the scope of the present research, the current DENV infection could be caused by any of four known dengue virus serotypes. Based on existing literature on Bangladesh collected after 2000 epidemic, it is reasonable to assume that most dengue cases are caused by DENV-3 (Rahman et al., 2002; Podder et al., 2006; Islam et al., 2006), with co-circulation of DENV-2 and DENV-4 (Aziz et al., 2002); however, there is no reliable data to back up this assumption. These findings are consistent with observations in several other countries where seroprevalence is very high. In Kamphaeng Phet, Thailand, Endy et al. (2002) observed transmission of all four DENV serotypes over a period of three years among school children, but with marked spatial and temporal variation. A study in Nicaragua, Mexico by Balmasada et al. (2005) recorded a similar rate where only two serotypes were in circulation and seroprevalence rates for existing serotypes were very high.

Among the demographic risk factors considered in this study, one ascribed characteristic, namely age, was found to be associated with the seroconversion of the population. Significant differences have been found between the new infection rates of children and adults in Dhaka. Similarly, statistically significant variation has been observed between females and males in terms of seroincidence. Several recent studies on seroincidence in Asia and Latin America have revealed a strong association between an increase in the dengue seroconversion rate and the commencement of formal schooling. In this regard, Ooi et al. (2001) observed in Singapore that between ages 0-6 years children spend most of their time at home, in nursery, or in kindergarten. The duration of these pre-school sessions is only a few hours per day. Formal half-day schooling begins at the age of 6 years. Amplification of seroconversion rate among the school children during epidemics has been reported in a number of countries, namely Peru (Morrison et al., 2010), the Dominican Republic (Yamashiro et al., 2004), Brazil (Teixeira et al., 2009), and Thailand (Burke et al., 1988). The age risk factor for seroconversion in the context of Dhaka city can be partially attributed to greater amount of time spent by children in communal settings (schools and post-school settings). In Dhaka, the density of child population (age group: 3-18 years) is directly associated with attendance of play schools, playgrounds, and post-school nurseries. The concentration of children in and outside of class takes place during the day, starting from early in the morning till late afternoon. It is likely that their propensity to expose themselves to *Ae. aegypti* mosquitoes is much higher during such time periods.

Association of domestic and peri-domestic risk factors with seroincidence has not yet been sufficiently investigated; however, a few studies have underscored its significance, highlighting the role of population behavior and socio-economic context. This study not only confirmed a statistically significant relationship between indoor household flower pots and seroprevalence, but also validated significant and strong association between flower pots and seroincidence. Similar to the Salvador study in Brazil (Teixeira et al., 2009) which observed strong association between premise index- a peridomestic factor - and incidence of DENV infection, I infer that even persons who do not reside in household in which foci of *Ae. aegypti* through flower pot larval development sites are found could be at increase risk of becoming infected.

Individual risk factors associated with intrinsic factors (such as age and ethnicity) and the process of dengue transmission are complex phenomena whereby the any of the four antigenically related viruses (DENV 1-4) is transmitted to individual humans by *Aedes* mosquito bites that are influenced by demographic, socioeconomic and ecological factors. One the one hand, these factors at multiple scales (including population growth, internal and international migration, rapid urbanization and unplanned sprawl of cities, substandard housing, inadequate water supply) that enhance the contact between vector and host facilitate an increase in dengue transmission (Guzman and Kouri, 2002). On the other hand, as the pathogenesis of all infectious diseases is the outcome of host and microbial factors (Halstead, 2008), extrinsic factors (e.g. immune status), and intrinsic factors (e.g. age, sex, innate immunity, individual or species-level genetics) associated with the host further complicates dengue disease incidence and its severity. Some DENV have the potential to cause DHF (Rico-Hasse, 2007); however, host factors such as, age (children are higher risk than adults for primary infection), ethnicity, chronic diseases, nutritional status, the individual's genetic composition, are also of importance (Sierra et al., 2007; Halstead, 2007; Bravo et al., 1987). Nonetheless, secondary infection is regarded as the main risk factor in dengue disease severity. Guzman and Vanquez (2010) argue that more research is required to elucidate Antibody-Dependent Enhancement (ADE)'s molecular mechanisms, specifically factors affecting the final outcome of the interaction among the virus, antibody and permissive cells.

5.5 Limitations

In our blood sample size, we targeted a total of 1,200 people from 12 Wards, and succeeded in collecting a total of 1,125 blood samples during the first serological survey during the premonsoon season of 2012. Due to a very high rate change in residence among Dhaka city dwellers, we collected only 600 paired sera samples during the post-monsoon survey, causing us to limit the sample size to only 50% of the initial target. A larger sample size of future study will provide a higher degree of confidence in making serological inferences. In order to confirm the presence of DENV and not other fluviviruses, I performed PRNT of 100 randomly selected samples from the 2012 pre-monsoon survey and 50 randomly selected samples from the 2012 post-monsoon serum survey. Considering the scope of this study, such samples size was thought to be adequate. With more resources and time, PRNT of a larger sample size of serum would allow achieving a higher level of confidence in statistical inferences.

References

Aziz, M. A., Gorham, J. R.,Gregg, M. B. (1967). "Dhaka fever"-an outbreak of dengue. *Pakistan Medical Journal of Research, 6*, 83-92.

Aziz, M., Hasan, K., Hasanat, M., Siddiqui, M., Salimullah, M., Chowdhury, A., . . . Hassan, M. (2002). Predominance of the DEN-3 genotype during the recent dengue outbreak in Bangladesh.

Balmaseda, A., Hammond, S. N., Perez, M. A., Cuadra, R., Solano, S., Rocha, J., . . . Harris, E. (2005). Short report: assessment of the World Health Organization scheme for classification of dengue severity in Nicaragua. *The American Journal of Tropical Medicine and Hygiene, 73*(6), 1059-1062.

Banu, S., Hu, W., Hurst, C., Guo, Y., Islam, M. Z., & Tong, S. (2012). Space time clusters of dengue fever in Bangladesh. *Tropical Medicine & International Health, 17*(9), 1086-1091.

Banu, S., Hu, W., Hurst, C., & Tong, S. (2011). Dengue transmission in the Asia-Pacific region: impact of climate change and socio-environmental factors. *Tropical Medicine & International Health, 16*(5), 598-607.

Braga, C., Luna, C. F., Martelli, C. M., Souza, W. V. d., Cordeiro, M. T., Alexander, N., . . . Marques, E. T. (2010). Seroprevalence and risk factors for dengue infection in socio-economically distinct areas of Recife, Brazil. *Acta Tropica, 113*(3), 234-240.

Bravo, J. R., Guzman, M. G., & Kouri, G. P. (1987). Why dengue haemorrhagic fever in Cuba? 1. Individual risk factors for dengue haemorrhagic fever/dengue shock syndrome (DHF/DSS). *Transactions of the Royal Society of Tropical Medicine and Hygiene, 81*(5), 816-820.

Brunkard, J. M., López, J. L. R., Ramirez, J., Cifuentes, E., Rothenberg, S. J., Hunsperger, E. A., . . . Haddad, B. M. (2007). Dengue fever seroprevalence and risk factors, Texas–Mexico border, 2004. *Emerging Infectious Diseases, 13*(10), 1477.

Burke, D. S., Nisalak, A., Johnson, D. E., & Scott, R. M. (1988). A prospective study of dengue infections in Bangkok. *The American Journal of Tropical Medicine and Hygiene, 38*(1), 172-180.

Cobelens, F. G. J., Groen, J., Osterhaus, A. D. M. E., Leentvaar-Kuipers, A., Wertheim-van Dillen, P. M. E., & Kager, P. A. (2002). Incidence and risk factors of probable dengue virus infection among Dutch travellers to Asia. *Tropical Medicine and International Health*, *7*(4), 331-338.

Cunha, R. V., Schatzmayr, H. G., Miagostovich, M. P., Barbosa, A. M., Paiva, F. G., Miranda, R. M., . . . Nogueira, R. M. (1999). Dengue epidemic in the State of Rio Grande do Norte, Brazil, in 1997. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 93*(3), 247-249.

Endy, T. P., Chunsuttiwat, S., Nisalak, A., Libraty, D. H., Green, S., Rothman, A. L., . . . Ennis, F. A. (2002). Epidemiology of inapparent and symptomatic acute dengue virus infection: a prospective study of primary school children in Kamphaeng Phet, Thailand. *American Journal of Epidemiology, 156*(1), 40-51.

Fatimil, L. E., Mollah, A. H., Ahmed, S., & Rahman, M. (2003). Vertical transmission of dengue: first case report from Bangladesh. *Southeast Asian J Trop Med Public Health* 34(4): 800-3.

Gubler, D. J. (2002). Epidemic dengue/dengue hemorrhagic fever as a public health, social and economic problem in the 21st century. *Trends in Microbiology, 10*(2), 100-103.

Gubler, D. J. (2004). The changing epidemiology of yellow fever and dengue, 1900 to 2003: full circle? *Comparative Immunology, Microbiology and Infectious Diseases, 27*(5), 319-330.

Guha-Sapir, D., & Schimmer, B. (2005). Dengue fever: new paradigms for a changing epidemiology. *Emerg Themes Epidemiol, 2*(1), 1-10.

Guzmán, M. G., & Kouri, G. (2002). Dengue: an update. *The Lancet Infectious Diseases, 2*(1), 33-42.

Guzman, M. G., & Vazquez, S. (2010). The complexity of antibody-dependent enhancement of dengue virus infection. *Viruses*, *2*(12), 2649-2662.

Halstead, S. B. (2007). Dengue. *The Lancet, 370*(9599), 1644-1652.

Halstead, S. B. (2008). Dengue virus-mosquito interactions. *Annu.Rev.Entomol., 53,* 273-291.

Hayes, J. M., Garcia-Rivera, E., Flores-Reyna, R., Suarez-Rangel, G., Rodriguez-Mata, T., Coto-Portillo, R., . . . Jubis-Estrada, J. (2003). Risk factors for infection during a severe dengue outbreak in El Salvador in 2000. *American Journal of Tropical Medicine and Hygiene, 69*(6), 629.

Hayes, J. M., Rigau-Pérez, J. G., Reiter, P., Effler, P. V., Pang, L., Vorndam, V., . . . Gubler, D. J. (2006). Risk factors for infection during a dengue-1 outbreak in Maui, Hawaii, 2001. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 100*(6), 559-566.

Heukelbach, J., Sales De Oliveira, F. A., Kerr-Pontes, L. R. S., & Feldmeier, H. (2001). Risk factors associated with an outbreak of dengue fever in a favela in Fortaleza, north-east Brazil. *Tropical Medicine and International Health, 6*(8), 635-642.

Hossain, M. J., Gurley, E. S., Montgomery, S., Petersen, L., Sejvar, J., Fischer, M., . . . Breiman, R. F. (2010). Hospital-based surveillance for Japanese encephalitis at four sites in Bangladesh, 2003-2005. *The American Journal of Tropical Medicine and Hygiene, 82*(2), 344-349.

Islam, M. A., Ahmed, M. U., Begum, N., Chowdhury, N. A., Khan, A. H., Parquet, M. d. C., . . . Suzuki, Y. (2006). Molecular characterization and clinical evaluation of dengue outbreak in 2002 in Bangladesh. *Japanese Journal of Infectious Diseases, 59*(2), 85-91.

Kaplan, J. E., Eliason, D. A., Moore, M. et al. (1983). Epidemiological investigations of dengue infection in Mexico, 1980. *American Journal of Epidemiology, 117*(3), 335-343.

Karim, M. N., Munshi, S. U., Anwar, N., & Alam, M. S. (2012). Climatic factors influencing dengue cases in Dhaka city: a model for dengue prediction. *The Indian Journal of Medical Research, 136*(1), 32.

Khan, E., & Hasan, R. (2011). Dengue infection in Asia; a regional concern. *Journal of Postgraduate Medical Institute (Peshawar-Pakistan), 26*(1)

Ko, Y. (1989). Epidemiology of dengue fever in Taiwan. *The Kaohsiung Journal of Medical Sciences, 5*(1), 1-11.

Kuno, G. (1995). Review of the factors modulating dengue transmission. *Epidemiologic Reviews, 17*(2), 321-335.

Miagostovich, M., Dos Santos, F., De Simone, T., Costa, E., Filippis, A., Schatzmayr, H., & Nogueira, R. (2002). Genetic characterization of dengue virus type 3 isolates in the State of Rio de Janeiro, 2001. *Brazilian Journal of Medical and Biological Research, 35*(8), 869-872.

Mondini, A., & Chiaravalloti-Neto, F. (2008). Spatial correlation of incidence of dengue with socioeconomic, demographic and environmental variables in a Brazilian city. *Science of the Total Environment, 393*(2), 241-248.

Morrison, A. C., Minnick, S. L., Rocha, C., Forshey, B. M., Stoddard, S. T., Getis, A., . . . Blair, P. J. (2010). Epidemiology of dengue virus in Iquitos, Peru 1999 to 2005: interepidemic and epidemic patterns of transmission. *PLoS Neglected Tropical Diseases, 4*(5), e670.

Ooi, E., Goh, K., & Gubler, D. J. (2006). Dengue prevention and 35 years of vector control in Singapore. *Emerging Infectious Diseases, 12*(6), 887-93.

Pervin, M., Tabassum, S., Ali, M., & Mammon, S. (2004). Clinical and laboratory observations associated with the 2000 dengue outbreak in Dhaka, Bangladesh. *Dengue Bull, 28,* 96-106.

Poddar G, Breiman R F, Azim T,Thu H M et al. (2006). Short Report: Origin of dengue type 3 viruses associated with the dengue outbreak in Dhaka, Bangladesh, in 2000 and 2001. *American Journal of Tropical Medicine and Hygiene, 74*(2), 263-265.

Rahman, M., Rahman, K., Siddque, A., Shoma, S., Kamal, A., Ali, K., . . . Breiman, R. F. (2002). First outbreak of dengue hemorrhagic fever, Bangladesh. *Emerging Infectious Diseases, 8*(7), 738-740.

Rahman, M. T., Tahmin, H. A., Mannan, T., & Sultana, R. (2002). Seropositivity and pattern of dengue infection in Dhaka city. *Mymensingh Medical Journal : MMJ, 16*(2), 204-208.

Rasul, C., Ahasan, H., Rasid, A., Khan, M., Lahiri, S., Shahab, T., . . . Dhulia, A. (2002). Epidemiological factors of dengue hemorrhagic fever in Bangladesh. *Indian Pediatrics, 39*(4), 369-372.

Ratnam, I., Black, J., Leder, K., Biggs, B., Matchett, E., Padiglione, A., . . . Pollissard, L. (2012). Incidence and seroprevalence of dengue virus infections in Australian travellers to Asia. *European Journal of Clinical Microbiology & Infectious Diseases, 31*(6), 1203-1210.

Ray, G., Kumar, V., Kapoor, A. K., Dutta, A. K., Batra, S., Caterino-de-Araujo, A., . . . Tio, P. H. (1999). Status of antioxidants and other biochemical abnormalities in children with dengue fever. *Journal of Tropical Pediatrics., 45*(1), 4-7.

Reiter, P., Lathrop, S., Bunning, M., Biggerstaff, B., Singer, D., Tiwari, T., . . . Hayes, J. (2003). Texas lifestyle limits transmission of dengue virus. *Emerging Infectious Diseases, 9*(1), 86.

Rico-Hesse, R. (2007). Dengue virus evolution and virulence models. *Clinical Infectious Diseases : An Official Publication of the Infectious Diseases Society of America, 44*(11), 1462-1466. doi:10.1086/517587

Shekhar, K. C., & Huat, O. L. (1992). Epidemiology of dengue/dengue hemorrhagic fever in Malaysia--a retrospective epidemiological study 1973-1987. Part I: Dengue hemorrhagic fever (DHF). *Asia-Pacific Journal of Public Health / Asia-Pacific Academic Consortium for Public Health, 6*(2), 15-25.

Sierra, B de la C, Kouri, G., & Guzman, M. (2007). Race: a risk factor for dengue hemorrhagic fever. *Archives of Virology, 152*(3), 533-542.

Siqueira, J. B., Martelli, C. M. T., Maciel, I. J., Oliveira, R. M., Ribeiro, M. G., Amorim, F. P., . . . Andrade, A. L. S. S. (2004). Household survey of dengue infection in central Brazil: Spatial point pattern analysis and risk factors assessment. *American Journal of Tropical Medicine and Hygiene, 71*(5), 646-651.

Teixeira, M. G., Costa, M. C. N., Coelho, G., & Barreto, M. L. (2008). Recent shift in age pattern of dengue hemorrhagic fever, Brazil. *Emerging Infectious Diseases, 14*(10), 1663.

Teixeira, M. G., Costa, Maria da Conceição N, Barreto, F., & Barreto, M. L. (2009). Dengue: twenty-five years since reemergence in Brazil. *Cadernos De Saúde Pública, 25*, S7-S18.

Thai, K. T., Binh, T. Q., Giao, P. T., Phuong, H. L., Hung, L. Q., Nam, N. V., . . . Vries, P. J. (2005). Seroprevalence of dengue antibodies, annual incidence and risk factors among children in southern Vietnam. *Tropical Medicine & International Health, 10*(4), 379-386.

Van Benthem, B., HB, Vanwambeke, S. O., Khantikul, N., Burghoorn-Maas, C., Panart, K., Oskam, L., . . . Somboon, P. (2005). Spatial patterns of and risk factors for seropositivity for dengue infection. *The American Journal of Tropical Medicine and Hygiene, 72*(2), 201-208.

Vasconcelos, P. F., Lima, J. W. O., Travassos da Rosa, P., Timbó, M. J., Travassos da Rosa, E., Lima, H. R., . . . Travassos da Rosa, J. (1998). Epidemia de dengue em Fortaleza, Ceará: inquérito soro-epidemiológico aleatório. *Rev Saúde Pública, 32*(5), 447-454.

Vasconcelos, Pedro Fernando da C, Lima, J. W., Raposo, M. L., Rodrigues, S. G., Travassos da Rosa, J., Amorim, S. M., . . . Travassos da Rosa, A. (1999). Inquérito soro-epidemiológico na Ilha de São Luís durante epidemia de dengue no Maranhão. *Rev Soc Bras Med Trop, 32*(2), 171-179.

Wali, J., Biswas, A., Handa, R., Aggarwal, P., Wig, N., & Dwivedi, S. (1999). Dengue haemorrhagic fever in adults: a prospective study of 110 cases. *Tropical Doctor, 29*(1), 27-30.

Waterman S H, Novac R J,Sather G E et al. (1986). Dengue transmission in two Puerto Rican communities in 1982. *American Journal of Tropical MEdicine and Hygiene, 34*, 625-632.

World Bank. (2010). *Country Assistance Strategy for the People's Republic of Bangladesh.* (No. 4).

World Health Organization.Dengue guidelines for diagnosis, treatment, prevention and control. 2009. WHO/HTM/NTD/DEN/2009.1. Available: http://whqlibdoc.who.int/publications/2009/9789241547871_eng.pdf. Accessed 2010 May 17.

World Health Organization. (2012). *Dengue and dengue severe.* (Fact sheet no 117).

Yamashiro, T., Disla, M., Petit, A., Taveras, D., Castro-Bello, M., Lora-Orste, M. et al. (2004). Seroprevalence of IgG specific for dengue virus among adults and children in Santo Domingo, Dominican Republic. *American Journal of Tropical Medicine and Hygiene*, *71*(2), 138-143.

Yew, Y. W., Ye, T., Ang, L. W., Ng, L. C., Yap, G., James, L., . . . Goh, K. T. (2009). Seroepidemiology of dengue virus infection among adults in Singapore. *Ann Acad Med Singapore, 38*(8), 667-675.

Yunus, E. B., Bangali, A. M., Mahmood, M. A. H., Rahman, M. M., Chowdhury, A., & Talukder, K. (2001). Dengue outbreak 2000 in Bangladesh: from speculation to reality and exercises. *Dengue Bulletin, 25*, 15-20.

CHAPTER SIX

SPATIAL EVALUATION OF DENGUE VECTOR ABUNDANCE AND ITS ASSOCIATION WITH SEROCONVERSION

Abstract

In this Chapter, I evaluate the role of multi-scale ecological factors in the spatial distribution of vector abundance and exposure to DENV using seropositivity and seroconversion, in order to determine the degree of association among these critical vector-pathogen-host variables. The studied area (12 Wards of the City of Dhaka) was analyzed by applying landuse and landcover data for the 2012-13 period to classify the city into broader "integrated urban ecological" (IUE) zones and determine their association with the spatial distribution of vector abundance and dengue seroconversion. A test of homogeneity among the IUE zones, based on landcover/landuse, was performed using the chi-square test of significance. Logistic regression was carried out to delineate spatial patterns in risk factors for seropositivity. Further, a binary logistic regression was carried out to assess the association between dengue seropositivity among the population in a household and the microhabitat and individual (human) scale explanatory variables. The results revealed that there was significant difference among the IUE zones in terms of proportion of pupae (the number of pupae/person) and the total number of pupae collected from these zones. When the association between seroconverted individuals and the presence of *Ae. aegypti* pupae was examined, it appeared that there was no significant statistical association between them. Only the appearance by any member of the household in public gathering places is significantly associated with dengue seroconversion. Household members who appear in public gathering places were also 8.69 (p-value: 0.033; 95% CI: 1.08-5.94) times more likely to experience seroconversion than the members who did not.

6.1 Background

A great deal of literature is available on the factors driving dengue vector abundance and seroconversion among a population function at multiple scales within nested hierarchical systems (Honorio et al., 2009; Scott and Morrison, 2010). In my research, I generalized and categorized the scales of these factors into two broad categories: i) landscape, landuse and land cover (i.e. macroenvironment) factors, which refer to sum total perspectives of elements of social-ecological systems on a scale ranging from ecotope to urban landscapes (Vanwambeke et al., 2006); and ii) microhabitat and individual (human) scale variables, which include elements within immediate surroundings of human and mosquito habitat as well as state of conditions and actions of human individuals. The analysis and organization of this chapter follows these two categorical frameworks.

6.1.1 Landscape, landuse and land cover factors affecting *Aedes* habitat

Patterns of dengue transmission are influenced in part by the abundance, lifespan, and behavior of the principal mosquito vector, *Aedes aegypti*; the level of immunity to the circulating virus serotype in the local human population; density and movement of humans; and the extrinsic incubation period (EIP) of DENV in *Ae. aegypti* (Halstead, 1990). The relative influence of these factors on the dynamics of virus transmission is poorly understood, as are the spatial distribution patterns and density of DENV vectors (Getis et al., 2010). Existing analysis of spatial patterns of *Ae. aegypti* distribution in relation to environmental variables is typically limited to vector distribution and habitat preferences (Kitron, 1998).

Sparse vegetation, low altitude, shades and diffused sunlight, good transportation routes, and uncontrolled urban development create conditions ideal for the spread of *Ae.*

aegypti (Van Benthem et al., 2005). Studies on associations between *Ae. aegypti* distribution patterns with environmental variables, at the city scale may help us understand the relationship between vector abundance and dengue transmission at the local landscape scale (Vanwambeke et al., 2007). Arguably, cities are the most "human dominated of all ecosystems" (Vitousek et al., 1997) and therefore, spatial interactions between anthropogenic and natural entities in the landscape may help explain DENV exposure patterns. Cities are subjected to a strong human influence, and management decisions have profound impacts on ecosystem function. One of the central tenets in landscape ecology is that processes can be inferred from geographical patterns, but such associations may not be so straightforward in urban landscapes where human activities both transcend habitat boundaries and differ across them. Instead, urban landscapes may be conceived of as composites of many different types of influence, all expressed on a single surface plane (Anderson, 2006). Anthropogenic landuse and their changes drive a range of infectious disease outbreaks and emergence events and alter the transmission of endemic infections (Patz et al., 2004) by favoring organisms which adapt better to new conditions and are thus more capable of rapid colonization. To understand the specific interactions between humans and ecological processes which occur in urbanizing regions, it is important to regard cities as emergent phenomena—phenomena that cannot be understood by reductively studying the properties of their individual components (Alberti et al., 2003). Landscape attributes can have an important effect, for example, on West Nile Virus disease dynamics and ecology by influencing host and vector presence, behaviour, and interactions. As well, urban landscape characteristics influence the epidemiology of dengue by affecting the availability and accessibility of humans to vectors (Cox et al., 2007).

To predict and prevent potential outbreaks of vector-borne diseases, scientists and public health organizations have attempted to apply landcover/landuse-vector relationships in order to develop place-based models of vector abundance and risk of exposure to DENV (Vanwambeke et al., 2011; Anderson 2006; Patz et al., 2004). Kolivras (2006) points out that the spatial epidemiology approach has provided numerous place-based models for malaria vectors but fewer place-based models have been formulated for other important vector-borne infections such as dengue. Also, while climate, landuse and mosquito abundance relationships are well-documented globally, nominal research has yet to be carried out in Bangladesh to investigate association between landuse and landcover variables and then possible influence on distribution and abundance of *Ae. aegypti* mosquitoes.

6.1.2 Influences of microenvironment on spatial distribution of *Aedes aegypti*

The significance of studying urban mosquito microhabitats is linked in the fact that *Ae. aegypti* is an anthropophilic species that thrives in human-modified landscapes (Hayden et al., 2010). Studying indoor and outdoor urban environments in endemic mosquito regions can provide important clues for understanding the specific factors that drive *Ae. aegypti* abundance and distribution.

As *Ae. aegypti* depends almost exclusively on human blood and tends to bite and rest indoors, Juliano and Lounibos (2005) determined that *Ae. aegypti* abundance in urban environments is closely associated with human population density. Vanwambeke et al. (2006) cited that “factors at the contextual and environmental level in which the individual is embedded (i.e. household factors) can be significant determinants” of DENV infection (p.3). In the rapidly-growing cities of developing countries, such as Dhaka in Bangladesh, such public gathering settings vary throughout the day. During the daylight hours, children and young adults gatherin schools, colleges, and various transportation nodes. The adult workforce, most of whom commute to the workplace, concentrate in bus and railway stations, offices and market places. In the evening, commercial shopping areas attract urban consumers. Crowded conditions, population movement, and lack of infrastructure - particularly inadequate piped water and solid waste disposal systems - were identified as major factors driving dengue vector abundance and dengue transmission (Gubler, 2002; Morrison et al., 2008). Investigating the geographical and ecological contexts of urban households and the role of associated microenvironments in *Ae. aegypti* abundance is therefore essential to understanding the large-scale epidemiological dynamics of urban landscapes.

6.1.3 Relationship between spatial distribution of dengue vector and seroconversion

An analysis of the spatial dynamics of *Ae. aegypti* populations and how environmental factors affect their abundance and distribution can help prevent dengue outbreaks determining the most effective periods for controlling mosquito populations (Landau & van Leeuwan, 2012). Nonetheless, risk factors for dengue infection and transmission are complex and tend to be highly spatially heterogeneous, largely affected by heterogeneous spatial distribution of transmission system components: vector, pathogens and hosts (Vanwambeke et al., 2011). In the urban environmental context, vectors and hosts depend on spatially diverse landuse/landcover conditions. Several recent studies have confirmed that different landuse patterns can alter contact patterns between susceptible humans and infectious vectors (Vanwambeke et al. 2007) as well as modify the distribution of human cases (Norris, 2004;

Vanwambeke et al., 2006). Heterogeneity in the risk of DENV transmission is produced by spatial heterogeneity in both urban landuse and landcover on the one hand, and dynamic vector-pathogen-host interfaces at various urban locations on the other. Vanwambeke et al. (2011) therefore argue that determining and understanding sources of spatial heterogeneity can facilitate dengue disease prevention and control.

Risk factors for exposure to DENV (measured as seropositivity and seroconversion) may vary by site, reflecting the variation in local infection and transmission patterns. Urban settings furnish a wide variety of suitable habitats for *Ae. aegypti*, and availability of larval development sites is often not a limiting factor for dengue infection (van Benthem et al. 2005). Rather, infection and subsequent transmission are more likely to be associated with housing quality and deployment of preventive measures (van Benthem et al., 2002). According to Halstead (1990), observed patterns of dengue transmission are associated specifically with four factors: i) the abundance, survival, and behavior of *Ae. aegypti*; ii) the level of immunity to the circulating virus serotype among the local people; iii) density, distribution and movement of people; and iv) the virus' incubation period within *Ae. aegypti*. However, the relative influence of these factors on dynamics of virus transmission is not well understood, both temporally and spatially. After investigating the spatial distribution of dengue vectors in Iquitos, Peru, Getis et al. (2010) called for further such research on *Ae. aegypti* and measures of DENV exposure including seropositivity and seroconversion (Halstead et al., 1969; Waterman et al., 1985). Honorio et al. (2009) noted that despite the theoretical relationship between vector abundance and infection risk, the precise nature of this relationship is not well understood (also see Thammapalo et al., 2008). Several scholars (e.g., Cunha et al., 1997; Teixeira et al., 2009; Morrison et al., 2008; Coelho et al., 2008) have therefore suggested the need for further research to integrate the epidemiological and entomological data regarding dengue. Such research has been severely lacking in Bangladesh. Among the few investigations already conducted on dengue infection in the country's urban contexts, only Ali et al.'s (2003) attempt to analyze spatial dimensions of vector distribution (mainly *Ae. albopictus*) and human dengue cases as reported by the Dhaka City dwellers themselves, is noteworthy.

In this chapter, I intend to examine the association between geographic distribution of *Ae. aegypti* mosquitoes and dengue infections in humans using spatial analytical tools, including mapping and remotely sensed data. In Chapters 4 and 5, I emphasized the socioeconomic risk factors among various urban zones in order to comparing large-scale spatial units (low, medium and high SES zones). The key landscape-related factors affecting the spatial distribution of dengue vectors and human cases were not addressed. In this Chapter, I therefore intend to evaluate the role of multi-scale ecological factors in the spatial distribution of vector abundance and exposure to DENV, using seropositivity and seroconversion, and to determine the degree of association among these critical vector-pathogen-host variables.

6.1.4 Landuse/land cover classification and characterization of Dhaka urban landscape patterns

The study area (12 Wards of the City of Dhaka) was analyzed by applying landuse and land cover data for the 2012-13 period to classify into broader "integrated urban ecological" zones (Pickett et al., 2001; 2008) and to determine associations between these zones and the spatial distribution of vector abundance and dengue seroconversion. I used remotely-sensed data acquired by RapidEye satellite sensor (launched from the DNEPR-1 Rocket on August 29, 2008) on 15th January 2013. As the RapidEye captures images with high spatial resolution of 5 meters with its multispectral sensor (440-850 nm band spectral resolution) and has frequent revisit intervals, it was possible to consider smaller objects of interest. Another merit of using RapidEye images is that all five satellites are equipped with identical sensors, enabling them to precisely discriminate between different topographical features. In addition, BlackBridge satellite can measure the Red-Edge band, which is sensitive to changes in chlorophyll content (Kim & Yeom, 2014).

Areas were selected in all 12 study wards for supervised classification, with 6 being collected for training and 4 for testing within each class. To remove class, a spectral majority filter was performed twice following the classification. A maximum-likelihood classification using Fisher liner classifier was then performed (Fukunaga, 1990). In the next step, landuse data (i.e. residential, commercial, industrial, and paved areas) from ancillary sources (*Rajdhani Unnayan Katripokhkho* [RAJUK], Dhaka City Corporation [DCC]) and land cover data (i.e., coarse vegetation, water bodies, bare soil) were merged and the associated map converted into vector format. The final integrated landuse and land cover map thus included seven classes: residential, commercial, industrial, paved areas, bare soil, water bodies and coarse vegetation. Ancillary data for built-up areas in the city were procured from Dhaka City Corporation surveys and used in the image processing, as this data are not available from RapidEye images. Finally, by using the ArcMap zonal statistics, the percentage of different classes for each study ward was calculated.

In the next step, ecological land cover cluster analysis using R statistical software and the *Ward* method was used to produce a dendogram of the different integrated urban ecological clusters in the selected 12 wards. *Ward* is a hierarchical clustering method that applies an ‘agglomerative algorithm’ (Murtagh &Legendre, 2011); it has been used in multiple areas of study, including health (Fraley and Raftery, 1998), marketing (Punj &Stewart, 1983), and ecology (Blackwood et al., 2003). Here I used Euclidean distance and the *Ward* method of different ecological variables to standardize the data.

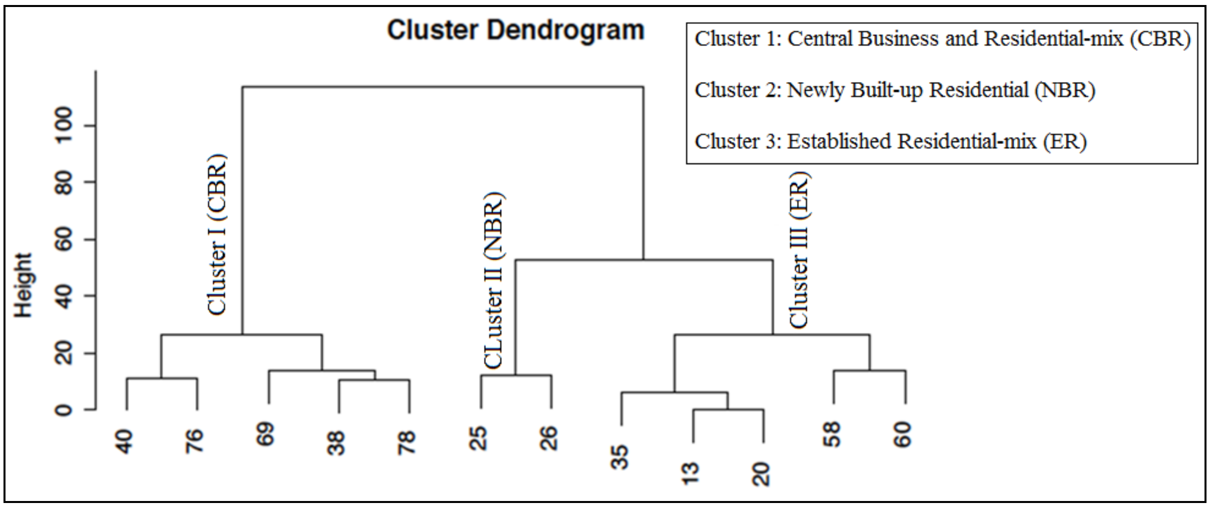


Figure 6.1: Cluster dendogram for the selected 12 wards based on landuse and landcover data,2012-13.

The dendogram shown in Figure 6.1 was used to identify three integrated urban ecological (IUE) zones. Wards 40, 76, 69, 38, and 78 were characterized mainly by commercial, residential, and administrative mix landuse and landcover; this was designated the Central Business and Residential-mix (CBR) zone. The second IUE zone consisted chiefly of old, well-established residential areas of the wards 35, 13, 20, 58, and 60 with relatively modest building ratios (60%-68%), designated as the Established Residential-mix (ER) zone. The final IUE zone, the Newly Built-up Residential (NBR), consisted of only two wards (25 and 26) and featured the highest building ratios (80%-85%).

6.2 Data Analysis

6.2.1 Statistical analysis

A test of homogeneity among the IUE zones, based on land cover/landuse in terms of *Stegomyia* indices, was performed using the chi-square test of significance. To test the hypothesis concerning seropositivity by age, the chi-square test of significance was carried out with respect to variation in seropositivity by age in each IUE zone. Logistic regression was carried out to delineate spatial patterns in risk factors for seropositivity. Odds ratios (ORs) and their 95% confidence intervals (95% CIs) were also calculated. Further, a binary logistic regression was carried out to assess the association between dengue seropositivity among the population in a household and the microhabitat and individual (human) scale explanatory variables. The microhabitat and individual (human) scale data, which included vegetation (i.e. potted plants and nearby trees), water vessels and tanks, number of doors and windows kept open, mosquito control measures, appearance at public gatherings, travel during last six months, and incidences of fever during last six months, were obtained from the socio-demographic questionnaire of the serological surveys of 2012 (Appendix X). All statistical analyses were performed using SPSS software (SPSS Inc., Chicago, IL).

6.2.2 Entomological data

The field work conducted for the present study is more thoroughly detailed in Chapter 3. Briefly, entomological surveys were conducted in 12 selected wards of the City of Dhaka, representing low, medium and high Socio-Economic Status (SES) zones. A total of 898 households were inspected for immature *Ae. aegypti* mosquitoes during July and August 2012. The rationale for using the 2012 monsoon entomological survey data was that both remotely sensed data on landuse and land cover and serological data were available for this time period.

6.2.3 Serological data

The laboratory work on serological samples has already been outlines in Chapter 3. Serological surveys were conducted in the 12 selected wards of the City of Dhaka during 2012 pre- and post-monsoon seasons. *Seroprevalence* is defined as the presence of IgG (OD/CO>=1) in serum samples and seroconversion is defined as where IgM and IgG results changed from OD/CO<=1 to OD/CO>=1 during post-monsoon 2012 in paired sample.

6.3 Results

6.3.1 Spatial distribution of immature *Aedes* and landue/land cover

During the entomological survey, a total of 898 household premises (total human population: 6,232) were inspected, with 222 (24.7%) found positive for *Ae. aegypti* larvae and/or pupae. 25.7% of wet containers (258 out of 1,003 containers inspected) contained immature *Aedes*. Traditional *Stegomyia* indices for the study area were a House Index (HI) of 24.7% (222 positive households of 898 sampled), a Container Index (CI) of 25.7% (258 positive containers of 1,003 sampled), and a Breteau Index (BI) of 28.7% (258 positive containers of 898 household premises inspected). A total of 1,380 *Ae. aegypti* pupae and 4,174 larvae were present in 258 (25.7%) of 1,003 containers containing water.

To evaluate the association between landuse/land cover characteristics and vector abundance, the traditional *Stegomyia* indices for each integrated urban ecological zone were calculated and compared statistically. A clearly defined dichotomized pattern between these zones was delineated in terms of the *Stegomyia* indices. In the CBR zone, infestation intensity was much higher than in the two other ecological zones. HI was 28.4% for the CBR Zone, as compared to 22.0% and 22.2% for the ER and NBR zones, respectively (Table 6.1). A similar pattern was observed for CI, which was 29.9% for the CBR zone, 22.6% for the ER zone, and 22.5% for the NBR zone. BI was also highest in the CBR (34.2%) zone compared to the ER (25.5%) and NBR (23.3%) zones.

Table 6.1: Distribution of *Stegomyia* indices with 95% CI (Confidence Interval) in different Integrated Urban Ecological (IUE) zones

IUE zones	HI (%)	95% Confidence Interval	CI (%)	95% Confidence Interval	BI (%)	95% Confidence Interval
CBR	28.4	(0.24-0.33)	29.9	(0.25-0.35)	34.2	(0.29-0.39)
ER	22	(0.18-0.26)	22.6	(0.18-0.27)	25.5	(0.21-0.30)
NBR	22.2	(0.16-0.28)	22.5	(0.16-0.29)	23.3	(0.17-0.30)

The null hypothesis stating that there was no significant difference in terms of House Index (HI) and Container Index (CI) [(HI:χ^2=4.68, df=2, p-value=0.096) and (CI:χ^2=7.00, df=2, p-value=0.030)] among different IUE zones could not be rejected. A similar conclusion was drawn for the Breteau index (BI), as this measurement is a combination of HI and CI. However, we found significant differences among the IUE zones in terms of proportion of pupa (the number of pupae/person) (χ^2= 160.8, df = 2, p-value < 2.2e-16) and the total number of pupa collected from these zones (χ^2= 731.0, df = 2, p-value < 2.2e-16).

6.3.2 Spatial patterns in seroprevalence, seroconversion, and landuse/land cover

The 2012 pre-monsoon serological survey results revealed that dengue seroprevalence was

79.9% in the city of Dhaka, and varied nominally among the IUE zones: 81.1% in the CBR zone, 80.2% in the ER zone, and 75.1% in the NBR zone (Figure 6.2; Table 6.2). Seropositivity was highest across all age groups in the CBR zones (Figure 6.3). As expected, frequency of seropositive samples increased with age in all IUE zones and the relationship between age and seroprevalence was consistently linear (Figure 6.4). Among all seropositive samples, 55.7% were female and 44.2% were male. Variation in seropositivity by age was found to be statistically significant (overall p-value <0.001) in each individual IUE zone. Notably, travel within last 6 months outside of the city of Dhaka was only found to be associated with seropositivity within the ER zone (Table 6.3).

Figure 6.5 depicts the spatial patterns of immature *Ae. Aegypti* mosquitoes in household premises by IUE zone. Each dot represents a household where *Ae. aegypti* larvae or pupae were collected, as well as households with persons who seroconverted to DENV. Based on a visual inspection, some degree of clustering of the households with *Ae. aegypti* infestations is apparent (Figure 6.5). In total, 95 individuals from 83 household premises seroconverted to DENV; the locations of these households are illustrated in Figure 6.6. Visual inspection of the data (the only possible analysis due to the small number of seroconversions), reveals a random pattern in the distribution of individuals who seroconverted, and no apparent significant variation between the IUE zones (except for Ward 13, in which no seroconversions were recorded).

Aedes aegypti larvae or pupae were not found during inspection in more than 96% of the households where DENV seroconversion was recorded, suggesting a weak relationship between the presence of vector mosquitoes and seroconversion (Figure 6.5). When the association between households of individuals who seroconverted and presence of *Ae.*

aegypti pupae, it appeared that there was also no significant statistical association between them (χ^2=0.42, df=1; p-value= 0.520).

Table 6.2: Seroprevalence, serocoversion, and median age of participants based on 2012 pre-monsoon and post-monsoon serological survey results in the Integrated Urban Ecological (IUE) zones, Dhaka, Bangladesh

IUE zone		Serum sample (IgG)-Surveys		
		Pre-monsoon 2012	Post-monsoon 2012	Seroconversion paired sample (IgM/IgG)
CBR	n	466	448	29
	Positives	378	397	15
	Median age	43 (0.6-85)	28 (3-76)	34 (7-66)
ER	n	502	481	61
	Positives	403	426	37
	Median age	30 (2-80)	28 (2-97)	25 (2-78)
NBR	n	157	139	5
	Positives	118	119	1
	Median age	28 (1-92)	27 (2-92)	30 (24-43)
Total	Positive/total	899/1125	942/1068	38/95

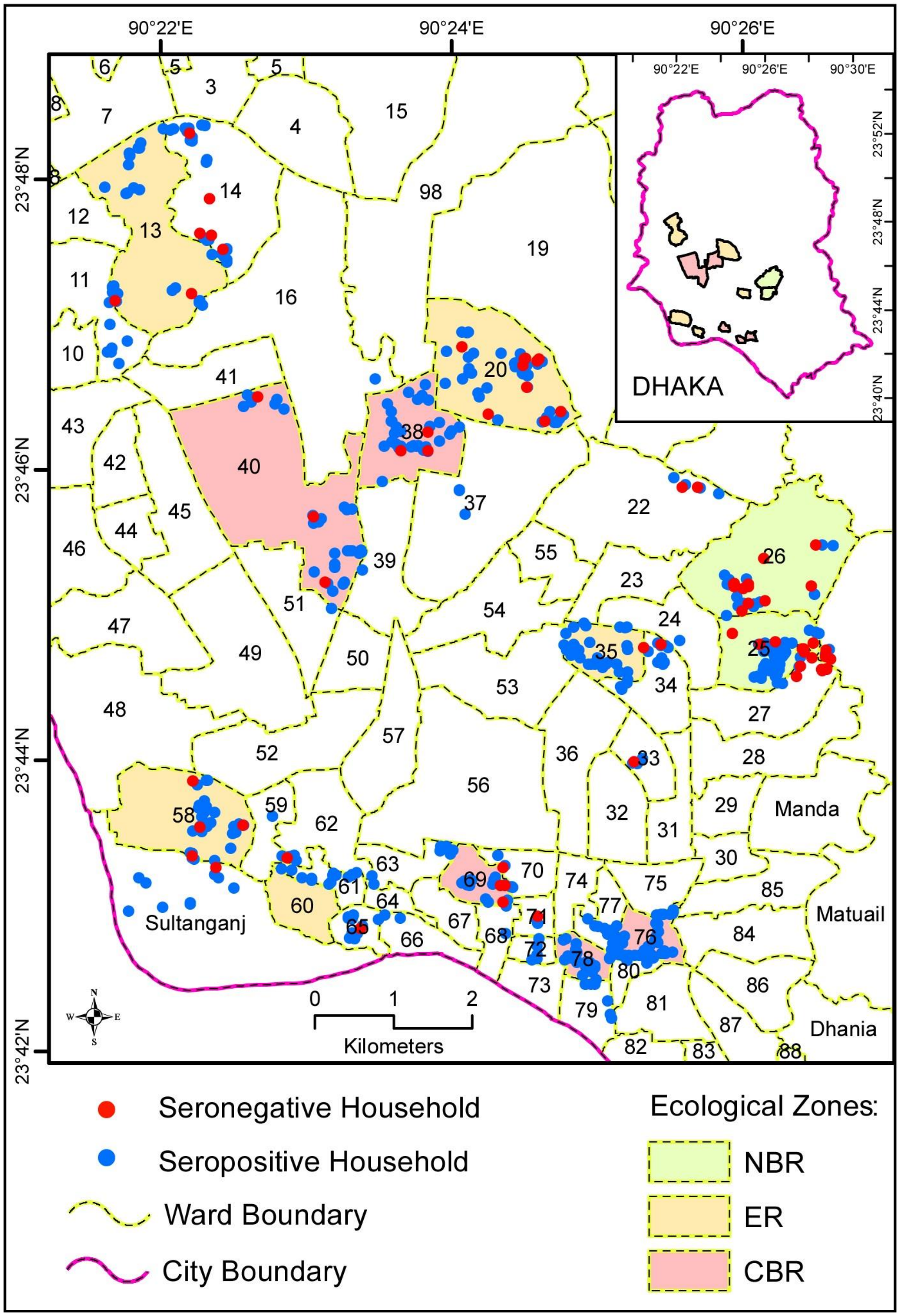


Figure 6.2: Spatial distribution of seropositive and seronegative household premises, 2012 (pre-monsoon)[ϒ]

ϒ Compiled after Dhaka City Corporation 2005; Field survey 2012; RapidEye Imagery, 2012

Table 6.3: Individual risk factors odds ratio for seroprevalence in Integrated Urban Ecological (IUE) zones, Dhaka, Bangladesh (2012 pre-monsoon)

Risk factor		CBR N	OR	p-value	ER n	OR	p-value	NBR n	OR	p-value
Sex	Male	171	1		178	1		48	1	
	Female	226	1.07	0.8	215	1.37	0.16	60	0.98	0.96
Age (years)	0-11	41	1		19	1		5	1	
	12-34	199	0.4	0.83	197	0.22	0.22	66	0.24	0.56
	>= 35	157	0.14	<0.0001★	177	0.09	<0.0001★	37	0.09	0.001★
Self-reported fever within last 6 months	No	1945	1		213	1		64	1	
	Yes	203	1.27	0.35	180	1.38	0.15	44	1.18	0.63
Travel within last 6 months outside the city of Dhaka	No	111	1		348	1		4	1	
	Yes	286	0.85	0.55	45	3.30	0.03★	104	0.59	0.50

★Significant variables at p=0.05 level

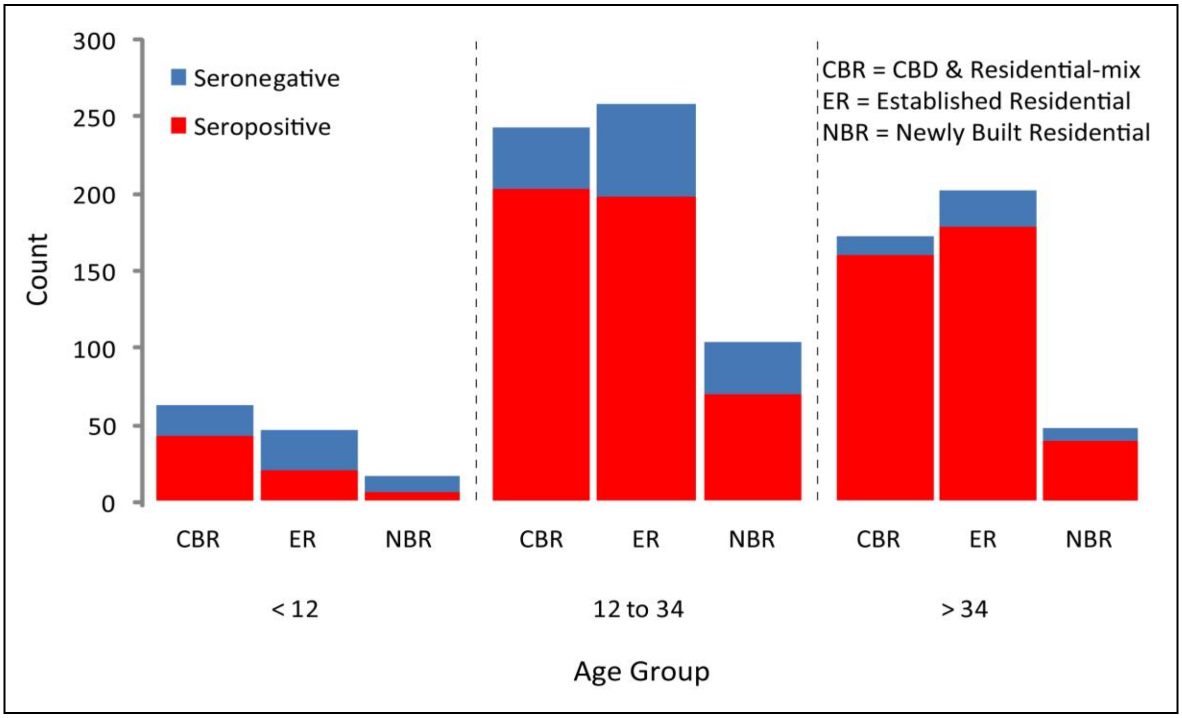


Figure 6.3: Distribution (count) of dengue seropositive and seronegative per age group by integrated urban ecological zone, 2012 (pre-monsoon)

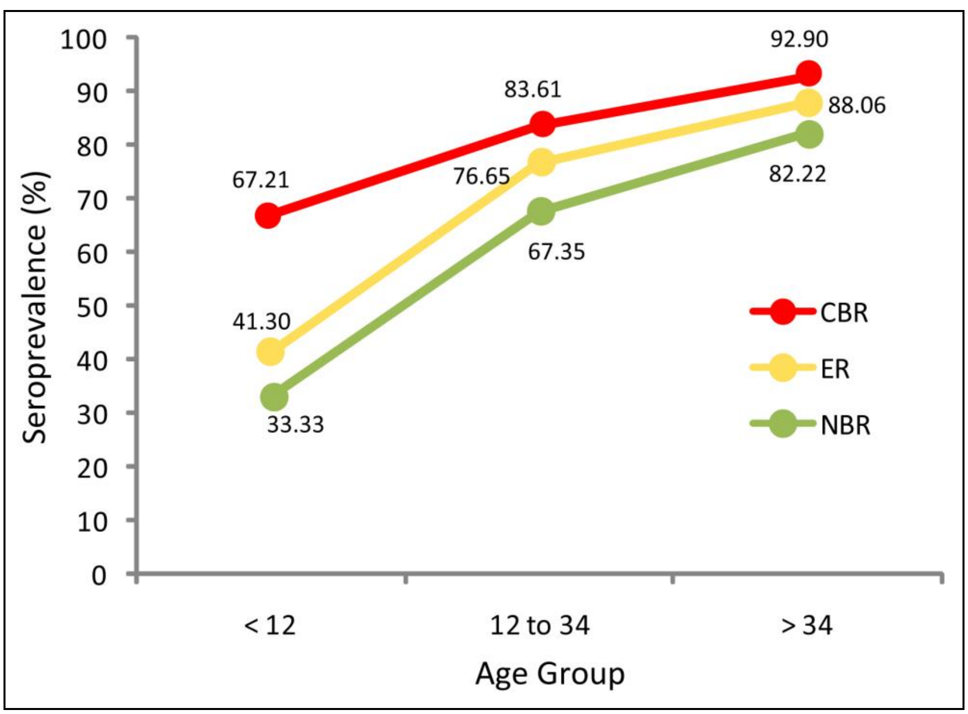


Figure 6.4: Patterns in the percentage distribution of dengue seroprevalence per age group by integrated urban ecological zone, 2012 (pre-monsoon)

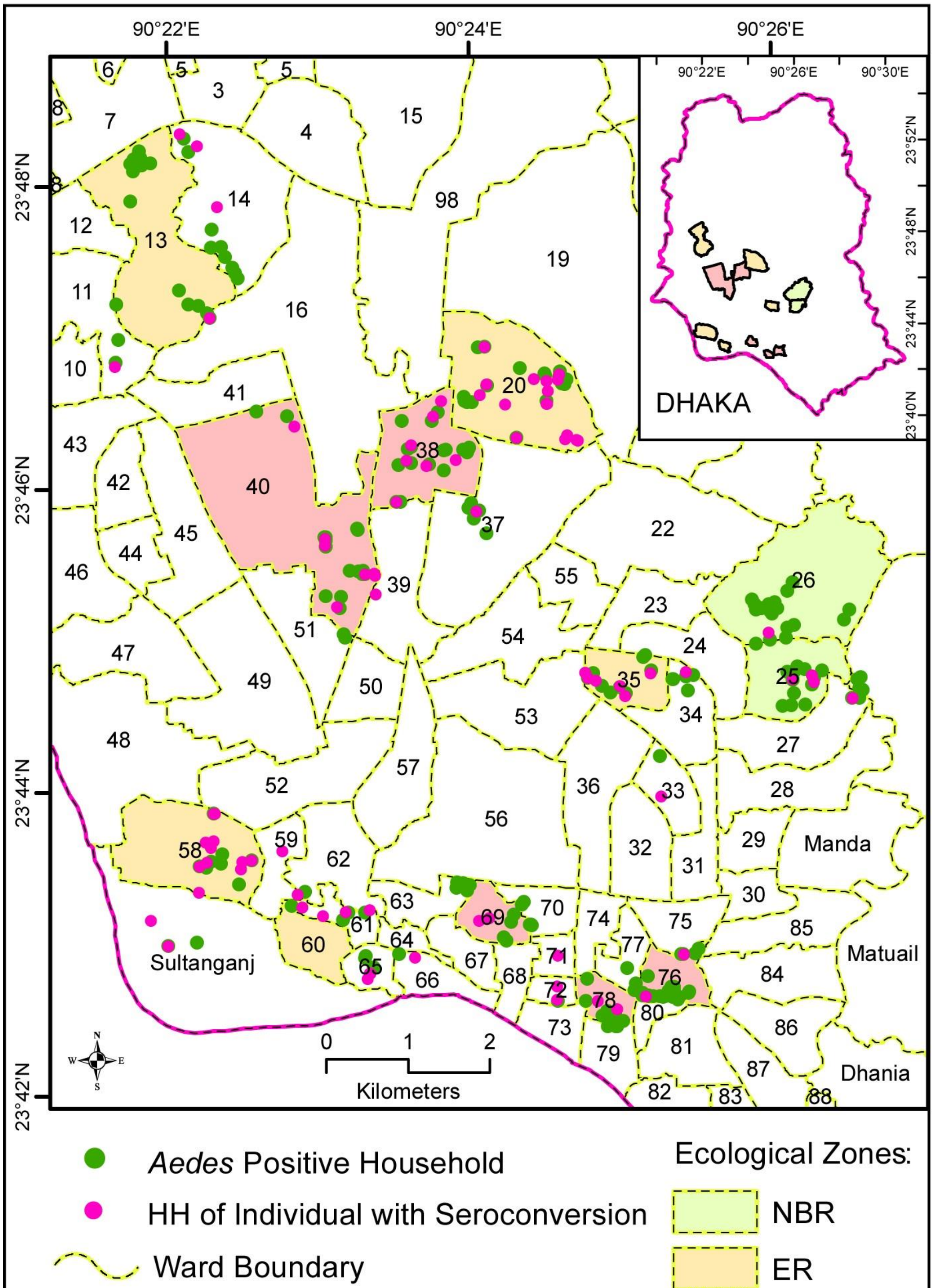


Figure 6.5: Spatial distribution of household where vector mosquitoes were found and where individuals who seroconverted were detected.[∂]

[∂] Compiled after Dhaka City Corporation 2005; Field survey 2012; RapidEye Imagery, 2012

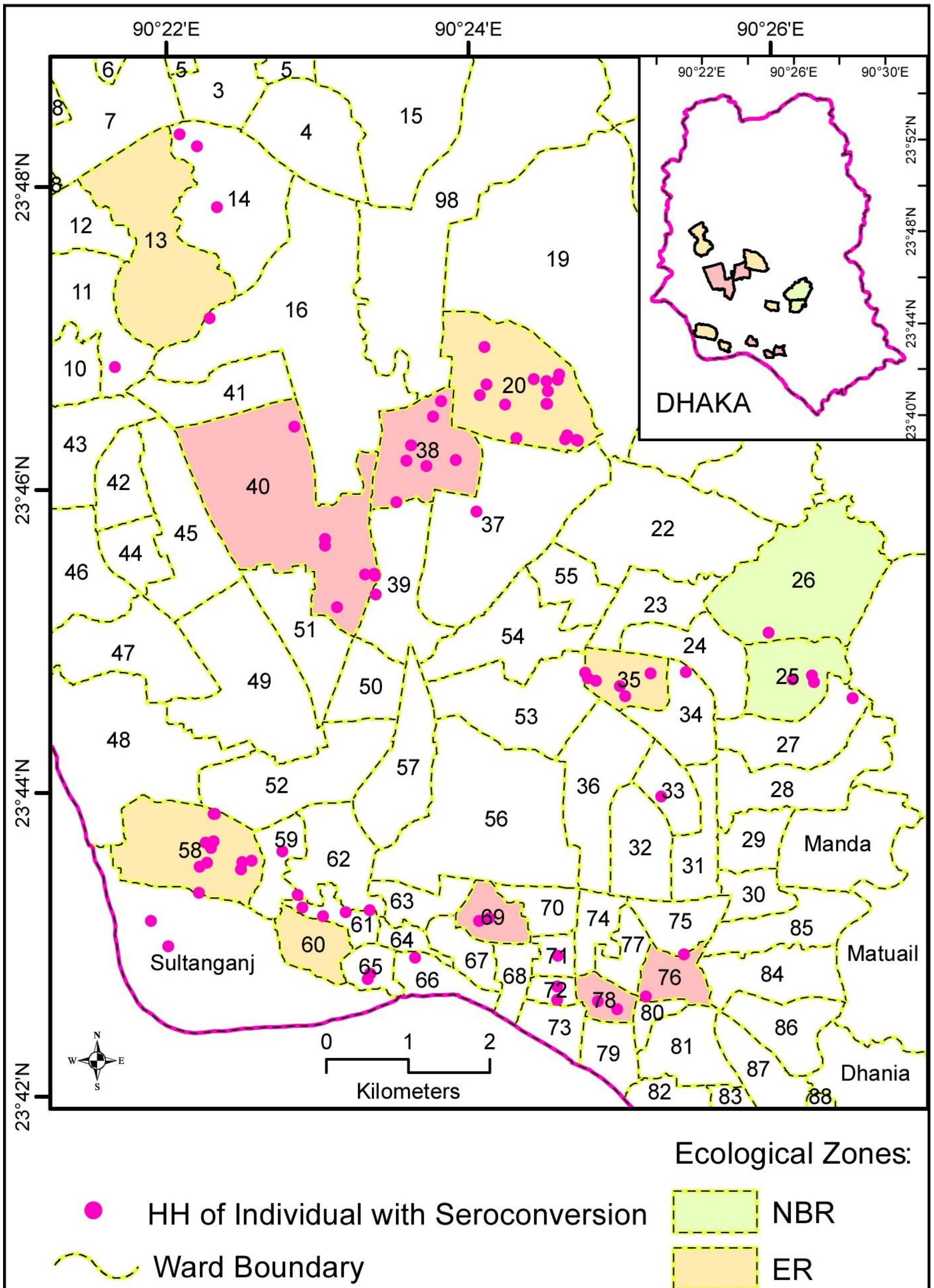


Figure 6.6: Spatial distribution of households where individuals seroconverted to dengue virus (DENV).∇

∇ Compiled after Dhaka City Corporation 2005; Field survey 2012; RapidEye Imagery, 2012

6.3.3 Logistic regression modeling of presence or absence of vector and seroconversion in households

In order to assess the association between the dengue seropositivity among household populations and microhabitat and individual (human) scale explanatory variables, a binary logistic regression analysis was carried out. The results of the 2012 pre- and post-monsoon serosurvey data have revealed that only the appearance by any member of the household in public gathering places such as schools, mosques, recreational parks, and restaurants is significantly associated with dengue seroconversion. Household members who appear in public gathering places were also 8.69 (p-value: 0.033; 95% CI: 1.08-5.94) times more likely to experience seroconversion than the members who did not. The other explanatory variables were not significant at 5% level of significance. The model fit the data well.

The above overall perspectives on the association between the microhabitat and individual (human) scale factors and seroconversion do not account for the theoretical differences among landuse/land cover classes in the city of Dhaka. Recognizing that such broad-scale urban ecological factors play a significant role in vector ecology and thus in dengue infection, it is important to find similarities and differences between landuse and land cover classes in terms of explanatory variables. Separate binary logistic regression models were therefore formulated for each urban ecological zone in Dhaka.

In terms of association between seroconversion and explanatory variables in three different urban ecological zones, I found two distinctive patterns. In the CBR zone, public gathering appearance, travel within the last 6 months, outdoor potted plants, and fever within the last 6 months were found to be significant explanatory factors for recent dengue infection and thereby seroconversion, at a 95% level of confidence (Table 6.4). The likelihood that people in the CBR zone who did not travel outside the home for a considerable period within the six months of the time of survey were recently infected was 2.4 times higher than the people who did travel during this time frame. By contrast, in both the ER zone and the NBR zone, none of the selected explanatory variables were significant in relation to seroconversion among the sample residents.

Table 6.4: Binary logistic regression results association between selected microhabitat and individual (human) scale explanatory variables and seroconversion

Variables	Adjusted Risk Ratio	P-value
Potted plants	0.86 (0.76-0.98)	0.020*
Public gathering appearance No appearance vs. appearance	8.69(1.80-4.20)	0.007*
Travel within the last 6 months No vs. Yes	2.49 (0.91-6.85)	0.077
Fever within the last 6 months No vs. Yes	0.34 (0.11-1.01)	0.052*

***Significant variables at p=0.05 level**

6.4 Discussion

In the context of rapidly-growing urban centers in the developing world, the existing literature overwhelmingly emphasizes the role of socioeconomic factors in dengue transmission, with particular emphasis on human population density and water use practices at the household level (Arunachalam et al., 2010; Schmidt et al., 2011). The household entomological survey and population serological survey were therefore initially designed by considering the Socio-Economic Status (SES) of the selected Wards of the city of Dhaka. Nonetheless, recognizing that in integrated social-ecological systems, societal and ecological factors function in a conjoined manner, I argue that it is crucial to include the analysis of ecological variables in influencing DENV infection through affecting *Ae. aegypti* distribution and DENV over geographical space and their interaction with host populations. For example, recent literature has revealed that shaded and vegetated neighborhoods with abundant rainwater collection sites and reduced sunlight create more favorable microhabitats for *Ae. aegypti* (Gleiser& Zalazar, 2010). At a larger scale, deforestation and new urbanization enhances larval habitats in artificial containers. Additionally, urban land cover/ landuse characteristics profoundly influence the epidemiology of vector-borne diseases, including dengue, by impacting host availability and accessibility.

In this context, Wilcox and Gubler (2005) have explained that the host-vector-virus nexus can be distorted by anthropological landscape alternations that significantly contribute to vector development conditions, resulting in shifts in host-vector-virus relationships. These dynamics are associated with land cover/use change as well as alterations in microhabitat of vector and virus. With these arguments in mind, in this chapter I attempted to examine the ecological factors -at both larger (landscape, landuse, and land cover) and micro scales - responsible for spatial evaluation of dengue vector abundance and its association with seroconversion. I considered both the landscape scale - focusing on landcover/ landuse characteristics of integrated urban ecological zones of the city of Dhaka - and the household and neighborhood scale, focusing on microhabitat and individual human agents.

6.4.1 Landuse/land cover variables influencing distribution of *Aedes* and seroprevalence

I assessed the hypothesis that different urban ecological conditions result in different patterns of *Aedes* infestation in the city of Dhaka, by counting immature *Ae. aegypti* in and around households in three different integrated urban ecological (IUE) zones. The analysis of

Stegomyia indices by different land cover/ landuse types, reflected in the IUE zones, revealed that *Aedes* habitats and urban land cover/ landuse in Dhaka are correlated. The most obvious case was the densely populated commercial, administrative and residential-mixed zone, defined by urban functions and anthropogenic economic activities. All of HI, CI and BI values were considerably higher in the CBR zone than in the in ER and NBR zones. Studies in other countries also found associations between urban landscape features and *Aedes* mosquito habitats. For example, Vanwambeke et al. (2007) associated 'human activities' with *Ae. aegypti* larvae in northern Thailand, and measured great variations in *Aedes* abundance between different types of human settlement. They further noted that artificial containers were found in very high densities in areas where human activities are concentrated.

Mirroring the variations in human activities and artificial containers, the findings of this study showed that there was significant difference among the IUE zones in terms of spatial distribution of the proportion of *Ae. aegypti* pupae (number of pupae/person). This can partially be explained by the fact that in the ER and NBR zones of Dhaka, the household premises were likely to be characterized by 'tidier' surroundings due to limited human activities. Direct detection of immature mosquito habitats in housing areas on remotely sensed images proved to be challenging, as noted by Vanwambeke et al. (2007), Jacob et al. (2005), and Moloney et al. (1998). As in a household premises, the surrounding land cover profoundly affects the characteristics of mosquito larval habitat; an analysis at a lower scale is needed to compliment the inference about larval habitats in household premises. The next subsection offers a discussion of these issues.

I identified a gradient in the spatial distribution of immature *Ae. aegypti* at the landscape scale in Dhaka. Multiple urban functions, transportation nodes, and public gathering spaces including educational institutions, community centers, the Parliament and associated administrative buildings, and produced the highest level of HI, CI and BI characterize the CBR zone. Both the older and newer residential zones exhibit similar HI, CI and BI, reflecting comparable economic activities though their land cover/ landuse patterns were distinct from each other. Overall, the findings of my study did not show any statistically significant variation among the IUE zones in terms of *Stegomyia* indices in Dhaka during the 2012 monsoon. This finding underscores the low degree of variation in the distribution of immature *Ae. aegypti* (HI ranging from 22% to 28% among the IUE zones; HI:χ^2=4.68, df=2, p-value=0.096) across the city of Dhaka. A similar spatial distribution of *Ae. aegypti* with nominal variation among urban zones was also observed in several countries in Latin America, namely Manaus in Brazil (Rios-Velasquez et al., 2007), and in the Amazonian city of Iquitos of Peru (Getis et al., 2010). A relatively uniform level of *Ae. aegypti* infestation throughout the city of Dhaka, as in Amazonian cities, can be attributed to "the relatively high availability of artificial containers throughout the city, high rainfall, and temperature" (Rios-Velasquez et al., 2007: 622).

The seroprevalence of DENV antibodies was ubiquitously high across the city of Dhaka. I also noticed conformity in spatial patterns of dengue seroprevalence among the IUE zones; in all three IUE zones, seroprevalence concentrated in areas with more intense commercial activity and a greater concentration of bus stations, transportation routes, schools and colleges, and community centers. Since sites of population agglomeration are more clustered in the CBR, seroprevalence and recent DENV infection were relatively higher in this zone than others. Such spatial clustering of dengue was also observed by a number of studies in Thailand (van Bentham et al., 2005; Mammem et al., 2008), and supports the notion that mosquito-borne disease incidence is highly focal (Mammem et al., 2008; Lloyd-Smith et al., 2005). As the spatial configuration of dengue seroprevalence intensity and dengue cases can be vigorously delineated by applying GIS-based statistical techniques such as Kernel Estimation (Gatrell et al., 1996; Ali et al., 2003), the Kriging method (Oliver & Webster, 1990), further studies should be undertaken with larger sample sizes in order to better understand the clustering patterns and processes in dengue seroprevalence, seroconversion, and distribution of human cases.

6.4.2 Microhabitat and individual (human) scale variables influencing presence of vectors and seroconversion at the household level

The large number of reported cases in the city of Dhaka is characteristic of the high dengue virus activity in Bangladesh during the past 14 years (Banu et al., 2012; Poddar et al., 2001). Subsequent studies confirmed the co-circulation of all DENV serotypes in Bangladeshi cities including Dhaka, the largest and most densely populated in the country. As cited by Honorio et al. (2009), seroconversion data is scarce - more so in the case of disaggregated data. I therefore decided to present the disaggregated data on seroconversion with special attention to spatial distribution by IUE zone. I observed the most seroconversion in residences where no immature *Aedes* were found during the 2012 monsoon season, suggesting that recent infections took place out of respondents' own residence, either in other premises (markets, shopping areas, mosques, schools) or outdoors, where most people stay during daylight hours when *Ae. aegypti* are most active).

It is notable that in Dhaka, gatherings of people are very age, sex, and socioeconomic-class specific. Relative concentration of such activities at shopping malls, formal and informal markets, vending nodes, mosques, and schools is much higher in the Central Business and Residential-mix (CBR) areas. In the modern shopping malls, both young and adult men and women from affluent socioeconomic class predominate, while in the informal markets are mostly frequented by adult males. These residents work mostly during the morning and late afternoon and evening hours of the day. Similarly, concentration of children aged 3-16 years in schools, playgrounds, and after-school nurseries is highest during the daytime. The results show that seroconversions were significantly associated with such population concentrations, a fact likely attributable to the fact that *Ae. aegypti* mosquitoes do not fly long distances between blood meals. In a crowded place, the infected mosquitoes can thus more easily transmit DENV to many people. The lack of coherence between household immature *Aedes* counts and seroconversion should be further investigated in future work, by taking *Aedes* samples from commercial, administrative, and institutional (schools, mosques) establishments and outdoor locations such as parks and recreational areas.

As the existing literature offers contrasting findings with regards to locations of highest dengue risk exposure; without vigorous scientific research, it is difficult to conclusively list specific places where dengue vector and human interactions take place. For example Chadee et al. (2000) in the West Indies and Pandian & Dwarakanath (1992) in India observed that exposure to infected mosquitoes is highest in and around houses due to the highly domesticated nature of female *Ae. aegypti*. *Aedes* mosquitoes mostly bite during daylight hours, with pronounced peaks of activity around sunrise and sunset. In contrast, van Benthem et al. (2005) argue that since not all family members stay at home during the day and *Aedes* bite mainly during this period, it is unlikely that transmission takes place in or around the house. In this study, the influence of microenvironmental factors (including vegetation, water vessels and water tanks, number of doors and windows kept open, mosquito control measures, travel during last six months, and appearance in public gatherings) in Dhaka clearly indicated that the major variable affecting dengue exposure risk, as measure via seropositivity, is participation in mass or public gatherings. This is indicative of the significance of spatial conglomeration of human socioeconomic and cultural activities in dengue exposure risk in Dhaka. Future research focused on movement patterns of affected human populations may provide further insights on the dynamics of dengue transmission and the main location(s) of transmission, which may be useful in developing an early warning system for future dengue outbreaks.

Several studies emphasized the significance of entomological surveillance for early detection of dengue transmission risk and for directing vector control measures (Honorio et al., 2009). However, this research suggests that such surveillance should be accompanied by epidemiological research so that statistical risk factors for human infection can be identified with a high degree of statistical confidence. Similarly to this study findings, numerous studies in Brazil have found that vector surveillance using Premise and Breteau indices were poorly correlated with ‘dengue incidence’ (Camara et al. 2007; Souza et al. 2007; Luz et al. 2008). Also, in assessing the relationship between serological and epidemiological surveys and mosquito density in Puerto Rico, Rodriguez-Figueroa (1995) observed that none of the household characteristics considered was significantly associated with recent dengue infection, except the number of female *Ae. aegypti* per person.

My results point to eco-spatial heterogeneity in the explanatory factors of dengue seroconversion. In the CBR zone, multiple microenvironmental factors, namely, participation in public gathering, travel during last six months, outdoor potted plants, and fever within last six months, were found to be correlated with seropositivity. This implies that in this zone, the relatively high degree of human mobility and number of outdoor potted plants significantly influence the interaction between the vectors and humans. In ER and NBR zones, other explanatory factors than those we considered are likely to affect seropositivity.

Overall, these results underscore the important role in dengue transmission of public spaces and socioeconomic activities where human movement is intense (Honorio et al. 2009). Many studies have argued that “people rather than mosquitoes rapidly move dengue virus within and among communities” (Honorio et al. 2009: 10), and the findings of my study are consistent with this notion.

6.5 Limitations

In this study, I did not examine the effects of landuse and land cover on vector productivity in outdoors areas outside of household premises. In order to determine the association between non-household premises and the containers in these sites with *Aedes* larvae and pupae productivity on a broader landscape scale, further entomological studies will be required. Vanwambeke et al. (2007)’s study in Northern Thailand can provide a useful guideline for such outdoor entomological survey-based investigations.

Due to resource and time constraints, the scope of this study was limited to inspecting only household premises in the city of Dhaka. Thus, non-residential (e.g. commercial and administrative sites) premises and outdoor areas (e.g. parks and recreational areas) were ommitted from the investigation.

Finally, only presence or absence (and abundance) of mosquitoes was only recorded in a single instance at each household. The data collected could therefore be insufficient to allow a full understanding of the role of mosquito abundance in transmission at the household level. Future studies should therefore be designed to include entomological time-series data collection.

References

Alberti, M., Marzluff, J. M., Shulenberger, E., Bradley, G., Ryan, C., & Zumbrunnen, C. (2003). Integrating humans into ecology: opportunities and challenges for studying urban ecosystems. *Bioscience, 53*(12), 1169-1179.

Ali, M., Wagatsuma, Y., Emch, M., & Breiman, R. F. (2003). Use of a geographic information system for defining spatial risk for dengue transmission in Bangladesh: role for Aedes albopictus in an urban outbreak. *The American Journal of Tropical Medicine and Hygiene, 69*(6), 634-640.

Andersson, E. (2006). Urban landscapes and sustainable cities.*Ecology and Society* 11(1):34. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art34/

Arunachalam, N., Tana, S., Espino, F., Kittayapong, P., Abeyewickrem, W., Wai, K. T., . . . Petzold, M. (2010). Eco-bio-social determinants of dengue vector breeding: a multicountry study in urban and periurban Asia. *Bulletin of the World Health Organization, 88*(3), 173-184.

Banu, S., Hu, W., Hurst, C., Guo, Y., Islam, M. Z., & Tong, S. (2012). Space-time clusters of dengue fever in Bangladesh. *Tropical Medicine & International Health, 17*(9), 1086-1091.

Blackwood, C. B., Marsh, T., Kim, S. H., & Paul, E. A. (2003). Terminal restriction fragment length polymorphism data analysis for quantitative comparison of microbial communities. *Applied and Environmental Microbiology, 69*(2), 926-932.

Câmara, F. P., Theophilo, R. L. G., Santos, G. T. d., Pereira, Silvia Regina Ferreira Gonçalves, Câmara, D. C. P., & Matos, Roberto Rodrigues C de. (2007). Regional and dynamics characteristics of dengue in Brazil: a retrospective study. *Revista Da Sociedade Brasileira De Medicina Tropical, 40*(2), 192-196.

Chadee, D. D., & Martinez, R. (2000). Landing periodicity of Aedes aegypti with implications for dengue transmission in Trinidad, West Indies. *Journal of Vector Ecology, 25*, 158-163.

Coelho, G. E., Burattini, M. N., Teixeira, M. d. G., Coutinho, F. A. B., & Massad, E. (2008). Dynamics of the 2006/2007 dengue outbreak in Brazil. *Memórias do Instituto Oswaldo Cruz, 103*(6), 535-539.

Cox, J., Grillet, M. E., Ramos, O. M., Amador, M., & Barrera, R. (2007). Habitat segregation of dengue vectors along an urban environmental gradient. *The American Journal of Tropical Medicine and Hygiene, 76*(5), 820-826.

Cunha, R. V. d., Maspero, R. C., Miagostovich, M. P., de Araújo, E. S., Luz, D. d. C., Nogueira, R. M., & Schatzmayr, H. G. (1997). Dengue infection in Paracambi, state of Rio de Janeiro, 1990-1995. *Revista Da Sociedade Brasileira De Medicina Tropical, 30*(5), 379-383.

Fraley, C., & Raftery, A. E. (1999). MCLUST: Software for model-based cluster analysis. *Journal of Classification, 16*(2), 297-306.

Fukunaga, K. (1990). *Introduction to Statistical Pattern Recognition*. New York and London: Academic Press (First published in 1972).

Gatrell, A. C., Bailey, T. C., Diggle, P. J., & Rowlingson, B. S. (1996). Spatial point pattern analysis and its application in geographical epidemiology. *Transactions of the Institute of British Geographers,* , 256-274.

Getis, A., Morrison, A. C., Gray, K., & Scott, T. W. (2010). Characteristics of the Spatial Pattern of the Dengue Vector, Aedes aegypti, in Iquitos, Peru. *Perspectives on Spatial Data Analysis* (pp. 203-225) Springer.

Gleiser, R., & Zalazar, L. (2010). Distribution of mosquitoes in relation to urban landscape characteristics. *Bulletin of Entomological Research, 100*(02), 153-158.

Gubler, D. J. (2002). Epidemic dengue/dengue hemorrhagic fever as a public health, social and economic problem in the 21st century. *Trends in Microbiology, 10*(2), 100-103.

Halstead, S. B. (1990). Global epidemiology of dengue hemorrhagic fever. *The Southeast Asian Journal of Tropical Medicine and Public Health, 21*(4), 636-641.

Halstead, S. B., Scanlon, J. E., Umpaivit, P., & Udomsakdi, S. (1969). Dengue and chikungunya virus infection in man in Thailand, 1962-1964. IV. Epidemiologic studies in the Bangkok metropolitan area. *The American Journal of Tropical Medicine and Hygiene, 18*(6), 997-1021.

Hayden, M. H., Uejio, C. K., Walker, K., Ramberg, F., Moreno, R., Rosales, C., . . . Janes, C. R. (2010). Microclimate and human factors in the divergent ecology of Aedes aegypti along the Arizona, US/Sonora, MX border. *Ecohealth, 7*(1), 64-77.

Honório, N. A., Nogueira, R. M. R., Codeço, C. T., Carvalho, M. S., Cruz, O. G., Magalhães, Mônica de Avelar Figueiredo Mafra, . . . Pinheiro, L. S. (2009). Spatial evaluation and modeling of dengue seroprevalence and vector density in Rio de Janeiro, Brazil. *PLoS Neglected Tropical Diseases, 3*(11), e545.

Jacob, B. G., Arheart, K. L., Griffith, D. A., Mbogo, C. M., Githeko, A. K., Regens, J. L., . . . Beier, J. C. (2005). Evaluation of environmental data for identification of Anopheles (Diptera: Culicidae) aquatic larval habitats in Kisumu and Malindi, Kenya. *Journal of Medical Entomology, 42*(5), 751-755.

Juliano, S. A., & Philip Lounibos, L. (2005). Ecology of invasive mosquitoes: effects on resident species and on human health. *Ecology Letters, 8*(5), 558-574.

Kim, H., & Yeom, J. (2014). Effect of red-edge and texture features for object-based paddy rice crop classification using RapidEye multi-spectral satellite image data. *International Journal of Remote Sensing,* (ahead-of-print), 1-23.

Kitron, U. (1998). Landscape ecology and epidemiology of vector-borne diseases: tools for spatial analysis. *Journal of Medical Entomology, 35*(4), 435-445.

Kolivras, K. N. (2006). Mosquito Habitat and Dengue Risk Potential in Hawaii: A Conceptual Framework and GIS Application∗. *The Professional Geographer, 58*(2), 139-154.

Landau, K. I., & van Leeuwen, W. J. (2012). Fine scale spatial urban land cover factors associated with adult mosquito abundance and risk in Tucson, Arizona. *Journal of Vector Ecology, 37*(2), 407-418.

Lloyd-Smith, J. O., Cross, P. C., Briggs, C. J., Daugherty, M., Getz, W. M., Latto, J., . . . Swei, A. (2005). Should we expect population thresholds for wildlife disease? *Trends in Ecology & Evolution, 20*(9), 511-519.

Luz, P. M., Mendes, B. V., Codeco, C. T., Struchiner, C. J., & Galvani, A. P. (2008). Time series analysis of dengue incidence in Rio de Janeiro, Brazil. *The American Journal of Tropical Medicine and Hygiene, 79*(6), 933-939.

Mammen Jr, M. P., Pimgate, C., Koenraadt, C. J., Rothman, A. L., Aldstadt, J., Nisalak, A., . . . Ypil-Butac, C. A. (2008). Spatial and temporal clustering of dengue virus transmission in Thai villages. *PLoS Medicine, 5*(11), e205.

Moloney, J. M., Skelly, C., Weinstein, P., Maguire, M., & Ritchie, S. (1998). Domestic Aedes aegypti breeding site surveillance: limitations of remote sensing as a predictive surveillance tool. *The American Journal of Tropical Medicine and Hygiene, 59*(2), 261-264.

Morrison, A. C., Zielinski-Gutierrez, E., Scott, T. W., & Rosenberg, R. (2008). Defining challenges and proposing solutions for control of the virus vector Aedes aegypti. *PLoS Medicine, 5*(3), e68.

Murtagh, F., & Legendre, P. (2011). Ward's Hierarchical Clustering Method: Clustering Criterion and Agglomerative Algorithm. *ArXiv Preprint:1111.6285.*

Norris, D. E. (2004). Mosquito-borne diseases as a consequence of landuse change. *Ecohealth, 1*(1), 19-24.

Oliver, M. A., & Webster, R. (1990). Kriging: a method of interpolation for geographical information systems. *International Journal of Geographical Information System, 4*(3), 313-332.

Pandian, R., & Dwarakanath, S. (1992). The biting activity rhythm in aedies mosquitoes of Madurai. *Comparative Physiology and Ecology, 17*(2), 66-70.

Patz, J. A., Daszak, P., Tabor, G. M., Aguirre, A. A., Pearl, M., Epstein, J., . . . Working Group on Landuse Change and Disease Emergence. (2004). Unhealthy landscapes: Policy recommendations on landuse change and infectious disease emergence. *Environmental Health Perspectives, 112*(10), 1092-1098.

Pickett, S. T., Cadenasso, M. L., Grove, J. M., Groffman, P. M., Band, L. E., Boone, C. G., . . . Jenkins, J. C. (2008). Beyond urban legends: an emerging framework of urban ecology, as illustrated by the Baltimore Ecosystem Study. *Bioscience, 58*(2), 139-150.

Pickett, S. T., Cadenasso, M., Grove, J., Nilon, C., Pouyat, R., Zipperer, W., & Costanza, R. (2001). Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annual Review of Ecology and Systematics*,127-157.

Poddar, G., Breiman, R. F., Azim, T.,Thu, H. M. et al. (2006). Short Report: Origin of dengue type 3 viruses associated with the dengue outbreak in Dhaka, Bangladesh, in 2000 and 2001. *American Journal of Tropical Medicine and Hygiene, 74*(2), 263-265.

Punj, G., & Stewart, D. W. (1983). Cluster analysis in marketing research: review and suggestions for application. *Journal of Marketing Research*,134-148.

Ríos-Velásquez, C. M., Codeço, C. T., Honório, N. A., Sabroza, P. S., Moresco, M., Cunha, I. C., . . . Luz, S. L. (2007). Distribution of dengue vectors in neighborhoods with different urbanization types of Manaus, state of Amazonas, Brazil. *Memórias do Instituto Oswaldo Cruz, 102*(5), 617-623.

Rodriguez-Figueroa, L., Rigau-Perez, J. G., Suarez, E. L., & Reiter, P. (1995). Risk factors for dengue infection during an outbreak in Yanes, Puerto Rico in 1991. *The American Journal of Tropical Medicine and Hygiene, 52*(6), 496-502.

Schmidt, W., Suzuki, M., Thiem, V. D., White, R. G., Tsuzuki, A., Yoshida, L., . . . Ariyoshi, K. (2011). Population density, water supply, and the risk of dengue fever in Vietnam: cohort study and spatial analysis. *PLoS Medicine, 8*(8), e1001082.

Scott, T. W., & Morrison, A. C. (2010). Vector dynamics and transmission of dengue virus: implications for dengue surveillance and prevention strategies. *Dengue virus* (pp. 115-128) Springer.

Souza, Izabel Cristina Alcantara de, Vianna, Rodrigo Pinheiro de Toledo, & Moraes, R. M. d. (2007). Modeling of dengue incidence in Paraíba State, Brazil, using distributed lag models. *Cadernos De Saúde Pública*, *23*(11), 2623-2630.

Teixeira, M. G., Costa, Maria da Conceição N, Barreto, F., & Barreto, M. L. (2009). Dengue: twenty-five years since reemergence in Brazil. *Cadernos De Saúde Pública, 25*, S7-S18.

Thammapalo, S., Chongsuwiwatwong, V., McNeil, D., &Geater, A. (2005).The climatic factors influencing the occurrence of dengue hemorrhagic fever in Thailand.. *Southeast Asian J Trop Med Public Health* 36(1): 191-6.

Van Benthem, B., Khantikul, N., Panart, K., Kessels, P., Somboon, P., & Oskam, L. (2002). Knowledge and use of prevention measures related to dengue in northern Thailand. *Tropical Medicine & International Health, 7*(11), 993-1000.

Van Benthem, B. H., Vanwambeke, S. O., Khantikul, N., Burghoorn-Maas, C., Panart, K., Oskam, L., . . . Somboon, P. (2005). Spatial patterns of and risk factors for seropositivity for dengue infection. *The American Journal of Tropical Medicine and Hygiene*, *72*(2), 201-208.

Vanwambeke, S. O., Bennett, S. N., & Kapan, D. D. (2011). Spatially disaggregated disease transmission risk: land cover, landuse and risk of dengue transmission on the island of Oahu. *Tropical Medicine & International Health, 16*(2), 174-185.

Vanwambeke, S. O., Lambin, E. F., Eichhorn, M. P., Flasse, S. P., Harbach, R. E., Oskam, L., . . . Walton, C. (2007). Impact of land-use change on dengue and malaria in northern Thailand. *Ecohealth, 4*(1), 37-51.

Vanwambeke, S. O., van Benthem, B. H., Khantikul, N., Burghoorn-Maas, C., Panart, K., Oskam, L., and Somboon, P. (2006). Multi-level analyses of spatial and temporal determinants for dengue infection. *International Journal of Health Geographics, 5*:5 doi: 10.1186/1476-072X-5-5

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of Earth's ecosystems. *Science, 277*(5325), 494-499.

Waterman, S. H., Novak, R. J., Sather, G. E., Bailey, R. E., Rios, I., & Gubler, D. J. (1985). Dengue transmission in two Puerto Rican communities in 1982. *The American Journal of Tropical Medicine and Hygiene, 34*(3), 625-632.

Wilcox, B. A., & Gubler, D. J. (2005). Disease ecology and the global emergence of zoonotic pathogens. *Environmental Health and Preventive Medicine, 10*(5), 263-272.

CHAPTER SEVEN
ROLE OF KNOWLEDGE, RISK PERCEPTION AND ATTITUDES, AND PRACTICES IN DENGUE TRANSMISSION*

Abstract

This chapter examines the knowledge, attitudes, practices and risk perception of local community members and experts regarding dengue transmission in the city of Dhaka, Bangladesh. It also investigates explanatory socioeconomic factors that affect community knowledge, beliefs and practices. A random sample of households (N=300) was surveyed in 12 wards of Dhaka. This survey was supplemented by 12 focus group discussions (n=107) and 18 key informant interviews in three selected wards. Based on the Mental Model process, a total of 65 community respondents and 15 health experts randomly selected from the three selected wards were directly interviewed with semi-structured survey instruments to understand risk perception. The efforts to illustrate the Mental Models of dengue-disease-risk among the public and experts revealed that the former identified a low level of risk associated with dengue disease while the latter identified a high level of dengue-disease-risk in the city. The results revealed that the overall level of awareness of dengue among the local community members is low. Multivariate logistic regression modeling revealed that the respondents in age group 45–60 years were 2.83 times more likely to have positive attitudes towards undertaking precautionary measures to prevent dengue than the respondents aged, 25 years and under. These findings confirm the presence in local communities of misconceptions and considerable knowledge gaps regarding dengue transmission that could be improved by formulating interventions targeting specific subgroups of the population.

---

*Parts of this chapter were published: authors: Dhar-Chowdhury, P., Haque, C. E., Driedger, S. M., & Hossain, S.; year: 2014; title: Community perspectives on dengue transmission in the city of Dhaka, Bangladesh. *International Health*, doi:10.1093/inthealth/ihu032

7.1 Background

In the absence of vaccines and antiviral drugs, the most effective strategy for preventing dengue transmission is to control its vector (*Aedes* mosquitoes) by eliminating larval habitats, reducing adult mosquito populations, and preventing mosquito-human contact (Eisen et al., 2009). During the 1980s, *Aedes* control programs shifted from a 'top-down' to a 'bottom-up' model (Gubler 2002; Spiegel et al., 2007), with emphasis on community-based mosquito control approaches such as environmental management, health education, and community mobilization. The motivation for this shift lies in the decentralization of health services, breakdowns in vertical control programs, and shortages of trained personnel typically found in developing countries.

In these areas, the prevalence of poverty and political instability often preclude the maintenance of routine vector control measures during non-epidemic periods and negate many of the benefits associated with public sector investments in heath areas. As a result, although community-based approaches have been found to be effective on small scales (Castro et al., 2012), this approach can likely have only a limited impact on large-scale community-based interventions for dengue prevention and control (Perez et al., 2007). In order to assess the effectiveness of a community empowerment strategy for dengue vector control in La Lisa (Cuba), Castro et al. (2012) carried out a cluster randomized control trial with 16 interventions and 16 control clusters. They found that not only did the community participation score rise from 1.4 to 3.4, but knowledge of larval development sites was enhanced by 52.8% and 27.5% in the intervention and control clusters, respectively. Although there were no significant shifts in *Ae. aegypti* control practices at the household level in the control clusters, efficacy was increased by 36.2% in the intervention clusters. By contrast, Perez et al.'s (2007) study of a pilot project in the health area "26 de Julio" (La Havana) for a five-year period (1999-2004) revealed that in order to be effective, community-based dengue prevention requires a social learning process, along with a transfer of power and responsibilities to local community members.

Finding sustainable solutions for dengue vector control programs requires addressing not only technical and financial challenges, but also the lack of risk identification by the local community and the cultural beliefs, attitudes, and practices that prevent solutions from being successfully implemented. To accomplish this, recent health research underscores the importance of community knowledge, attitudes, and practices as well participation with a 'sense of ownership'(Ebi & Semenza, 2008). Understanding how people perceive the risk associated with dengue and its vector may help to at least partially solve this problem. Indeed, considerable improvements in local knowledge of dengue transmission and control have already been made in Colombia (Quintero et al., 2009), Thailand (van Benthem et al., 2002), and Cuba (Pérez et al., 2007). Because many risks associated with disease appear abstract and remote, and in many cases individuals are either overly optimistic or ignorant about these risks, an important aspect of public health information campaigns is explaining dengue risks in a manner which makes them appear immediate and real. In the developing world, dengue is often considered a 'mild' and common disease not requiring great personal investment - unless symptoms become unexpectedly severe (Gomez-Dantes & Willoquet, 2009). Recent studies have confirmed that local perceptions of risk are a critical factor in the performance of intervention programs as they significantly influence locals' motivation to participate in mosquito abatement efforts (Gómez-Dantés & Willoquet, 2009). Although public health campaigns and effective information dissemination can enhance dengue risk perception and control measures significantly, in most tropical developing regions, there is little appreciation for or sense of urgency concerning the dengue problem (Gómez-Dantés & Willoquet 2009). The ultimate purpose of mapping risk perception of dengue is to understand the role of individuals as proactive human agents and the local community as a collective entity in taking up prevention and control measures through behavior modification and the influencing of the policy domain.

In this regard, attempts to capture the public's and experts' conceptualizations, misconceptions, and belief systems through the formulation of mental models have proven quite successful (Dhar Chowdhury and Haque, 2011). Such exercises allow researchers to prescribe risk communication messages and appropriate strategies through identification of gaps in perception and knowledge among the stakeholders. I therefore set out to examine perceptions of various critical dimensions of dengue disease among both the lay-citizens, experts, and health managers in the City of Dhaka, Bangladesh. Recent health research asserts that understanding the role and importance of community knowledge, attitudes and practices (KAP) as well their *participation* with a 'sense of ownership' is necessary for improving disease control effectiveness (Leung, 2004). As a result, data on human perception, choice, preferences and behavior or practice constitute a substantial part of my research. To my knowledge, no systematic study has yet been conducted to understand the community level of knowledge, attitudes and practices (KAP) for dengue prevention among the population of Bangladesh.

The objectives of this chapter are to: i) identify the gaps in the public's and experts' mental models concerning dengue disease, its causes, transmission, and prevention and control measures; and ii) to explore both scientific and local interpretative views on dengue disease and its vectors, and how demographic and socio-economic explanatory and contextual factors may influence these views. In order to better analyze the KAP of local decision-makers, professionals, housewives and other community members possess concerning dengue (Chambers, 1992; 1994), focus group discussions (FGDs) and key informant interviews (KIIs), were employed.

The prevalence of multiple serotypes of dengue virus and a widespread population of healthy competent vectors in one of the most densely settled cities in the world created ideal conditions for the emergence of DF, DHF, and dengue shock syndrome (DSS) in Dhaka. The city's dengue disease risk configuration thus experienced significant amplification during the last two decades. The first documented outbreak of dengue fever in the Dhaka city was in 1964 (Russel et al., 1966), followed by a few sporadic cases of DF in 1977-78 and 1996-1997 (Karim et al., 2012). The first epidemic of DF and DHF in all major cities of Bangladesh, including Dhaka, took place during the monsoon of 2000, resulting in 5,521 reported cases with 93 fatalities. The monthly number of DF cases ranged from 0 to 3,281 (mean = 197.7, SD = 454.05), and the highest number of cases was reported in August 2002 (Banu, 2012). In the absence of scientifically-designed surveillance systems in Bangladesh (Mahmood and Mahmood, 2011), institutional responses to DF and DHF epidemics of 2000 and 2002 relied on information available from mass media and local public health concerns expressed through elected officials (such City Mayors and Ward Councilors) and public health personnel. The dengue epidemic prevention and control measures therefore remained in the form of *post-facto* interventions made as a result of public or political pressure upon the concerned authorities.

Over the last decade, as a result of both public health sector and private sector involvement, mass public education campaigns on dengue disease risk in association with exposure to *Aedes* mosquito bites were implemented using television, radio, and newspapers. Nonetheless, specific details concerning the host-vector-environment nexus was generally absent from such programs. In response to public and political pressure, the DCC authority reluctantly undertook periodic programs of spraying larvicides (e.g. DDT) and organophosphate insecticides (e.g. fenthion, malathion). For example, following the 2002 epidemic, the mayor of Dhaka City Corporation, Mr. Sadek Hossain Khoka, initiated a program to import 15,000 litres of larvicide for fumigation throughout the city of Dhaka (Mahmood, 2006). A number of critiques have argued that these measures were largely ineffective (Mahmood and Mahmood 2011). In explaining the 2002 dengue epidemic, the Daily Star (a local newspaper) reported that the DCC did neither "approve purchase of larvicide to kill the *Aedes* mosquito larvae …[nor did] it send any sample of the larvicide to the plant protection wing for approval. The worst thing was [that] DCC did not have a plan at hand to face dengue attack despite warnings previous year that the fatal infection would come in a wave" (cited in Mahmood, 2006:4).

7.2 Data Analysis

The methodology applied for collecting data from the Knowledge, Attitude and Practice (KAP) survey as well as for formulating 'mental models' of lay-persons and experts is detailed in Chapter 3. It is important here to reiterate that a total of 300 heads of households were interviewed in the KAP survey, and a total of 80 participants, of which 65 were local community members and 15 'experts' representing various stakeholders, were directly involved with the mental models formulation (Table 7.1). KAP Survey data were manually entered into Microsoft Excel® and all analyses were performed using SPSS statistical software, version 22, August, 2013, NY, U.S.A.

In order to synthesize the data, descriptive statistics were calculated for each variable of interest. Bivariate analyses were performed using Pearson's χ^2 methodology to compare responses to questions related to KAP of respondents from localities or wards characterized by distinct socioeconomic status. A p-value of ≤ 0.05 was considered statistically significant. Respondents were asked seven questions on knowledge and perception of dengue disease and *Ae. aegypti* mosquitoes; the responses were either in the form of a 'yes' (have knowledge of dengue and *Ae. aegypti* mosquitoes) or 'no' (do not have knowledge of dengue and *Ae. aegypti* mosquitoes) outcome. The number of questions for which the respondents were positive was counted and this score was then categorized as binary outcome based on the median (0 = score index ≤ 4 and 1= score index >4). Respondents were also asked five questions about their attitudes, and individual and institutional practices regarding prevention and control of dengue and its vector in the form of either an 'agree', or 'unsure'/'disagree' answer. For these responses, scores were then categorized as binary outcomes based on the median (score index = 0 and score index >0 = 1).

Table 7.1: Breakdown of interviewees by category

Interviewee by Category	Number of Interviewees	Percentage
A. Public Mental Model (n=65)		
i. Community members		
Male Service Holder⊗	19	29.2
Female Service Holder⊗	5	7.7
Housewives	32	49.2
ii. Local health workers	5	7.7
iii. Community leaders	4	6.1
Total	**65**	**100**
B. Expert Mental Model (n=15)		
i. Government officials	2	13.3
ii. Health professionals	7	46.6
iii. Academics	4	26.6
iv. Health sector entrepreneurs	2	13.3
Total	**15**	**100**

Logistic regression models were constructed to determine the effects of socioeconomic and demographic explanatory variables upon these survey responses. Univariate logistic regression analyses were initially performed to identify the potential explanatory variables for each outcome variable. Following Dhand et al.'s (2012) examples, I discarded explanatory variables with a likelihood ratio p-value of >0.25 for further analyses in the multiple logistic regression models. To facilitate interpretation, the stepwise selection method was chosen to identify important explanatory variables, which provided odds ratio estimates. The Hosmer-Lemeshow goodness-of-fit test was used to assess the validity of the final regression models. Focus group and key informant interview transcripts were imported into QSR International NVivo® (version 10) software for analysis. Written textual material was initially analyzed for its surface descriptive content, and then analyzed more

⊗ Service holders refer to the adult household members who are gainfully employed in tertiary economic sectors. Usually females are employed in light industry and office services whereas males are employed in retail, utilities, transportation, managerial, and administrative services.

interpretively for thematic content. As part of an ongoing engagement process, many participants and communities were debriefed of findings to assess congruency as well as to involve participants in subsequent phases of the research.

Public and experts' "Mental Models" development involved drawing "influence diagrams" which are essentially directed networks (Atman et al., 1994), composed of arrows or influences connecting related "nodes" (Morgan et al., 2001). In my study, influence diagrams were developed and analyzed in four stages: i) reviewing the literature; ii) performing a content analysis of the state of risk contained in the literature; iii) conducting FGDs with local community members, and experts; and iv) validating the consolidated influence diagram with a group of external experts in the scientific and policy domains. Data analysis was carried out using the original *Bengali* transcriptions; quotes presented in this Chapter have been translated into English. Because the present investigator is fluent in both Bengali and English, the translation fidelity is high. The transcripts were imported into QSR International NVivo® (version 10) software for analysis. Written textual material was initially analyzed for its surface descriptive content, and then analyzed more interpretively for thematic content. As part of an ongoing engagement process, many participants and communities were debriefed of findings to assess for congruency as well as to involve participants in subsequent phases of the research. Descriptive statistics were calculated for each variable of interest (Table 7.1).

7.3 Results

7.3.1 Public Mental Model

The influence diagram representing the public mental model of dengue disease risk, as delineated in Figure 7.1, consists of numerous physical, biological and human factors and their associated processes. Overall, a systematic categorization of the explanatory factors in the public model was absent; however, they were designated in various orders. In the first order, mosquito related features were delineated (Figure 7.1). The issues of city planning, market growth and land development - which affect the immediate city environment- were identified in the second order. Large scale, dispersed features were delineated in the third order (e.g. 'environmental pollution', 'change in weather patterns', 'marginalization of citizens' voices').

7.3.1.1 Perception of dengue disease and its vector

The results of my study revealed that the overall level of awareness of dengue among local community members was low. All interviewees (n=65) had heard about dengue but only 25 (38.5%) believed it posed a "serious threat". Furthermore, only two respondents were aware of the first major dengue outbreak in Dhaka in 2000; all respondents were also unaware of its resurgence in the following years. A total of 47 (72.3 %) interviewees knew that mosquitoes are primary vector of dengue; however, most were unaware that *Ae.aegypti* mosquitoes prefer to lay their eggs in water containers. Overall, responses did not reveal a clear understanding of the nexus of dengue virus, *Aedes* mosquitoes, and water containers; misconceptions regarding dengue disease transmission were registered in several areas. For example, 14 (21.5%) of the public participants believed that dengue is also caused by water-borne pathogens, other animals, or environmental pollution.

Regarding the causes of dengue, several other types of misconceptions were registered in the public mental models. For instance, 11 (16.9%) participants in public FGDs believed dengue to be an airborne disease, and that patients with respiratory diseases, like asthma, are more easily affected. Five (7.7%) participants believed that arsenic in the drinking water was also a natural route of dengue transmission. In the public mental model, dengue is also viewed as a food-borne disease; two community members believed 'eating chicken' to be a cause of dengue infection. One participant explained this notion as follows:

> *My brother got severe fever last year immediately after having a meal of chicken and rice in a restaurant. He was hospitalized and diagnosed as a dengue patient. I think eating chicken is another cause of dengue fever. We have to be careful about eating chicken in our daily meals* (interviewee number 10).

Recognizing that mosquitoes dengue's sole vector, 28 (43.1%) community members observed that recent social and urban infrastructural changes in the form of rapid house construction, urban sprawl, unplanned landuse and a decline in vegetation cover have led to the multiplication of larval development sites and an increase in dengue infection. In addition, 9 (13.8%) community members explained that rainfall is usually minimal during the winter season, and that heavy rainfall during this typically dry season - as has been experienced in recent years - increases dengue disease risk.

7.3.1.2 Perception of dengue disease symptoms

As a result of a general lack of awareness that dengue virus infection is potentially fatal, only 5 (7.7%) respondents regarded dengue fever as a "serious" disease. Considerable variation in knowledge concerning dengue symptoms exists among citizens, leading to the problems of under-diagnosis and confusion with other illnesses. It appeared that local people only knew about the disease's symptoms if they knew a family member or a friend who had suffered from the disease. They recognized that muscle pain, headache, bleeding, and rash are associated with dengue fever. Some degree of misconception was also noticed among the participants who had not been affected by the disease. For instance, diarrhea was falsely recognized as a symptom of dengue fever by 12 public FGD participants (18.5%).

Community members tend to think that dengue exhibits symptoms like skin disease, cough, diarrhea, or symptoms common to other diseases such as common cold, influenza, and jaundice. For female members of local communities, headache, muscle pain, and vomiting are very routine symptoms in their lives. Female community members believe that these symptoms do not require any special attention before 7 days of onset of the symptoms. One female participant expressed this notion in the following manner:

> *In Dhaka, having fever and cold is a daily phenomenon. If we panic about fever, then nothing in our family will be steady. Our children and husband are dependent on us. How can I visit a doctor just for a fever by ignoring other household chores?* (interviewee number 17)

7.3.1.3 Perception and practices regarding dengue prevention

When interviewees were asked how they could avoid exposure to dengue virus infection and illness, 46 (70.8%) perceived that using bed net while sleeping would be appropriate measure. Only 10 (15.4%) of the public FGD participants exercising their knowledge of dengue as a vector-borne disease, regularly cleaned water-holding containers to control mosquito larval development sites. Thirty two (49.2%) participants believed that aerial spraying of insecticides by government health departments can control mosquito abundance, while 28 (43.1%) participants perceived that controlling mosquitoes and avoiding their bites would not be possible under the prevailing socioeconomic and environmental conditions in the City of Dhaka.

> *We see too many mosquitoes throughout the year and the City of Dhaka has a unique problem with daily power cuts. It is therefore impossible to avoid mosquito bites especially during night times* ***(interviewee number 31).***

Local community members strongly believe that local government policies and practices regarding community health and development are ineffective, as evidenced by the absence of city garbage collection or regular cleaning of roadside drains. Forty two (64.6%) participants expressed frustration that the necessary information about dengue morbidity and mortality in the City was not readily available from government authorities. As they saw it, apathy and ignorance on the part of city authorities have resulted in the prevalence of water-containing potholes, roadside drainage ditches, and waste disposal sites. Notably, the aforementioned water-filled potholes are usually not suitable habitats for mosquito larvae; reflecting some degree of misconceptions among local community members concerning mosquito life-cycles.

7.3.2 Experts' Mental Model

The influence diagram on dengue disease risk developed from experts based on their beliefs, attitudes and values was "provisional" because the formulation of such diagrams demands both disciplinary and interdisciplinary orientation, and many dynamic factors would change their validity (Dhar Chowdhury et al., 2012). We noticed that experts' mental models of dengue disease risk were highly structured in terms of three causal factors: a) mosquito abundance; b) host characteristics and susceptibility; and c) human knowledge, attitude, and practices regarding dengue disease risk.

The expert mental model of dengue disease risk, outlined in Figure 7.2, is segmented in three generalized parts, each representing an interconnected but distinct domain. These include hydrometeorological variables such as rainfall, temperature and humidity, along with biological elements such as larval density and adult female mosquito density in Part 1, and characteristics of virus infection in terms of serotypes, sequence of infection, circulation, as well as host immunity and nutritional status in Part 2 (Figure 7.2). The right side of Part 3 depicts the social, economic, and cultural, and personality traits that significantly influence an individual's KAP concerning dengue disease risk. The left side includes macro-level institutional variables such as rapid urbanization, unplanned landuse, lack of compliance with building codes, and improper construction of buildings.

The main factors influencing dengue risk in a rapidly growing urban context are: changes in landscape and waterscape characteristics; changes in climatic elements including temperature, rainfall, and humidity; and increasing mosquito density. It was determined that host immunity characteristics in terms of age, gender, and racial background play a significant role in determining the degree of susceptibility. Peoples' susceptibility also depends on co-circulating serotypes of dengue virus in the concerned area.

The model reveals that the risk of dengue disease is not only a function of biological attributes of mosquitoes and humans, but also of multi-level socio-ecological attributes. The social-ecological attributes include human perception and behavior regarding dengue risk and resource use (e.g. water, vegetation, and waste disposal); individual decisions concerning health; public health services; urban sprawl; unplanned land-use; and poor housing conditions. One expert underscored the role of public institutions with following cautionary words:

> *The reported cases of dengue in this city will increase unless government take initiatives to help improving personal health and hygiene at the individual level, and allocate necessary financial and other resources for water supply and power supply maintenance at the municipal level* (expert FGD participant number 8).

7.3.3 KAP survey findings

The socio-demographic breakdown of KAP survey participants is depicted in Table 7.3. Among the 300 respondents of the KAP questionnaire survey, 60.7% were women and most were adults (the 25-44 age-group accounted for 58.4%). Almost half (46.8%) of respondents never attended a school and only 30.7% had an educational background beyond the grade 12 level. Occupationally, 36.3% of the respondents were involved in 'business' and 32% were professionals and/or governmental service workers (termed here as 'service holders'). The majority (55%) of the respondents' family had 'medium' income status, and only one-fifth (11.7%) belonged to the 'high' income category (Table 7.3). The socio-demographic characteristics of the participants in both focus group discussions and key informant interviews were relatively skewed towards higher educational attainment and higher income earning than the KAP survey respondents, reflecting predominance of male, educated, and high income earners in community and professional leadership positions in Bangladesh society (Table 7.3).

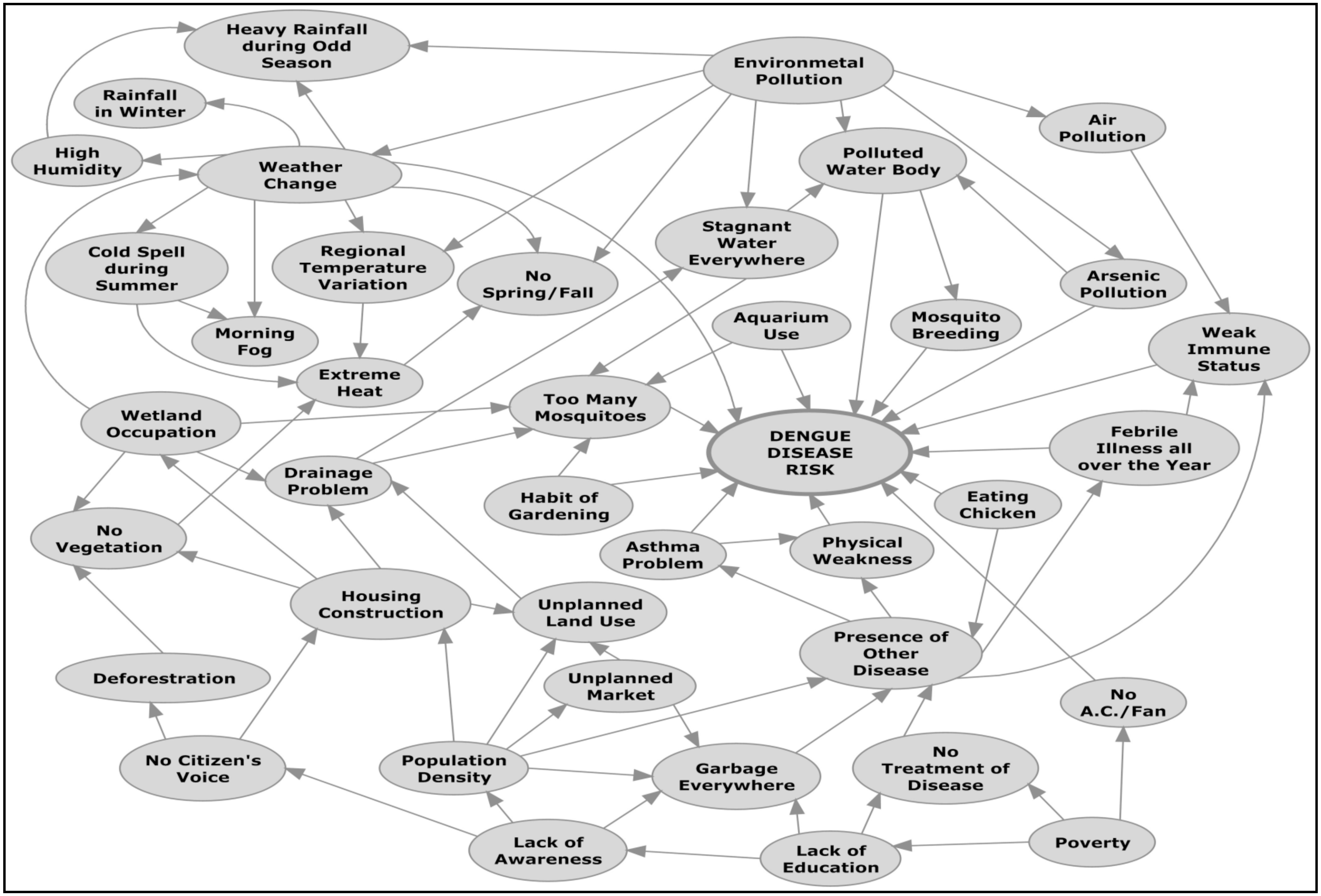


Figure 7.1: Public mental model of dengue disease risk in Dhaka, Bangladesh

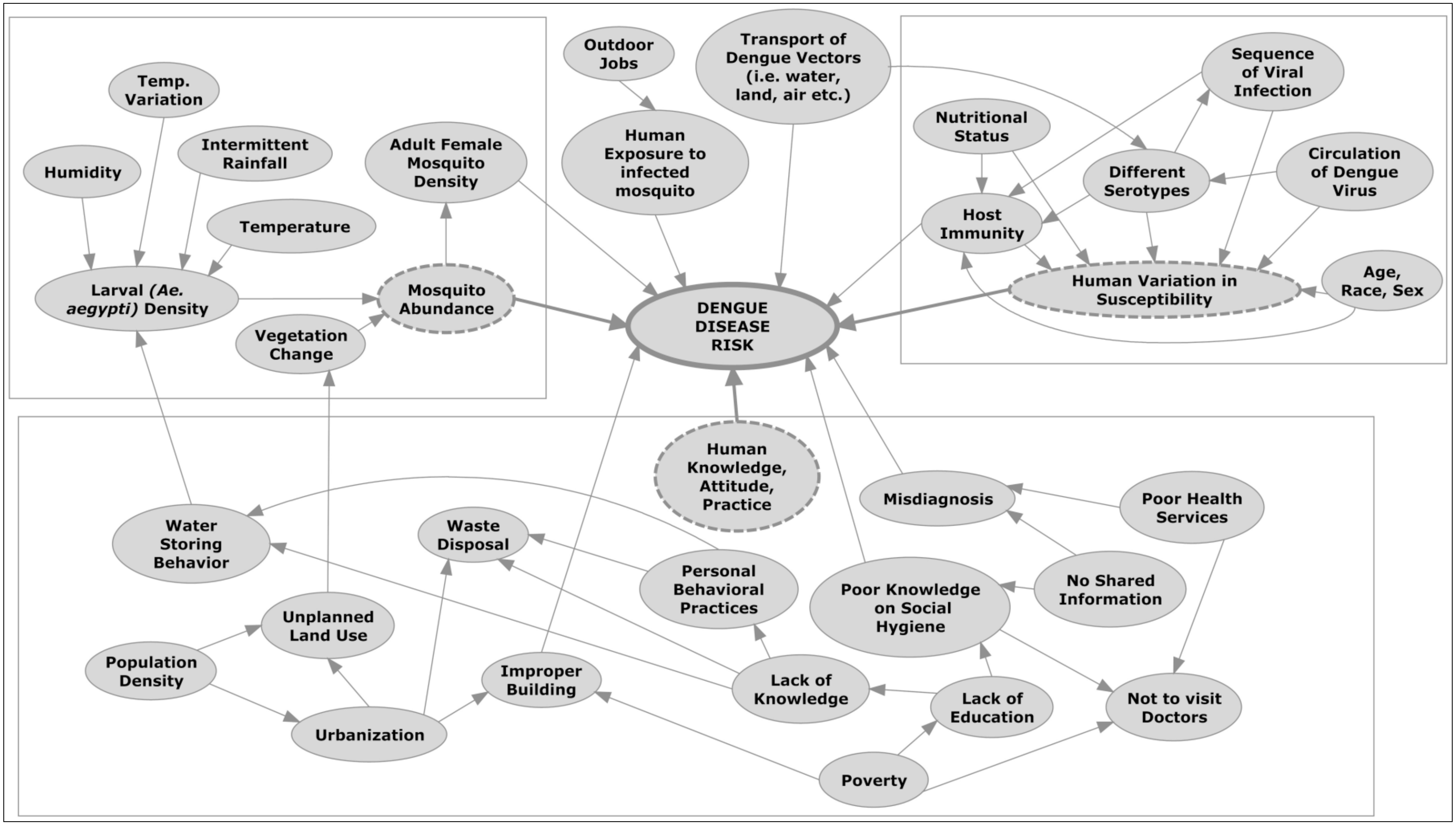


Figure 7.2**:** Expert mental model of dengue disease risk in Dhaka, Bangladesh

Table 7.2: Comparison between public and expert mental models regarding dengue disease risk, with gaps in knowledge and perception

Public mental models	Expert mental models	Gaps in knowledge and perception
People suffer from febrile illness throughout the year and dengue disease risk is nominal relative to other health issues	In terms of health risk, dengue is the second most important arboviral disease in Bangladesh, following malaria	Disease risk indicators and measurements vary significantly between experts and the public. Numerous misconceptions about dengue disease symptoms, severity, and risk exist among the public while experts have specific knowledge of dengue disease surveillance
"Dengue is a mosquito borne disease; however, mosquitoes are a day-to-day nuisance, and it is impossible to eliminate them from the urban environment "	Dengue disease spread is associated with virus-vector-host nexus, and in the absence of vaccine, vector control can reduce dengue disease burden and epidemic potential	Experts have specific knowledge of the role of *Aedes* mosquitoes in disease transmission, while the public has broader, unspecified knowledge about *Aedes* and its role in disease transmission
Very limited knowledge of dengue hemorrhagic fever (DHF) and dengue shock syndrome as potentially deadly threats	Dengue disease is caused by four serotypes of dengue virus (DENV) and the sequence of DENV serotype infection is an important risk factor with regards to disease severity (i.e. the development dengue hemorrhagic fever, dengue shock syndrome)	Significant knowledge gaps concerning disease severity exist in public mental models; the public rely heavily on experiential knowledge
Failure to take action against dengue vector mosquitoes is primarily associated with inefficiency of larger institutional activities related to water and power supply, which forces people to store water inside the house	Knowledge, Attitude and Practice (KAP) by the population regarding mosquito larval development sites inside and outside households play a significant role in dengue disease risk	Expert mental models recognize the significant role of individuals' knowledge, perception and behavior in controlling disease spread, while external forces (such as, government, foreign donors, NGOs) are viewed by the public as factors of dengue disease spread and risk to population
Local and national governments' failure to fumigate sustainably and disseminate public information is responsible for the continued dengue disease threat to the city population	Awareness of dengue disease risk among the population can effectively be enhanced by designing and implementing collaborative public information campaign programs with the cooperation of local communities and government departments	To reduce the burden of dengue, experts believe in the development of partnerships between government departments, the private sectors, and the local community, while the public focus is on local and national governments' capacity and accountability

7.3.3.1 Knowledge about dengue and its vector

Bivariate analyses of the respondents' knowledge of dengue disease and its vector (*Ae. aegypti*) were depicted in Table 7.4. Among survey respondents, 91.3% had heard of dengue. They obtained their knowledge from multiple sources; of which watching television (89.7%), reading newspapers (42.3%), interactions with friends and neighbors (30.3%), and staying in hospitals (16.7%) were predominant (Table 7.5). A total of 93.7% of the respondents identified that mosquito act as the primary vector of dengue. Of those respondents who had heard of dengue, the majority believed that dengue is a 'dangerous' and fatal disease (83%), and that dengue disease can be prevented (74.3%). However, most local community members (87.3%) were unaware that *Aedes* mosquitoes' preferred sites to lay their eggs are water containers (Table 7.4).

In terms of SES of communities (wards), significant differences exist among the respondents concerning their knowledge that *Aedes* mosquitoes prefer to lay their eggs in water containers (p-value = 0.019) as well as whether adequate local community efforts have been made to prevent or control dengue (p-value = 0.01; Table 7.4). Only 7.3% of the respondents from 'medium' SES communities were aware of the preferential behavior of *Aedes* mosquitoes' oviposition, while the corresponding datum for respondents in 'high' SES communities was relatively higher (25%).

In total, 65.7% of the respondents believed that local community efforts to prevent and control dengue were inadequate (Table 7.4). FGD and KII participants indicated that they frequently suffered from various kinds of mild fever-inducing illnesses. A total of 42% of FGD (n = 107) participants also believed that dengue fever was one of the illnesses which 'may be transmitted by water-borne pathogens, other arthropods, other animals and a dirty environment'. Within the KAP survey sample (n = 300), misconceptions about preferential oviposition by *Ae. Aegypti* was more prevalent among the daily laborers and housewives than other occupational categories (Figure 2a); 90% or respondents from these categories were 'unsure' or 'disagreed' that *Ae. Aegypti* mosquitoes prefer to lay their eggs in water containers (Figure 7.3.a). Although such knowledge was linearly associated with respondent's educational attainment, illiterates (i.e. 'no education' in Figure 7.3.b) were more aware because their higher exposure to mass media (Figure 7.3.b).

One male non-government health worker, as a key informant participant, explained that:

> *Mosquitoes that bite mostly breed in outside containers and they don't lay eggs inside houses. Our government leaders do not do much to control mosquitoes; also government departments do not coordinate among themselves. What can one expect from such a mess in the management of our city business?*

Table 7.3:Characteristics of knowledge, attitude and practice (KAP) survey (n = 300), focus group discussions (FGD) (n= 107), key informant interview (KII) (n =18) respondents in 12 and 3 communities, respectively in Dhaka, Bangladesh during 2011

Demographic and Socioeconomic characteristics	KAP Survey n (%)	FGD* n (%)	KII** n (%)
Gender			
Male	118 (39.3)	59 (55.1)	13 (72.2)
Female	182 (60.7)	48 (44.9)	5 (27.8)
Age (years)			
<25	42 (14.0)	11 (10.3)	0 (0)
25-44	175 (58.4)	51 (47.7)	8 (44.4)
45-60	61 (20.3)	34 (31.8)	7 (38.9)
60+	22 (7.3)	11 (10.8)	3 (16.7)
Education			
No schooling/education	139 (46.8)	3 (2.8)	0 (0)
Secondary	36 (12.1)	20 (18.7)	0 (0)
Higher Secondary	31 (10.4)	27 (25.2)	2 (11.1)
Graduate	56 (18.9)	43 (40.2)	7 (38.9)
Post Graduate	35 (11.8)	7 (6.5)	9 (50.0)
Occupation			
Service holder	96 (32.0)	39 (36.4)	5 (27.8)
Business	109 (36.3)	30 (28.0)	3 (16.7)
Housewife	20 (6.7)	22 (20.6)	0 (0)
Daily labor	21 (7.0)	2 (1.9)	0 (0)
Others (students, retired)	54 (18.0)	14 (13.1)	10 (55.6)
Income category (Taka/month)			
Low (<10,000)	72 (24.0)	4 (3.7)	0 (0)
Medium (10,000–49,999)	165 (55.0)	59 (55.1)	7 (38.9)
High (50,000>)	35 (11.7)	27 (25.2)	11 (61.1)
No Response	28 (9.3)	17 (15.9	0 (0)
Sources of dengue related information			
Television	269 (89.7)		
Radio	54 (18.0)		
Newspaper	127 (42.3)		
Friends/Neighbors	91 (30.3)		
Hospital	50 (16.7)		
Health Workers	6 (2.0)		
Others	10 (3.3)		

*Focus Group Discussion
** Key Informant Interviews

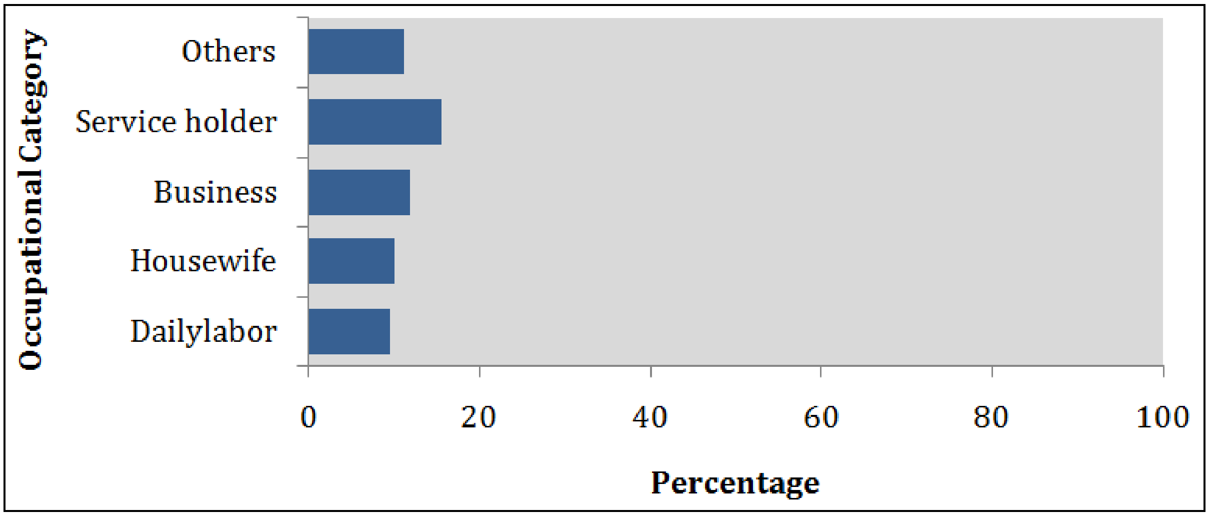


Figure 7.3.a: Distribution of responses by knowledge, attitude and practice (KAP) survey participants (n=300) to the statement that *Aedes* mosquitoes prefer to lay eggs in water containers' by occupational categories in Dhaka

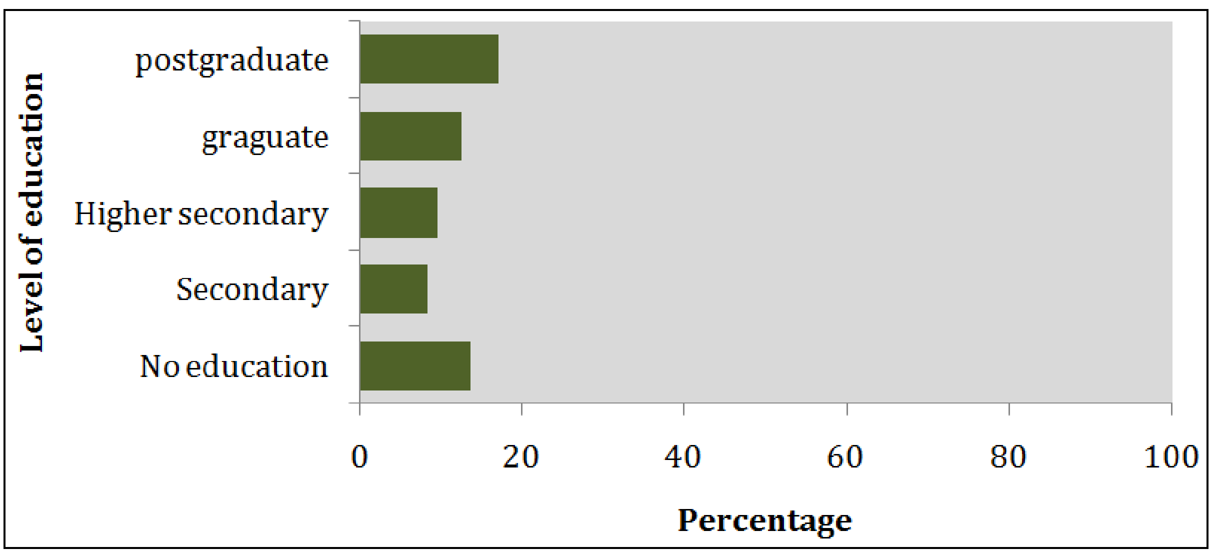


Figure 7.3.b: Distribution of responses by knowledge, attitude and practice (KAP) survey participants (n=300) to the statement that *Aedes* mosquitoes prefer to lay eggs in water containers' by educational attainment in Dhaka

Table 7.4: Descriptive and bivariate χ2 analyses of responses to questions related to the community members knowledge, belief, and perceptions of dengue and its vector, comparing respondents living in wards with 'low', 'medium', and 'high' Socio-Economic Status (SES) status, Dhaka, Bangladesh during 2011

Variable/category	n (%)	Respondent's socioeconomic zone of living [n (%)]			p-value
		Low	Medium	High	
	n = 300	n=154	n=110	n=36	
A. KAP regarding dengue disease					
Have heard of dengue					0.212*
Yes	274 (91.3)	142 (92.2)	97 (88.2)	35 (97.2)	
No	26 (8.7)	12 (7.8)	13 (11.8)	1 (2.8)	
Believe that dengue is a 'dangerous' and fatal disease					0.177*
Yes	249 (83.0)	131 (85.1)	92 (83.6)	26 (72.2)	
No	51 (17.0)	23 (14.9)	18 (16.4)	10 (27.8)	
Believe that dengue is transmitted by mosquitoes					0.822
Yes	281 (93.7)	144 (93.5)	104 (94.5)	33 (91.7)	
No	19 (6.3)	10 (6.5)	6 (5.5)	3 (8.3)	
Believe that dengue can be prevented or controlled					0.144*
Yes	223 (74.3)	116 (75.3)	85 (77.3)	22 (61.1)	
No	77 (25.7)	38 (24.7)	25 (22.7)	14 (38.9)	
B. KAP regarding dengue vector (*Aedes aegypti*)					
Believe that *Aedes* mosquitoes do not bite during day time					0.632
Yes	136 (45.3)	68(44.2)	49 (44.6)	19 (52.8)	
No	164 (54.7)	86 (55.8)	61 (55.4)	17 (47.2)	
Believe that *Aedes* mosquitoes prefer to lay eggs in water containers					0.019*
Yes	38 (12.7)	21 (13.6)	8 (7.3)	9 (25.0)	
No	262 (87.3)	102 (86.4)	102 (92.7)	27 (75.0)	
Believe that adequate community efforts were undertaken to prevent/control dengue					0.01*
Yes	103 (34.3)	65 (42.2)	27 (24.6)	11 (30.6)	
No	197 (65.7)	89 (57.8)	83 (75.4)	25 (69.4)	

These explanatory variables with a likelihood ratio p-value of < 0.25 were considered significant for further analysis

7.3.3.2 Explanatory factors associated with knowledge and perception of dengue and its vector

A binary logistic regression analysis was carried out to assess the association between the outcome binary variable based on knowledge, beliefs and perception of dengue disease, its vector, and the explanatory variables - namely, gender, age, watching television, reading newspapers, and staying in hospitals. The results are presented in Table 7.5. The variables included in the analysis had p-values of < 0.25 and the final model was constructed using the stepwise procedure. The findings indicate that respondents who stayed in hospital were 3.13 (CI 1.61-6.07) times more likely to hear about the dengue disease than respondents who did not (Table 7.5). I found that other explanatory variables are not significant at 5% level of significance. The model fit the data well (Hosmer-Lemeshow goodness-of-fit test, p-value = 0.997).

When cross-tabulated, it appeared that, as expected, a total of 77.2% of respondents who went to school believed that dengue disease can be prevented or controlled by human interventions; the corresponding datum for the respondents with no education was 71% (p-value = 0.224; Table 7.6). Such variation is likely to be attributed to the fact that the latter group is generally preoccupied more with day-to-day livelihood issues and tends to rely more on external forces (such as government, NGOs, *Allah*) for healthcare intervention than educated, better-off households.

Table 7.5: Final multivariate logistic regression model of explanatory factors associated with community members' knowledge, belief and perceptions of dengue disease and its vector in 12 wards of Dhaka, Bangladesh during 2011

Variable	Estimates	Standard Errors	p-value	OR (95%CI)
Constant	-1.075	0.404	0.007	
Watching Television (Yes vs. No)	0.713	0.413	0.085	2.04 (0.91-4.58)
Reading newspapers (Yes vs. No)	0.372	0.242	0.126	1.45 (0.90-2.33)
Staying in hospital (Yes vs. No)	1.141	0.338	0.007	3.13 (1.61-6.07)

Hosmer-Lemeshow goodness-of-fit test = 0.0471; p = 0.997

Table 7.6: Descriptive and bivariate $\chi 2$ Analyses of responses to questions related to the community members' knowledge, belief, and perceptions of dengue and its vector, comparing between illiterate (no education) and literate in 12 wards of Dhaka, Bangladesh 2011 (n = 300)

Variable/category	Respondent's educational Status [n(%)]		p-value
	Illiterate (no education /schooling)	Literate (all types of education)	
A. KAP of dengue disease			
Have heard of dengue			0.668
Yes	125 (90.6)	149 (92.0)	
No	13 (9.4)	13 (8.0)	
Believe that dengue is transmitted by mosquitoes			0.549
Yes	128 (92.8)	153 (94.5)	
No	10 (7.2)	9 (5.5)	
Believe that dengue can be prevented or controlled			0.224*
Yes	98 (71.0)	125 (77.2)	
No	40 (29.0)	37 (22.8)	
B. KAP of dengue vector (*Aedes aegypti*)			
Believe that *Aedes* mosquitoes do not bite during day time			0.737
Yes	64 (46.4)	72 (44.4)	
No	74 (53.6)	90 (55.6)	
Believe that *Aedes* mosquitoes prefer to lay eggs in water containers			0.596
Yes	19 (13.8)	19 (11.7)	
No	120 (86.2)	143 (88.3)	

* These explanatory variables with a likelihood ratio p-value of < 0.25 were considered significant for further analysis.

7.3.3.3 Attitude and institutional practice towards dengue vector control

The bivariate analyses of respondents' attitudes towards prevention of dengue via vector control have revealed that more than three quarters of local community members were seriously concerned about the dengue disease burden on their families, especially during the rainy seasons. The overwhelming majority of the households (89.7%) were inclined towards undertaking precautionary measures to avoid dengue disease (Table 7.7). However, when queried about whether "it is necessary to clean water containers in and around the house once a week," 82.7% of the respondents were 'unsure' or 'disagreed' with such a proposition (Table 7.7). Community members generally felt (85%) that those government institutions responsible for public health did not take the necessary steps to help prevent or control dengue. Moreover, 94% of the local community members reported that they did not receive any support from local leaders or organizations to prevent and control dengue.

Community members and other local residents participating in focus group discussions thought that insecticides were generally effective in controlling the mosquito population. However, they also believed that due to a lack of sustained action by government mosquito control programs, locals remained susceptible to mosquito bites throughout the year. Some people reported that a few governmental programs, such as the public risk communication campaigns delivered through media channels and cultural activities such as, street theatre, seasonal fair, have helped in disseminating information on dengue-mosquito-human relationships.

7.3.3.4 Explanatory factors associated with attitude and institutional practices

Another binary logistic regression model was formulated to assess the association between the outcome variables related to attitude towards prevention and control of dengue and institutional measures and the demographic and socioeconomic explanatory variables. The results are presented in Table 7.8. Respondents who are engaged in business are less likely [OR = 0.47 (CI 0.25-0.85)] to undertake proactive measures to prevent dengue compared to other occupational categories, such as daily laborers and housewives. The odds ratio for the age group 45-60 compared <25 years was 2.83 and the differences were statistically significant (p = 0.021). This implies that the respondents in the age group 45-60 were 2.83 times more likely to have positive attitudes towards undertaking measures to prevent dengue than the respondents in the age groups 25 years and less (Table 7.8). [OR=2.83, CI: 1.16-6.90]. The model fitted the data well (Hosmer-Lemeshow goodness-of-fit test, p-value= 0.928).

Table 7.7: Descriptive and bivariate $\chi 2$ analyses of responses to questions related to the community members' attitude and perceptions of prevention and controlling dengue and its vector, comparing respondents living in wards with 'low', 'medium', and 'high' Socio-Economic Status (SES) status, Dhaka, Bangladesh during 2011

Variable/ category	n (%)	Respondent's socioeconomic zone of living [n (%)]			p-value
	n = 300	Low n=154	Medium n=110	High n=36	
Would like to take precautionary measure during monsoon, rainy season					0.277
Agree	269 (89.7)	137 (89.0)	97 (88.2)	35 (97.2)	
Unsure/Disagree	31 (10.3)	17 (11.0)	13 (11.8)	1 (2.8)	
Would like to clean water holding containers in and around the house once a week					0.241*
Agree	52 (17.3)	32 (20.8)	16 (14.5)	4 (11.2)	
Unsure/Disagree	248 (82.7)	122 (79.2)	94 (85.4)	32 (88.8)	
It is impossible to eliminate mosquito larval development sites/places					0.21*

Variable/ category	n (%)	Respondent's socioeconomic zone of living [n (%)]			p-value
	n = 300	Low n=154	Medium n=110	High n=36	
Agree	20 (6.7)	14 (9.1)	5(4.5)	1 (2.8)	
Unsure/Disagree	280 (93.3)	140 (90.9)	105 (95.5)	35 (97.2)	
Government has taken necessary measures to prevent/control dengue					0.483
Agree	45 (15.0)	24 (15.6)	18(16.4)	3 (8.3)	
Unsure/Disagree	255 (85.0)	130 (84.4)	92 (83.6)	33 (91.7)	
					0.261
Received adequate support from local level community organizations to prevent/control dengue					
Agree	18 (6.0)	10 (6.5)	8 (7.3)	0 (0)	
Unsure/Disagree	282 (94.0)	144 (93.5)	102 (92.7)	36 (100)	

* These explanatory variables with a likelihood ratio p-value of < 0.25 were considered significant for further analysis.

Table 7.8: Final multivariate logistic regression model of explanatory factors associated with community members' attitude and perceptions of prevention and controlling dengue and its vector in 12 wards of Dhaka

Variable	Estimates	Standard Errors	p-value	OR (95%CI)
Constant	-1.14	0.415	0.006	
Illiterate vs. Literate	0.481	0.266	0.071	1.62 (0.96-2.72)
Occupation				
Business vs. others	-0.764	0.306	0.013	0.47 (0.25-0.85)
Service holder vs. others	-0.392	0.323	0.225	0.68 (0.36-1.27)
Age				
25-44 vs. <25	0.765	0.404	0.058	2.14 (0.97-4.74)
45-60 vs. <25	1.041	0.454	0.022	2.83 (1.16-6.90)
65+ vs. <25	1.095	0.572	0.055	2.99 (0.97-9.18)

Hosmer-Lemeshow goodness-of-fit test =3.09; p = 0.928

7.4 Discussion

Analysis of multiple factors including the dengue epidemic in 2000 and recurrent incidences, high levels of poverty and population density, poor water supply infrastructure, poor waste management provisions (whereby significant number of containers become breeding sites for *Ae. aegypti* mosquitoes), and observations of health professionals have assisted in determining that there is in fact a high level of dengue disease risk in the city of Dhaka. However, my attempts to illustrate mental models of dengue disease risk among the public and experts have revealed that the public perceived dengue infection risk to be low, while the experts (e.g., health regulators, managers, practitioners) identified a high level of dengue disease risk in the city (Table 7.2). In particular, with respect to the causes of dengue disease and it various forms (i.e. DHF and DSS), health experts used specific cause-and-effect relational tools to explain the host-vector-environment nexus. Local community members were much less likely to be aware of the prevalence and seriousness of dengue fever and dengue hemorrhagic fever and tended to believe that the symptoms of this disease were simply a feature of everyday life. The role of socioeconomic attributes of households was found to be profoundly important to dengue transmission knowledge attainment. For example, daily wage earners and housewives, had the least knowledge of *Ae. aegypti* behavior relative to other occupational categories.

The findings revealed that a mild fever is a daily occurrence among the medium and low SES groups, many community members have accepted such risk as a routine part of life - most likely because other problems (e.g., being able to feed their family) are much more immediate and pressing (Suarez et al., 2005). In the absence of comparable studies of dengue disease risk mental models for in other regions of the world, I found the findings of my investigation to be consistent with risk perceptions and beliefs regarding other types of diseases. For example, in a study of waterborne disease-related risk perceptions in northern Mexico, Morua et al. (2011) recorded low levels of risk identification and awareness. Such low levels of awareness were also observed in several Latin American countries (Lal et al., 2012). Lal et al. (2012) recorded that most respondents in the City of Jaipur, India had some knowledge of dengue fever, mostly gathered from mass media, but lacked specific knowledge of dengue disease transmission. Such deficiencies in knowledge were more predominant among the elderly (65+ years of age). These findings conform to my observations in the City of Dhaka. In Dhaka, community members at large were also confused as to the source of dengue virus, confirming similar misconceptions found in other studies.

Overall, a high degree of confusion and ambiguity in conceptualizing dengue transmission was evident among local community members. My study also revealed significant differences in knowledge, attitude, and perceptions among respondents from 'low', 'medium' and 'high' SES wards. While the majority were aware of some important dengue vector characteristics (e.g. daytime exposure, peak seasons), people were generally unsure of how they, as individual agents, could address vector-borne diseases like dengue. Many community members held the misconception that dengue vectors lay eggs only in 'dirty water'. *Such misconceptions about developmental sites were also found in other Asian and Central American countries. For example, study by Lal et al.*(2012) *found that the vast majority of respondents identified 'dirty water' and 'garbage' disposal sites as the most important larval development sites.* Another common misconception among Dhaka residents was related to the causal link between dengue and food. *In Puerto Rico*, Pérez-Guerra et al. (2009) study identified five types of misconception among the participants, including incorrect description of the Aedes aegypti mosquitoes, type of water and containers, the ubiquitous nature of humid places and vegetation, 'cleanliness', and confusion of dengue with common cold. Misconception of dengue symptoms was also registered at the local level, along with a general failure to manage water containers and *Aedes* larval development sites. These findings are indicative of significant gaps in public health education.

It is worth noting here that several studies in Taiwan (Pai et al., 2005) and Vietnam (Tran et. al., 2010) have revealed that public health education campaigns by the prevailing institutions can effectively enhance knowledge of causes of diseases among citizens and address public misconceptions. Nonetheless, several Latin American (Quinteroet al., 2009; Gómez-Dantés et al., 2009; Pérez-Guerra et al., 2009) and Southeast Asian (Pai et al., 2005; Tran et al., 2010) investigations revealed that control and prevention practices do not solely depend on clear conception and knowledge of disease risk. In this regard, significant enhancement has been made in community awareness and knowledge of dengue prevention and control at the local level in various parts of the world, such as Puerto Rico (Winch et al., 2002) and Thailand (Pylypa et al., 2009). In Nicaragua and the Philippines, collaborative education campaign programs have proven their efficacy in increasing knowledge and awareness of the disease and its transmission. In Bangladesh, people - especially those in low-SES groups - tend not to visit clinics and hospitals when suffering mild fevers. Social and infrastructural factors also often function as deterrents against clinic or hospital use. For example, traffic congestion in Dhaka is among the worst of all cities in the world, and visit a clinic can demand many hours of travel time. Many of these actions are highly correlated with motivational factors, including the ranking of community and individual-level concerns and the willingness to act (Giddens, 1984; Metcalfe et al., 2010) Effective education campaigns, formal training, and community education programs should therefore focus specifically on dengue transmission, early dengue diagnosis and treatment, and the potential complications of hemorrhagic dengue and neuro-dengue, as well as the establishment of more easily accessible primary health care centers.

Gómez-Dantés and Willoquet (2009) noticed that dengue disease is not viewed by the poor communities in the developing world as medical priority because social, economic and environmental priorities are more compelling than "an inadvertent, mild fever solved by self medication which rarely requires clinical attention." Studies on diarrhea (McLennan, 2000) and water-borne diseases (Morua et al., 2011) have also found that the public were not adopting recommended measures. Complex sets of socioeconomic, psychosocial and cultural factors are likely responsible for such reluctance to adopt disease prevention and control measures. Many people underestimate their health risk due to what Weinstein (1980) calls 'optimistic bias'. In Dhaka, the population in general felt that dengue could be largely controlled in the city by the use of insecticides, but such institutional actions were lacking. There were a few community-based dengue vector control and public education campaigns, but there existed serious deficiencies in coordinating such measures. Mosquito-borne disease prevention campaigns should therefore concentrate on clearly explaining why these diseases are a 'problem' that can have immediate impact on a household's capacity to work and put food on the table, and how they can be prevented without much personal financial investment. Most community members, particularly women, had heard of dengue but were 'passive' in undertaking household-level preventive measures. This pattern was also evident in the comparison between the illiterate and those who attended school. Because the level of knowledge and awareness of the disease risk was significantly correlated with working outside the home, exposure to mass media (especially television), public health policy on dengue control should focus on reaching out to those people who largely remain at home (e.g. housewives, the elderly). Moreover, community members frequently mentioned local health authorities and local leaders as trusted information sources (Appendix XVII; Images7.1 and 7.2). Hence, if these two authorities were used to disseminate dengue transmission and prevention strategies, people might be more likely to follow health recommendations.

The issues which community members are most concerned about are quite challenging for risk communicators to handle. In many cases, the concerns that the public have about dengue disease risk, causes and consequences are associated with individual perceptions and behavior along with socioeconomic and cultural contexts, and cannot be entirely addressed by institutional interventions. However, as health and disease risk communication plays a pivotal role in the construction of mental models of the public concerning these phenomena, there is significant room for improvement in institutional efforts in risk communication. A more collaborative and integrated communication strategy between experts, decision-makers, and community stakeholders is needed. Too often, communication is unidirectional, with messages focusing on linking health and disease issues with prevailing local community level social, economic and environmental issues. In an era where the global environment and the risks posed by dengue and other emerging infectious diseases are continuously evolving, it is critical now more than ever to develop better strategies for bringing together experts and the public. Community-focused, individual needs-based health and livelihood issue programs are likely to produce better outcomes in terms of motivational and behavioral changes. A system of interactive communication between key decision makers and community members, focusing specifically on health policies and interventions, would help greatly in developing such programs.

Motivation, unlike information and education, is the psychological element that stimulates interest, concern, and action; awareness of risk and strategies may mitigate risk to some extent but may not necessarily transform human agency to undertake direct action (Ronan and Johnston, 2005). The motivating element to prevent and control dengue at the community level is strongly associated with addressing the daily life issues of the poor and the socioeconomic incentives of the larger community. A sense of powerlessness among the public underpins public inaction and attitudes towards the transfer of public health responsibility to government institutions. Effective community engagement in dengue disease risk mitigation demands more than just dissemination of information; it requires processes for formulating community ownership and participation grounded on a partnership with an understanding of public knowledge, beliefs, attitudes and local community norms and culture.

My study modified a generic methodology for understanding knowledge, beliefs, and practices concerning dengue risk in the City of Dhaka, Bangladesh. Conventionally, the mental model treats expert knowledge and perception as the benchmark for understanding the causal links between various relevant elements (in this case, virus-vectors-hosts, epidemic potential and its associated risk, and appropriate interventions). The formulated expert mental models are then compared with the general public mental models, capturing their knowledge, perception and beliefs. I have, by departing from this conventional approach, attempted to modify the mental model approach so that incorporates a high degree of complexity and contextual richness in its public representation and understanding. These include considerations such as the effect that community members' livelihoods have on their understanding of local inhabitants' risk to dengue disease. Also, personal situational factors that may influence public uptake of risk communication messaging and recommendations to protect public health, particularly from emerging infectious diseases, were considered. In my study, a considerable proportion of laypeople did not believe that mosquitoes can be controlled by eliminating larval development sites or by fumigation, which suggests that such misconceptions need to be addressed first in risk communication measures. A more nuanced understanding of people's knowledge and beliefs is required to help guide responsible communications. The merit of applying the suggested modified mental model, in which the usage of expert's mental model as benchmark is avoided and both the publics' and experts' mental models are treated as parts of a continuum of knowledge, is that the true scope of human belief systems encompasses both scientific and social/cultural ideas and factors.

Dengue disease risk and control options campaigns need to focus on clearly explaining why dengue is a serious problem and how it can be controlled or avoided - especially without resorting to bed nets and mosquito coils. Dengue risk communication strategies need to describe the transmission process, the role of *Aedes* mosquitoes in transmission, the significance of water-filled containers as larval development sites, preferred *Aedes* biting times, and the importance of the sequence of dengue virus serotype infection in disease severity (i.e. in the development of dengue hemorrhagic fever, and dengue shock syndrome). In conclusion, addressing prevailing misconceptions regarding dengue fever should be the first step in enhancing community members' capacity to effectively participate in research and change their behavior to mitigate risk of dengue infection. Targeted dengue prevention and control programs are needed for special subgroups of the population, according to categories such as gender (housewives), age (less than 25 years), occupation (daily laborers, businessmen, and women), and education (adult illiterate). These specific categories of citizens play critical roles in water, waste and other types of resource management within the households as well as in the larger social structure. It is evident that any strategy to further enhance individual and collective consciousness and change behavior must also address the issues associated with poverty in order to achieve a greater impact.

7.5 Limitations

Findings of my study contribute to the very limited understanding of dengue disease risk perceptions in developing countries. They have revealed that misunderstandings and misconceptions regarding the causes of dengue, the risks posed by the disease, and potential solutions for controlling infection are common among the public, particularly at the local level.

Prevalence of such misconceptions, and knowledge and information gaps among the public is a significant barrier to the implementation of dengue prevention and control programs. My findings suggest that, in a developing country like Bangladesh where arboviral fevers are a regular and common occurrence, many people view these health conditions as a routine part of life - most likely because other livelihoods issues and problems, such as feeding their families, are more pressing.

References

Atman, C. J., Bostrom, A., Fischhoff, B., & Morgan, M. G. (1994). Designing risk communications: Completing and correcting mental models of hazardous processes, part I. *Risk Analysis, 14*(5), 779-788.

Banu, S., Hu, W., Hurst, C., Guo, Y., Islam, M. Z., & Tong, S. (2012). Space-time clusters of dengue fever in Bangladesh. *Tropical Medicine & International Health : TM & IH, 17*(9), 1086-1091.

Castro, M., Sanchez, L., Perez, D., Carbonell, N., Lefevre, P., Vanlerberghe, V., & Van der Stuyft, P. (2012). A community empowerment strategy embedded in a routine dengue vector control programme: a cluster randomised controlled trial. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 106*(5), 315-321.

Chambers, R. (1992). *Rural apprasial: rapid, relaxed and participatory* Institute of Development Studies (UK).

Chambers, R. (1994). Participatory rural appraisal (PRA): Analysis of experience. *World Development, 22*(9), 1253-1268.

Creswell, J. W. (2009). *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*. Los Angeles, London, New Delhi,Singapore: Sage.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches* Sage Publications, Incorporated.

Dhand, N. K., Rai, B. D., Tenzin, S., Tsheten, K., Ugyen, P., Singye, K., & Ward, M. P. (2012). Community-based study on knowledge, attitudes and perception of rabies in Gelephu, south-central Bhutan. *International Health, 4*(3), 210-219.

Dhar Chowdhury, P., Haque, C. E., & Driedger, S. M. (2012). Public versus expert knowledge and perception of climate change-induced heat wave risk: A modified mental model approach. *Journal of Risk Research, 15*(2), 149-168.

Dhar-Chowdhury, P., Emdad Haque, C., Michelle Driedger, S., & Hossain, S. (2014). Community perspectives on dengue transmission in the city of Dhaka, Bangladesh. *International Health*, doi:10.1093/inthealth/ihu032.

Ebi, K. L., & Semenza, J. C. (2008). Community-based adaptation to the health impacts of climate change. *American Journal of Preventive Medicine, 35*(5), 501-507.

Eisen, L., Beaty, B. J., Morrison, A. C., & Scott, T. W. (2009). Proactive vector control strategies and improved monitoring and evaluation practices for dengue prevention. *Journal of Medical Entomology, 46*(6), 1245-1255.

Gómez-Dantés, H., & Willoquet, J. R. (2009). Dengue in the Americas: challenges for prevention and control. *Cadernos De Saúde Pública, 25*, S19-S31.

Gubler, D. J. (2002). Epidemic dengue/dengue hemorrhagic fever as a public health, social and economic problem in the 21st century. *Trends in Microbiology, 10*(2), 100-103.

Karim, M. N., Munshi, S. U., Anwar, N., & Alam, M. S. (2012). Climatic factors influencing dengue cases in Dhaka city: a model for dengue prediction. *The Indian Journal of Medical Research, 136*(1), 32.

Lal, V., Chandra, D., & Gupta, S. D. (2012). Knowledge of dengue and related preventive attitude and practices among urban slum dwellers of Jaipur city, Rajasthan, India. *Dengue*, *36*, 197.

Leung, M. W., Yen, I. H., & Minkler, M. (2004). Community based participatory research: a promising approach for increasing epidemiology's relevance in the 21st century. *International Journal of Epidemiology, 33*(3), 499-506. doi:10.1093/ije/dyh010

Mahmood, B. A. I., & Mahmood, S. A. I. (2011). Emergence of Dengue in Bangladesh a major international public health concern in recent years. *Journal of Environmental Research and Management, 2,* 035-041.

Mahmood, S. A. I. (2006). Dengue: An Epidemic Is Largely a Failure in Public Health Administration! The Role of Dhaka City Corporation, DCC of Bangladesh. *World Health and Population,* doi:doi:10.12927/whp.2005.17900

McLennan, J. D. (2000). Prevention of diarrhoea in a poor district of Santo Domingo, Dominican Republic: practices, knowledge, and barriers. *Journal of Health, Population and Nutrition, ,* 15-22.

Metcalfe, J., Eich, T. S., & Castel, A. D. (2010). Metacognition of agency across the lifespan. *Cognition*, *116*(2), 267-282.

Morgan, M. G., Fischhoff, B., Bostrom, A., & Atman, C. J. (2001). *Risk communication: A mental models approach* Cambridge University Press.

Morua, A. R., Halvorsen, K. E., & Mayer, A. S. (2011). Waterborne disease-related risk perceptions in the Sonora River basin, Mexico. *Risk Analysis : An Official Publication of the Society for Risk Analysis, 31*(5), 866-78. doi:10.1111/j.1539-6924.2010.01570.x

Pai, H., Lu, Y., Hong, Y., & Hsu, E. (2005). The differences of dengue vectors and human behavior between families with and without members having dengue fever/dengue hemorrhagic fever. *International Journal of Environmental Health Research, 15*(4), 263-269.

Pérez, D., Lefèvre, P., Sánchez, L., Sánchez, L., Boelaert, M., Kourí, G., & Van Der Stuyft, P. (2007). Community participation in Aedes aegypti control: a sociological perspective on five years of research in the health area ‘‘26 de Julio’’, Havana, Cuba. *Tropical Medicine & International Health*, *12*(5), 664-672.

Pérez-Guerra, C. L., Zielinski-Gutierrez, E., Vargas-Torres, D., & Clark, G. G. (2009). Community beliefs and practices about dengue in Puerto Rico. *Revista Panamericana De Salud Pública, 25*(3), 218-226.

Pylypa, J. (2009). Local perceptions of dengue fever in northeast Thailand and their implications for adherence to prevention campaigns. *Anthropology and Medicine, 16*(1), 73-83.

Quintero, J., Carrasquilla, G., Suárez, R., González, C., & Olano, V. A. (2009). An ecosystemic approach to evaluating ecological, socioeconomic and group dynamics affecting the prevalence of Aedes aegypti in two Colombian towns. *Cadernos De Saude Publica, 25*(SUPPL. 1), S93-S103.

Ronan, K. R., & Johnston, D. M. (2005). *Promoting community resilience in disasters* Springer.

Russell, P. K., Buescher, E. L., McCown, J. M., & Ordonez, J. (1966). Recovery of dengue viruses from patients during epidemics in Puerto Rico and East Pakistan. *The American Journal of Tropical Medicine and Hygiene, 15*(4), 573-579.

Spiegel, J. M., Ibarra, M., Kouri, G.,et al. (2007). An integrated ecosystem approach for sustainable prevention and control of dengue in central Havana. *International Journal of Occupational and Environmental Health, 13*(2), 188-194.

Suarez R, Gonzalez C,Carrasquila G et al. (2005). An ecosystem perspective in the socio-cultural evaluation of dengue in two Colombian towns. *Cad. Saude Publica, 25*(Sup 1), S104-S114.

Tran, H. P., Adams, J., Jeffery, J. A., Nguyen, Y. T., Vu, N. S., Kutcher, S. C., . . . Ryan, P. A. (2010). Householder perspectives and preferences on water storage and use, with reference to dengue, in the Mekong Delta, southern Vietnam. *International Health, 2*(2), 136-142. doi:10.1016/j.inhe.2009.12.007; 10.1016/j.inhe.2009.12.007

Van Benthem, B., Khantikul, N., Panart, K., Kessels, P. J., Somboon, P., & Oskam, L. (2002). Knowledge and use of prevention measures related to dengue in northern Thailand. *Tropical Medicine & International Health, 7*(11), 993-1000.

Weinstein, N. D. (1980). Unrealistic optimism about future life events. *Journal of Personality and Social Psychology, 39*(5), 806.

Winch, P. J., Leontsini, E., Rigau-Perez, J. G., Ruiz-Perez, M., Clark, G. G., & Gubler, D. J. (2002). Community-based dengue prevention programs in Puerto Rico: impact on knowledge, behavior, and residential mosquito infestation. *The American Journal of Tropical Medicine and Hygiene, 67*(4), 363-370.

CHAPTER EIGHT

TOWARDS UNDERSTANDING DENGUE TRANSMISSION: INTEGRATION FOR TRANSDISCIPLINARY KNOWLEDGE DEVELOPMENT*

8.1 Application of an Ecohealth Approach to Understand Dengue Transmission

As a unique infectious disease, the geographical and demographic extent of dengue is global and is spreading rapidly across many countries. Over the last 30 years, dengue outbreaks have expanded to new geographical areas at an unprecedentedly rapid pace, and all four dengue virus serotypes (DENV1–4) are now circulating in Asia, Africa and the Americas. In fact, dengue has become the most rapidly advancing vector-borne disease worldwide, with an estimated 50 million dengue infections occurring every year (Guzman et al., 2010). Consequently, an estimated 3.61 billion people in 124 countries worldwide are now at risk of being infected (Baly et al., 2012; Beatty et al., 2010).

The historical evolution of dengue virus (DENV) to become the most important arboviral disease of humans is closely tied to the evolution of urbanization and globalized trade. The primitive cycle of DENV involved canopy-dwelling mosquitoes and non-human primates in the rainforests of Asia and possibly Africa. Humans were exposed to the viruses through the bite of infected mosquitoes when they entered the forests to hunt, cut wood, or perform other activities (Wilcox et al., 2008). In the seventeenth, eighteenth, and nineteenth centuries, as global trade and the shipping industry developed, water

* Parts of this chapter were published: authors: Dhar Chowdhury, P., Haque, C. E.;year: 2014; title: Why is an Integrated Social-Ecological Systems (ISES) Lens Needed to Explain Causes and Determinants of Disease? A Case Study of Dengue in Dhaka, Bangladesh, in Maya K. Gislason (ed.) *Ecological Health: Society, Ecology and Health (*Advances in Medical Sociology, Volume 15*)* Emerald Group Publishing Limited, Bingley, UK, pp.217 - 239

barrels carried on sailing vessels were frequently infested with mosquitoes, and ships maintained active transmission of DENV across countries through infected mosquitoes and crew members (Gubler, 1997; 2002).

During the post-World War II era, urban growth in tropical and subtropical regions without well-organized water and waste management systems has resulted in increased populations of mosquitoes living in intimate association with crowded human populations. Specifically, unplanned and unchecked urbanization in most tropical countries, along with the plethora of water-holding containers, have supported the intense larval development of dengue vectors. Also, emerging vector abundance has not remained locally confined as ever-increasing commercial shipping and air traffic have greatly enhanced the spread of *Aedes* mosquitoes and the dissemination of DENV through the rapid transit of viraemic individuals around the world. Since the agglomeration of human population to a certain threshold (in the range between 10,000 and 1,000,000) has been found to be a critical factor in sustaining dengue disease transmission (Kuno, 1997), ever-increasing population densities have radically changed the risk scenarios in the tropical world.

By embracing linear thinking about disease causation and distribution, concerned public health authorities during the 1960s and 1970s opted for vector control through environmental perturbation and pesticide application. As there is not yet any effective vaccine or treatment for dengue, it was generally accepted that the most feasible means to prevent dengue transmission was to reduce the population size of its principal vector (i.e., *Aedes aegypti*) through larval source reduction. Primarily based on disciplinary knowledge of entomology and toxicology, relevant government departments in many countries of the tropical world adopted intervention programs focusing on larval control in domestic water storage and collection containers as well as the use of insecticides (mainly DDT) (Spiegel et al. 2007; Heintze et al. 2007).The thrust of such government-initiated, vertically structured (i.e., top-down) institutional programs was simplistic, hinging on the assumption that because mosquito larval development precedes disease transmission, controlling the vector population before the disease would break the disease transmission cycle.

The historical predominance of disciplinary approaches to disease causation, their emergence and reemergence, was analyzed in a study by Dhar-Chowdhury and Haque (2013) and Parkes et al. (2005), in which they underscored that such disciplinary lenses were grounded in a framework that treats biological, physical, and societal spheres as discrete, separate entities. In addition, the roles of social and ecological factors were largely neglected by the prevailing paradigms (Dhar-Chowdhury and Haque, 2013). Parkes et al. (2005) asserted that, until recently, while some researchers have been advancing an understanding of disease emergence occurring within biological, ecological and social spheres, most analysts continued to consider social and ecological factors to be separate rather than interactive within the context of emergence. The inherent limitations of the disciplinary-based, compartmentalized conceptual frameworks therefore generally failed to encapsulate the complex, intertwined reality of dengue emergence and reemergence involving multi-scale ecological, biological and social spheres and finding a sustainable solution. In this context, Guzman et al. (2010) cited that householders' resistance to the treatment of their drinking water and difficulties in attaining high and regular levels of insecticide coverage have resulted in the general failure of vector and dengue fever control programs. As a result, a reemergence of DENV, with increased virulence, occurred during the 1990s and early 2000s. It appeared at a several-fold higher overt attacking rate in Singapore compared to in the 1960s (Ooi et al., 2006). Reports of autochthonous dengue fever transmission on the U.S.A. side of the Texas–Mexico border have been rare — only 64 cases were reported during 1980–1999, compared with 62,514 cases on the Mexican side of the border (Brunkard et al., 2007).

Because dengue transmission is closely associated with the intertwined ecological and societal spheres, responses and interventions that are inclined toward disciplinary, non-participatory and technological quick-fixes are inadequate to solve the transmission problem. In consideration of these gaps, efforts were made to formulate interdisciplinary and transdisciplinary, integrative approaches. For instance, the application of Ecohealth approach or 'Ecosystem approaches to health' (Waltner-Toews, 2001; Lebel, 2003) for understanding dengue transmission - which adopted a "social ecological systems" perspective, in which cities and their surroundings are seen as "coupled human-natural systems" -have been helpful in explaining patterns of disease emergence in relation to rapid urbanization (Wilcox and Colwell, 2005; Wilcox and Gubler, 2005). The 'social-ecological systems perspectives' was advocated by McMichael (1999) in the U.S.A., and Kay (2000) and Berkes et al. (2003) in Canada. Reinforcing assertions of such 'coupled' social and ecological spheres within systems thinking, Dhar Chowdhury and Haque (2013) framed disease and health problems using an Integrated Social-Ecological Systems (ISES) lens and by considering multiple biological, ecological, behavioral and societal levels and dimensions. As 'system thinking' focuses on the relationships among these elements (Charron, 2012) within the complex whole, according to this view, humans are both a part of nature and largely conditioned by societal practices. A separation between the biophysical ecosystem and social system is therefore arbitrary and unnecessary (Berkes et al., 2003).

In contrast to the more traditional approaches to dengue control, ISES thinking underscores the importance of looking for complex patterns by considering the interplay between social, biological or ecological systems. However, the ISES lens also called for a ‘coupled social-natural systems’-based explanation (Berkes et al., 2003; Gunderson and Holling, 2002) to show dengue to be a unique type of EID, albeit one in its infancy (Waltner-Toews et al., 2008; Wilcox and Colwell, 2005). Only a handful of analyses thus far have attempted to provide a rationale for and demonstrate the merits of such efforts (Wilcox and Colwell, 2005). As Liu and his colleagues (2007) have determined, the outcomes of ISES analysis are nonlinear dynamics with thresholds, reciprocal feedback loops, time lags, resilience, heterogeneity, and surprises.

The ‘EcoHealth’ lens focuses on the interaction between the ecological and societal dimensions of a given situation, their effect on human and animal health, as well as on how individuals and populations receive utility or impact ecosystems, including the provision of ecosystem services and sustainability. By departing from an exclusive orientation to biomedical thinking, and by adopting ‘systems thinking’, scholars championing this new arena of research and practice such as Waltner-Toews and his colleagues(2008), Jean Lebel (2003) and Dominique Charron (2012), have attempted to formulate a set of principles of the ‘EcoHealth’ or ecosystem approach to health. This emerging field seeks to encapsulate the ‘coupled ecological and social systems’ within which human health vis-a-vis disease is generated and challenged. These principles were formulated, as described in details in Charron (2012), to assist in comprehending the nested, interdependent systems in which diseases emerge, maintain themselves by self-organization and re-organization, and evolve into a multi-level system (molecular, organismal, communal, national and global) (Parkes et al., 2005; Wilcox and Colwell, 2005).

It is critical here to recognize that Charron's (2012) identification of a set of six principles of an Ecosystem Approach to health, which were designated as 'guide posts' to the execution of ecohealth research, are the most comprehensive explanation of what the "Ecosystem Approach" is all about. These six thematic areas of the principles include: i) systems thinking; ii) transdisciplinary research; iii) participation; iv) sustainability; v) gender and social equity; and vi) knowledge to action. Although all six principles have guided my research on understanding dengue transmission in Dhaka (Bangladesh), only the systems thinking, transdisciplinary research and participation tenets were directly relevant to my investigation.

8.1.1 Systems thinking

The adoption of 'system thinking' in dengue disease transmission was preceded by the inquiries into multi-causality (Krieger, 2001). The interplay of human as host, mosquito as vector, and DENV biology contributes to the dengue transmission as each sphere influences and affects the others in the context of ecology and against the backdrop of society. However, most research on dengue transmission has to date been grounded on contributions made by highly specialized researchers working on particular problems, ranging from the molecular to the cellular and the whole animal. The accumulated knowledge instigated enquiries into the dynamics of the dengue system that is also affected by human behavior, climate, and the movement of viruses and humans. Without the adoption of system thinking, the work carried out by specialists tended to view the overall behavior of the disease from disciplinary perspectives. Most virologists, for example, assert that human population herd immunity, variation in viral virulence, and co-circulation of different DENV serotypes are the important determinants of dengue transmission dynamics. Many entomologists strongly argue that the density and distribution of vector populations, vector competence, and vertical transmission of DENV in *Aedes* mosquitoes are most critical determinants for dengue epidemics. Understanding of the transmission dynamics by integrating the components of the system, so that its behavior and causes could be comprehended, remained poor.

Among a handful attempts to adopt a systems approach to understanding dengue transmission and emergence, the ‘eco-bio-social conceptual framework’ (Tana et al., 2012) emphasized the importance of including ecological and socio-economic factors into the host-virus-vector nexus of dengue transmission. Nonetheless, two major shortcomings of this framework are that a) the nature of linkages and relationships among the identified variables are ignored; b) the social-structural aspects of dengue transmission (e.g. gender dimension, socio-economic inequity and inequality, participatory governance, power relations) are not considered.

Systems thinking with regard to explaining dengue transmission demands an emphasis upon the interactive relationships not only among the ecological, biological, and human spheres, but also the societal dynamics and contexts within which the disease occur. In consideration of this interconnectedness of factors in dengue disease emergence, I examined dengue vector abundance in 12 selected Wards of the city of Dhaka, placing emphasis on human behavior along with ecological factors of vector larval development sites (Chapter 4). In order to treat the social and ecological systems together, I analyzed the types and frequency of vector larval development containers in households, along with the choice and preferences of household members for possessing certain types of larval development containers. Considering that scale as an important factor for social-ecological systems thinking (Charron, 2012), I have also examined how national, city and/or zonal level factors (e.g. seasonal diversion of electricity for irrigation and consequent power cuts in the city, and electricity shortages due to corruption in management systems) affect household-level water storage and use behavior.

As stated above, the City of Dhaka has undergone unprecedented demographic, socio-economic and physical changes as a result of the effects of globalization since the mid-1990s. Most notably, an export-oriented garment industry has grown exponentially on the low wages paid to female workers. In the face of these mounting demographic pressures, many government sectors and public utilities have failed. One succinct example of such failures is the city's inability to provide a sustained electricity supply to households. Locally known as the 'load shedding' of electricity, intermittent interruptions of power have become a common phenomenon in the last few decades. Due to the low distribution pressure in public water pipes (supply being much less than demand), households use their own pumps to lift water to roof-top tanks, from where water is distributed to different units of the building. When a major 'load shedding' happens or if it happens frequently, water supply over a large area can be affected. Frequent power failure also causes more mechanical issues with the pumps and increases the operating and maintenance cost for the system as a whole. This, in turn, has resulted in serious disruptions in water supply to households via municipal pipelines as most households in Dhaka rely on pumping water to a higher elevation by using electrical pumps located inside the household. Consequently, the need to store water (for drinking, taking baths, doing household chores and other necessary work) in containers of various sizes within the houses has created a perfect environment for mosquito larval development, especially during monsoon seasons.

The prevalence of multiple serotypes of DENV, along with the multiplication of mosquito larval development containers in one of the most densely settled cities of the world has produced the necessary conditions for the emergence of DF, DHF and DSS in Dhaka. These multi-level socioecological positive feedback loops which cause dengue occurrence in Dhaka are depicted in Figure 8.1. Dengue disease affects various types of phenomena negatively at multiple levels. At the micro-level, it impacts individuals' health and well being through loss of income. At the community level, social order and cohesion are hampered and the sub-national economy suffers due to labor shortages. At the macro-level, the national economy declines due to loss of labor productivity and rises in public health costs. These negative feedback loops add further complexities to EID in low-income countries like Bangladesh (Figure 8.1). As stated earlier, more than one-third of the population of the city of Dhaka is poor and lives in dense squatter settlements, their livelihoods based mainly on daily wage earnings. Hospital reporting by this segment on this population is fragmented, and infected people often travel across the city for work as well as to other towns and rural areas to visit extended family members. The rapidly changing urban complex, characterized by high population growth, increased mobility and migration, income inequality, inadequate water and waste management infrastructure, and limited awareness of the *Aedes* mosquito habitat among the city dwellers, enable the continuation of the 2-3-year dengue cycle. Therefore, the risk of exposure to DENV among the population and the potential for a dengue epidemic in the future remain major public health concerns.

The case of the City of Dhaka reveals that the biomedical and 'individually oriented' theories of disease causation, in which population risk is treated as the sum of individuals' risks, are grossly inadequate for the task of explaining the complex interplay within systems driving dengue disease emergence. Underscoring the dynamics of the integrated social and natural systems within which the people of Bangladesh and the natural components of the Brahmaputra-Ganges deltaic systems interact is important here. The risks for burden of diseases are being materialized within the conjoined social-ecological systems and affected groups within a population. Thus, specific social classes, genders, ages, ethnicities and groups are facing disproportional disease burden due to prevailing socio-political relations of power and authority and other socioeconomic factors.

In the context of Dhaka, it is important to underscore that the complexity of 'coupled systems' has not yet been well understood, largely for two reasons: (i) the traditional separation of ecological and social sciences, and (ii) most work has been anecdotal and piecemeal rather than systematic, scientific and comprehensive. Therefore, much more theoretical and empirical work needs to be carried out, recognizing that the 'ISES' lens is only one of many necessary frameworks needed to comprehend the complexity of disease occurrence in human society (Liu et al., 2007).

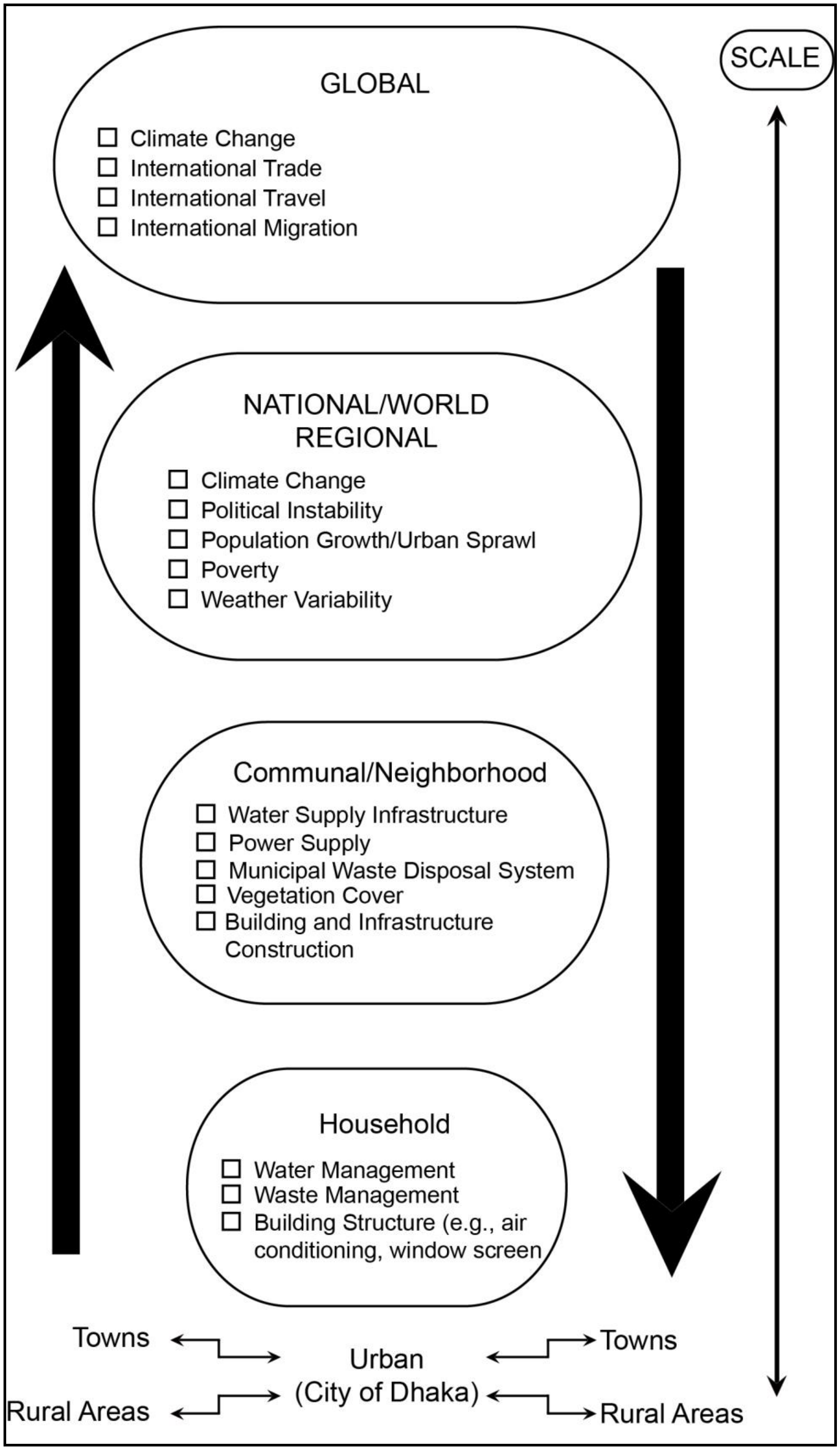


Figure 8.1:Multi-level social-ecological systems within which dengue occurs in Dhaka

8.1.2. Transdisciplinarity

In my thesis research on dengue transmission in Dhaka, following a critical review of the distinctions between multi-, inter-, and transdisciplinary approaches (see chapter 3, section 3.1.3), I applied transdisciplinarity as a principle of Ecohealth. Following McDonnell (2000), I emphasized that "integrating language of relationships [is taken] to the extent of there being a transcendent language, a metalanguage, in which terms of all pertinent disciplines are, or can be, expressed" (p. 27). In applying such a lens, representatives of various disciplines are inspired to transcend their separate conceptual and methodological orientations to develop a shared approach to a problem and its associated research. Therefore, I worked with various researchers of disciplinary orientation as well as participants from local communities, city authorities, entomological, virological, ecological, sociological, anthropological, and epidemiological national government departments, specialists, and practitioners. The knowledge acquired through this research process has evolved into a transdisciplinary understanding of dengue transmission in the social-ecological contexts of the city of Dhaka, whereby 'horizontal' and 'vertical' types of integration of perspectives was accomplished. It is worth reiterating here that 'horizontal' integration refers to integration across different disciplinary knowledge perspectives or knowledge-faculties, while 'vertical' integration refers to integration among different types of knowledge users, ranging from local communities and cultures to NGO staff and academics (Parkes et al., 2005; Wilcox and Colwell, 2005; see Chapter 3 for details).

I have adopted a transdisciplinary research design to find more effective ways to understand and explain complex, interwoven problems concerning dengue disease in the city of Dhaka, Bangladesh. Bangladesh was thought to be free from dengue except for some sporadic cases since 1965. The dengue outbreak of 2000 changed everything. Since 2000, DF cases have been reported every year in all major cities of Bangladesh. More than 23,872 cases have been reported between 2000 and 2009, 233 of them fatal. From June 2000 onwards, dengue outbreaks with severe cases like Dengue haemorrhagic fever (DHF) were reported in Dhaka and a few larger cities including Chittagong, Khulna, and cases were reported from 17 other smaller cities. Of 5551 reported cases in 2000, 71.4% (i.e., 3964 cases) were from Dhaka, as were 51 of 93 deaths (54.8%). Both *Aedes aegypti* and *Aedes albopictus* were identified as potential vectors for DF transmission in Dhaka (Ali et al. 2003). From this scenario, it is clear that dengue fever is an old disease in Dhaka and that it can be treated as a classic example of disease re-emergence in that country. As Wilcox et al. (2008) explained, urbanization, increased jet travel, and modern transportation, which began around 1960 and accelerated in the 1970s and 1980s, provided the ideal mechanism for the 'hyperendemic dengue melting pot' of Southeast Asia. Eventually, Dhaka became epicentre which seeded the rest of Bangladesh with DENV.

To analyze the dynamics of dengue emergence in cities like Dhaka, Bruce et al., proposed a new way of thinking (i.e. coupled human–natural system) that has proven helpful in explaining patterns of disease emergence in relation to urbanization (Wilcox and Colwell, 2005; Wilcox and Gubler, 2005). They argued that changes at the level of the regional environment affects successively smaller (i.e. local) and larger scales (i.e. national, global) to facilitate the emergence or re-emergence of infectious diseases. Their framework integrates multidisciplinary knowledge from urban ecosystem, climate change, agricultural science, and vector ecology against the backdrop of the social ecological perspective (Wilcox and Colwell, 2005). By recognizing the shortcomings of this ecological oriented framework, which does not adequately account for socio-political power dynamics, an ecosystem approach to understanding the transmission of dengue was put forward by Tana et al. (2012). This ecohealth framework incorporates ecological, biological, and social factors in order to consider the multiple layers of social and ecological determinants that influence dengue transmission. Their conceptual framework includes ecological factors like climate and the natural and anthropogenic ecological setting, biological factors relates to the behavior of the vector, and social factors such as vector control and health services, and their political context as well as social inequality and community KAP dynamics (Tana et al., 2012).

In my application of the ecohealth framework to explain dengue transmission in Dhaka, I emphasized the combination of scientific knowledge of the host-virus-vector nexus and non-academic knowledge of dengue transmission among the stakeholders. Viewing dengue transmission through a transdisciplinary lens, I have generated and examined a range of disciplinary academic knowledge from vector ecology, virology, urban ecology, and urban sociology along with non-academic knowledge from community KAP to policy makers' knowledge (Figure 8.2).

Low socioeconomic status households are at greater risk of exposure to DENV than high, and medium socioeconomic status households, since the types and frequency of the most productive water containers (MPCs) were higher in LSES households. Another possible reason is that as dengue vector mosquitoes breed in water holding containers in and around household premises, and because LSES households are being “driven” to store water for considerable period of time or days due to power shortages and load sheading, they are more at risk of exposure than others.

In understanding the dengue transmission dynamics, it is critical to determine the abundance of *Aedes* pupae at multiple scales, including spatial an ecological entities (households, neighborhoods, zones, cities, or ecotopes, ecozones, and landscapes). Through household entomological surveys we found that, at the household level, ‘ornamental’ categories of containers (Chapter 4; Section 4.3.5) produce the greatest numbers of larvae and pupae.

Serological data obtained from blood samples collected from various SES community members showed that indoor potted plant containers (i.e. one of several under ‘ornamental’ category) were most significant risk factors, for dengue seroprevalence and seroincidence. These findings led to a greater understanding of whether the city of Dhaka people were getting mosquito bites in their households or outside the household premises. Statistical analysis led us to explore further connections between integrated urban ecological zones and vector abundance and dengue infection in the city. The results showed that CBR (central business districts and residential mixed areas) – the intersections of major economic activities and large population concentrations, are ‘hotspots’ for dengue disease transmission. It can thus be deduced that the dengue transmission cycle can be greatly affected by anthropological alternations associated with human activities.

The findings from Chapters 4 and 5 tells us about the homogeneous distribution of dengue vector abundance and seroprevalence across the different socioeconomic status wards, which is insufficient to specify the dengue transmission dynamics in the city in terms of risk exposure and case incidences. However, from Chapter 6, we successfully determined the spatial configuration of the intensity of dengue prevalence and its correlation with vector abundance by applying spatial statistical methods and tools. Although these perspectives offer valuable insights regarding the interfaces among hosts, vectors, and viruses, they are inadequate to encapsulate factors of human cognition and social, political, and economic power relations.

The results from Chapter 7 discussed in detail the perceptual models of dengue and its transmission among the community members as well as other stakeholders (i.e. experts/specialists). The results show that the community members have misconceptions about the dengue vector larval development sites and its causes. In addition, the level of awareness about that dengue is transmitted by stored clean water and daytime bites by infected *Aedes* mosquitoes among the community members was low. As a result for expert knowledge model development in this research, we gained the valuable new insight into where the gaps lie between the community and experts - gaps which demand the development of new risk communication strategies.

A fuller perspective on water and waste management and their association with infectious disease dynamics in Dhaka is generally absent. However, some research efforts were successfully made to unravel the socio-economic and political power dynamics that play significant roles in household and community-level water and waste management. These investigations did not attempt to relate such issues with diseases and their transmission among the populations. Due to pervasive and perpetual impoverishment among the marginal populations of the city, they are limited from receiving piped or other forms of supplied water, possessing lidded containers, and influencing the local and national decision makers regarding prevention and control of infectious diseases. They expressed a feeling of socio-structural constraint and ‘helplessness’. As explained in Chapter 4 (Section 4.4), middle and higher-income groups also face irregular water supply, as they are incapable of effectively influencing the authorities - either politically or financially. These SES groups were also frustrated with the city service systems; nonetheless, they looked for alternative ways to address irregular water supply and waste collection services. For example, many high-SES households built larger water reserve tanks in their household premise to back up water storage. In addition, several important infrastructural aspects were found to be directly associated with *Aedes* larval development sites outside household premises, especially storm water drainage problems, potholes, and the construction of private buildings and public infrastructure. Voluminous literature has illustrated the degree mistrust among the concerned government departments as well as their lack of communication and coordination as major reasons for their failure to meet the required infrastructural needs of the city (Islam et al., 2010; Jamil and Pande, 2012). Notably, the policies and programs concerning public health issues have not been effectively integrated with the city planning and implementation. It is beyond the scope of my thesis to discuss these issues in detail; further research should be undertaken in these areas.

8.1.3 Participatory

Participation of stakeholders in research is one of the key principles of the ecohealth approach to health issues, and is defined in terms of effective engagement of stakeholders in order to supplement knowledge generated by research and enhance corrective actions stemming from the research (Charron, 2012). Community participation in research efforts began to materialize within public health practices following the Alma Ata declaration (WHO, 1978) in 1978 and evolved through a highly-variable history practical implementation (Draper et al., 2010). Although the specificity in defining community in pertinent literature on ecohealth is generally missing or nominal, most research on ecohealth perspectives has used the term 'community' in reference to the local community and interchangeably with the concept of local and other stakeholders. In my research, I have adopted the former definition of 'community'.

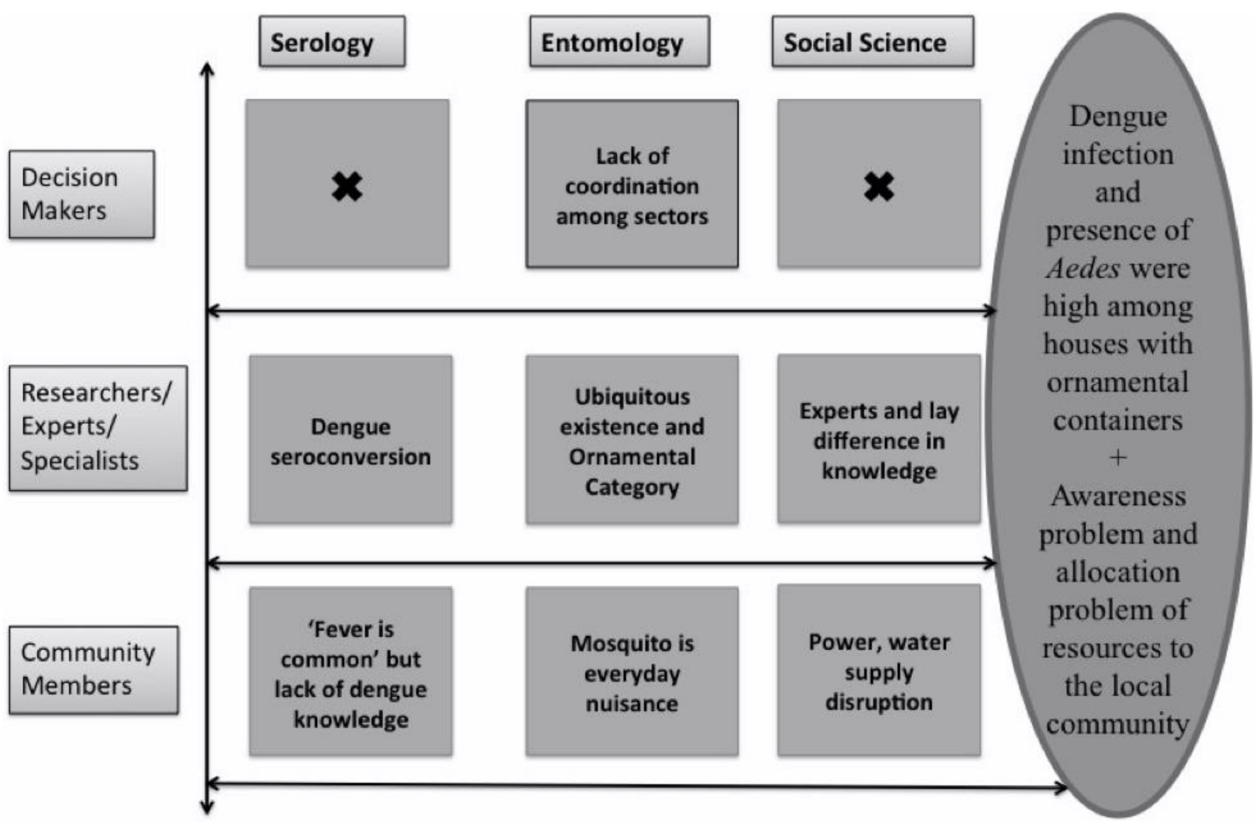


Figure 8.2: Integration of disciplinary knowledge and stakeholders' knowledge of dengue transmission in Dhaka

It is also important to highlight that community-focused research, particularly the ones that emphasize participation of local members, and defines the term ‘community’ as a collective social entity within a given geographical entity. Such conventional concept of a community may not be appropriate to capture the local situation and dynamics where the elements of social-ecological systems are rapidly changing. For example, the city of Dhaka has seen a change in population growth rate increased by more than 7% per year over the last 25 years, along with associated changes in land cover and landuse, housing, infrastructure, and vegetation. The rate of change in residents is extremely high and the sense of ownership to a particular local community is characterized by a transitional form of ‘belongingness’. In my research in Dhaka, I have therefore used a common denominator of administrative and geographical entity (Ward) to refer to local communities.

In my research, both local community members and other stakeholders have directly participated and contributed to delineate the research agenda, needs, knowledge and action in multiple stages of implementation. As analyzed in Chapter 7, I attempted - with the active participation of both male and female members representing three local communities and stakeholders representing the city level regulators, managers, health specialists and practitioners - to formulate the mental models of dengue-disease-risk. Due to a departure from the conventional expert driven Mental Model comparison with local community one in my research design, the local communities had the opportunity to be ‘in the driver seat’ to formulate their own Mental Models about dengue. This outcome has significantly shaped the investigation of Mental Models about dengue among the stakeholders. My results have revealed that the local community members identified a low level of risk associated with dengue disease while the health regulators, managers, and practitioners identified a high level of dengue-disease-risk in the City. Although many local community members were aware of a number of factors that influence population health (e.g. water contamination and diarrhea; rainy season and flu viruses), this awareness did not extend to the prevalence and seriousness of the dengue fever and dengue hemorrhagic fever. Many tended to downplay dengue symptoms as a feature of everyday life. Consequently, very nominal efforts are being made by City residents to prevent and control dengue, resulting in a high risk of exposure to DENV infection. Contrary to these local community level perspectives, the expert mental model recognizes dengue disease and its transmission in the city of Dhaka as a major national public health concern.

Engaging local community members in academic and action research demands particular attention to both personal situational factors as well as social-structural issues. Interactive risk communication efforts, whereby the local communities have an effective voice in communicating and influencing outcomes, are needed to address health and disease control issues as a collective priority. It is also important to underscore the urgent need for addressing the gaps and misconceptions about dengue transmission in local communities. Attempts in several countries, namely Taiwan (Pai et al., 2005) and Vietnam (Tran et al., 2010), in this regard have revealed that public health education campaigns by the relevant health agencies can effectively enhance understanding of the causes of diseases among citizens and address public misconceptions. Nonetheless, several Latin American (Quintero et al., 2009; Gómez-Dantés et al., 2009; Pérez-Guerra et al., 2009) and Southeast Asian (Tran et al., 2010) studies revealed that control and prevention practices do not solely depend on clear conceptions and knowledge of disease risk. A substantial part of these actions are highly correlated with motivational factors including how the risk ranks alongside community and individual-level concerns as well as a willingness to act to address those issues of greatest concern.

8.2 A Transdisciplinary Framework for Understanding Dengue Disease Transmission in Dhaka

A gap in understanding how the transmission and dynamics of dengue disease differ with ecological, biological, and social factors has been identified (Ellice and Wilcox, 2009; Tana et al., 2012). In addition, the requirement for an approach that regards the multiple layers of social and ecological determinants that influence dengue has also been established (Spigel et al., 2005), and attempts have been taken to develop a conceptual framework that illustrates some of these factors (Pongsumpun et al., 2008). Among a handful attempts to create conceptual frameworks for dengue disease emergence and dynamics of epidemics, Bruce et al. (2008) and Tana et al. (2012) are most relevant to the application of ecohealth approach to dengue transmission in Dhaka. Using a 'social-ecological system' perspective, Wilcox and Colwell (2005) and Wilcox et al. (2008) illustrated the linkage of human systems on a regional scale with natural systems, such as ecological communities and host-parasite complexes, on successively smaller ecological scales. They argue that changes at the level of the regional environment (e.g., population growth) cascade down through these successively smaller scales to influence the emergence or re-emergence of infectious diseases like dengue. This integrated system thus transmits diseases in the opposite direction, up through the system to potentially impact human health at varying scales.

In order to encapsulate the interactive and overlapping nature (i.e. integration) of ecological, biological, and social factors that affect dengue transmission and emergence, Tana et al. (2012) adopted a Venn diagram to illustrate the identified factors and their location within the system. As stated above, their conceptual framework includes ecological factors like climate and the natural and anthropogenic ecological setting, biological factors that relate to the behavior of the vector, and social factors that incorporate a series of factors including vector control and health services, and their political context as well as social inequality and community dynamics (Tana et al., 2012).

To conceptualize the transmission of dengue in the context of Dhaka city, I developed a conceptual explanatory framework that explains disease transmission and emergence from an 'integrated human-natural system' perspective and by considering eco-bio-social factors at the backdrop (Figure 8.3). This framework suggests that our biophysical and socioeconomic systems need to be considered together at various scales of human organization of natural and social phenomena (i.e. from the household to the national level). As well, the role of humans as 'agents' must be accounted for beyond their role as hosts for disease transmission. This framework is meant to encapsulate the conceptualization of key eco-bio-social factors for dengue transmission as well as different stakeholders' knowledge, attitudes, and practices regarding dengue transmission in the city of Dhaka.

In this framework, a graphical representation of three different hierarchical levels (i.e. household, neighborhood or regional, and national) of social-ecological systems has been attempted to illustrate the linkages among various social, economic, cultural and ecological variables that function at local scale and their association with social, institutional (e.g. governance) and environmental (e.g. global climate system) factors and drivers that function interactively at a much larger scale (i.e. regional and natural). *Aedes* pupae productivity at the household level is affected by the human behavior of water storage in containers, and such practices are directly linked with regional water supply and electricity power supply at the regional and/or city level. Limited capacity of the political institutions, reflected in the lack of transparency and accountability of various government departments and non-governmental organizations, in turn profoundly affect the performance of various public sector projects and programs. Lack of coordination and mutual trust among these organizations has resulted in the poor performance of the electrical power and water supply, inefficient infrastructure construction and restoration, and misallocation of financial and other resources. Poor governance issues at the national level ultimately cascade down through the various organizational strata of society to affect the dengue vector-virus-host nexus (Figure 8.3).

In effect, the prevailing social, cultural, ecological and demographic characteristics and conditions in Bangladesh significantly affect certain population groups or sub-groups more than others in terms of vulnerability to DENV infection. In Dhaka, IgG positive cases were 79.9% during pre-monsoon and 88.2% during post-monsoon season in the year of 2012 and seroconverted or recent dengue infected cases were found among 7.9% during 2013. Beyond the scope of this research, a 47 clinically confirmed dengue samples from Dhaka Medical College Hospital were collected and analyzed by PCR at the NML to detect specific DENV serotypes. DENV serotype 3 was detected from 7 serum samples. It is important to note here that in a retrospective, cross-sectional seroepidemiological study carried out in 2002 in Dhaka also identified DENV serotype 3 in the blood samples from 13 dengue positive cases in a recreation club (Wagatsuma et al., 2004). A few other studies (Pervin et al., 2002; Poddar et al., 2006; Rahman et al., 2002) also confirmed the predominant nature of DENV serotype 3 during the 2000 dengue epidemic in Bangladesh, which is enterted from neighboring country Thailand and Myanmar (Poddar et al., 2006). The pre-existence of antibodies to DENV, which was asserted by Halstead (1984) to be the most important risk factor for DHF/DSS, could be an important risk factor for future dengue outbreaks in Dhaka. The baseline seroprevalence investigation of the present research revealed that 77% of children were seropositive by the age of 9, indicating that children are the most at risk demographic cohort among the population of urban areas of Bangladesh to secondary type of infection.

In summary, this conceptual framework reflects the rapidly changing urban socio-ecological systems within which dengue transmission and reemergence occurs. Therefore, it could be applied to studying other, similar dengue transmission contexts. However, using this framework to explain dengue transmission dynamics in other countries or societies will require consideration of these countries' specific historical, socio-economic, and cultural contexts.

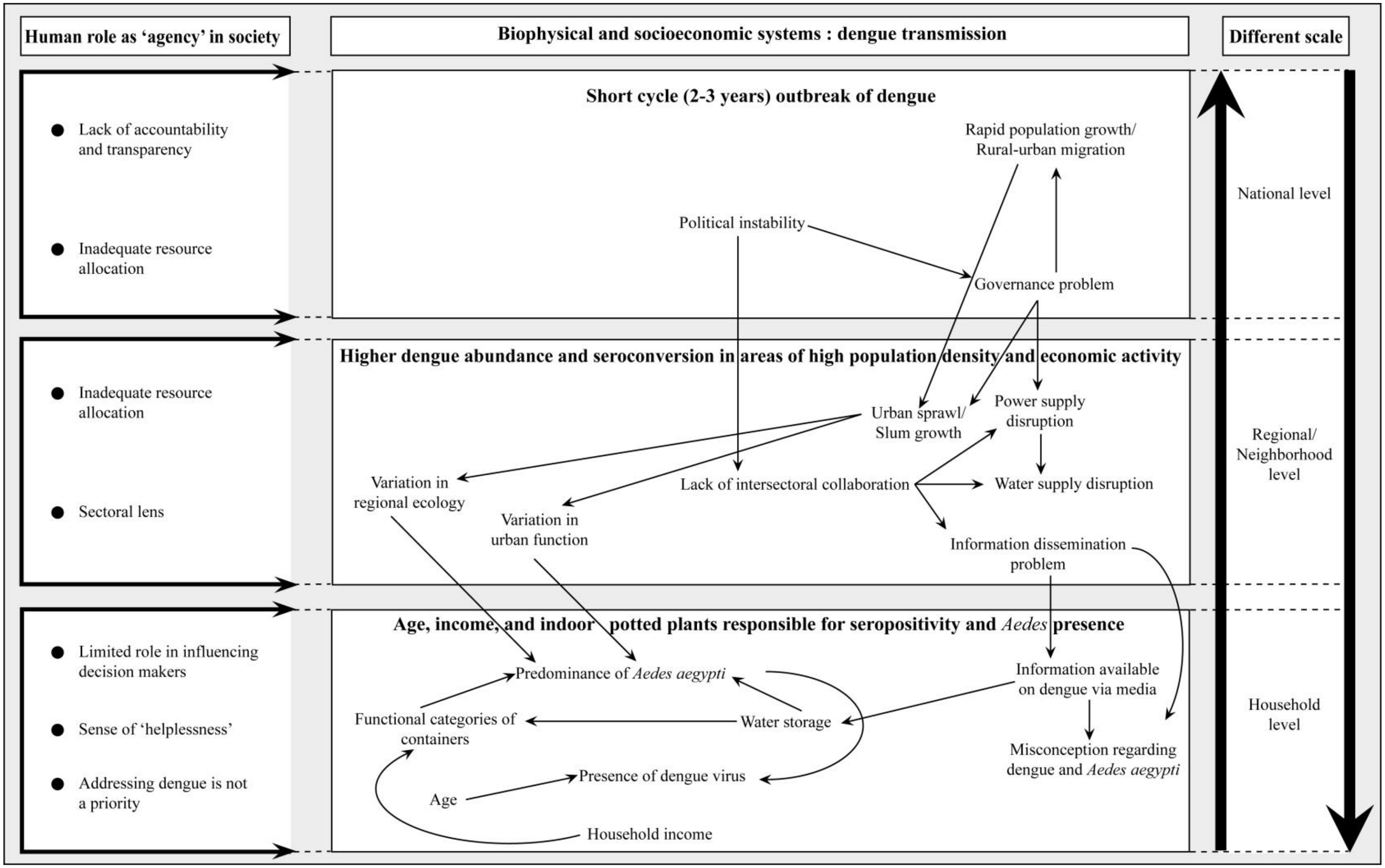


Figure 8.3: Ecohealth conceptual framework, integrating social-ecological systems and human agency, of dengue transmission in Dhaka, Bangladesh

References

Ali, M., Wagatsuma, Y., Emch, M., & Breiman, R. F. (2003). Use of a geographic information system for defining spatial risk for dengue transmission in Bangladesh: role for Aedes albopictus in an urban outbreak. *The American Journal of Tropical Medicine and Hygiene, 69*(6), 634-640.

Baly, A., Toledo, M. E., Rodriguez, K., Benitez, J. R., Rodriguez, M., Boelaert, M., . . . Van der Stuyft, P. (2012). Costs of dengue prevention and incremental cost of dengue outbreak control in Guantanamo, Cuba. *Tropical Medicine and International Health, 17*(1), 123-132.

Beatty, M. E., Stone, A., Fitzsimons, D. W., Hanna, J. N., Lam, S. K., Vong, S., . . . Margolis, H. S. (2010). Best Practices in Dengue Surveillance: A Report from the Asia-Pacific and Americas Dengue Prevention Boards. *PLoS Neglected Tropical Diseases, 4*(11), e890-e890.

Berkes, F, Colding, J., Folke,C. (2003). *Navigating social-ecological systems*. Cambridge: Cambridge University Press.

Brunkard, J. M., López, J. L. R., Ramirez, J., Cifuentes, E., Rothenberg, S. J., Hunsperger, E. A., . . . Haddad, B. M. (2007). Dengue fever seroprevalence and risk factors, Texas–Mexico border, 2004. *Emerging Infectious Diseases, 13*(10), 1477.

Charron, D. F. (Ed.). (2012). *Ecohealth research in practice: Innovative Applications of an Ecosystem Approach to Health*. Ottawa, Canada: Springer.

Dhar Chowdhury, P., & Haque, C. E. (2013). Why is an Integrated Social-Ecological Systems (ISES) Lens Needed to Explain Causes and Determinants of Disease? A Case Study of Dengue in Dhaka, Bangladesh. *Advances in Medical Sociology, 15*, 217-239.

Draper, A. K., Hewitt, G., & Rifkin, S. (2010). Chasing the dragon: developing indicators for the assessment of community participation in health programmes. *Social Science & Medicine, 71*(6), 1102-1109.

Ellis, B. R., & Wilcox, B. A. (2009). The ecological dimensions of vector-borne disease research and control. *Cadernos De Saude Publica, 25*, S155-S167.

Gómez-Dantés, H., & Willoquet, J. R. (2009). Dengue in the Americas: challenges for prevention and control. *Cadernos De Saúde Pública, 25*, S19-S31.

Gubler, D. J. (Ed.). (1997). *Dengue and dengue hemorrhagic fever: its history and resurgence as a global public health problem* CAB International.

Gubler, D. J. (2002). Epidemic dengue/dengue hemorrhagic fever as a public health, social and economic problem in the 21st century. *Trends in Microbiology, 10*(2), 100-103.

Gunderson, L. H., Holling,C.S. (2002). *Panarchy: understanding transformations in human and natural systems*. Washington, D. C.: Island Press.

Guzman, M. G., Halstead, S. B., Artsob, H., Buchy, P., Farrar, J., Gubler, D. J., . . . Peeling, R. W. (2010). Dengue: a continuing global threat. *Nature Reviews.Microbiology, 8*(12), S7-16.

Halstead, S. B. (1984). Selective primary health care: strategies for control of disease in the developing world. XI. Dengue. *Review of Infectious Diseases, 6:* 251-264.

Heintze, C., Garrido, M. V., & Kroeger, A. (2007). What do community-based dengue control programmes achieve ? A systematic review of published evaluations. *Tropical Medicine,* doi:10.1016/j.trstmh.2006.08.007

Honório, N. A., Nogueira, R. M. R., Codeço, C. T., Carvalho, M. S., Cruz, O. G., Magalhães, Mônica de Avelar Figueiredo Mafra, . . . Pinheiro, L. S. (2009). Spatial evaluation and modeling of dengue seroprevalence and vector density in Rio de Janeiro, Brazil. *PLoS Neglected Tropical Diseases, 3*(11), e545.

Islam, M. S., Rahman, M. R., Shahabuddin, A., & Ahmed, R. (2010). Changes in wetlands in Dhaka city: trends and physico-environmental consequences. *Journal of Life and Earth Science, 5,* 37-42.

Jamil, I., & Panday, P. (2012). Inter-organizational coordination and corruption in urban policy implementation in Bangladesh: A case of Rajshahi City Corporation. *International Journal of Public Administration, 35*(5), 352-366.

Kay, J. J. (Ed.). (2000). *Ecosystems as self-organizing holarchic open systems: narratives and the second law of thermodynamics* CRC press.

Krieger, N. (2001). Theories for social epidemiology in the 21st century: an ecosocial perspective. *International Journal of Epidemiology, 30*(4), 668-77.

Kuno, G. (Ed.). (1997). *Factor influencing the transmission of dengue viruses*. New York: CAB International.

Lebel, J. (2003). *Health: an Ecosystem Approach*. Ottawa: International Development Research Centre.

Liu, B. M., Abebe, Y., McHugh, O. V., Collick, A. S., Gebrekidan, B., & Steenhuis, T. S. (2007). Overcoming limited information through participatory watershed management: Case study in Amhara, Ethiopia. *Physics and Chemistry of the Earth, Parts A/B/C, 33*(1), 13-21.

McDonell, G. (2000). Disciplines as cultures: towards reflection and understanding. Transdisciplinarity. *Recreating Integrated Knowledge,* 25-38.

McMichael, A. J. (1999). Prisoners of the proximate: Loosening the constraints on epidemiology in an age of change. *American Journal of Epidemiology, 149*(10), 887-897.

Ooi, E., Goh, K., & Gubler, D. J. (2006). Dengue prevention and 35 years of vector control in Singapore. *Emerging Infectious Diseases, 12*(6), 887-93.

Pai, H. H., Hong, Y. J., & Hsu, E. L. (2006). Impact of a short-term community-based cleanliness campaign on the sources of dengue vectors: an entomological and human behavior study. *Journal of Environmental Health, 68*(6), 35-39.

Parkes, M. W., Bienen, L., Breilh, J., Hsu, L., McDonald, M., Patz, J. a., . . . Yassi, A. (2005). All Hands on Deck: Transdisciplinary Approaches to Emerging Infectious Disease. *Ecohealth, 2*(4), 258-272.

Pérez-Guerra, C. L., Zielinski-Gutierrez, E., Vargas-Torres, D., & Clark, G. G. (2009). Community beliefs and practices about dengue in Puerto Rico. *Revista Panamericana De Salud Pública, 25*(3), 218-226.

Pervin, M., Tabassum, S., Ali, M. M., Mamun, K. Z., & Islam, M. N. (2004). Clinical and laboratory observations associated with the 2000 dengue outbreak in Dhaka, Bangladesh. *Dengue Bull*, *28*, 96-106.

Podder, G., Breiman, R. F., Azim, T., Thu, H. M., Velathanthiri, N., Le quynh, M. A. I., ... & Aaskov, J. G. (2006). Origin of dengue type 3 viruses associated with the dengue outbreak in Dhaka, Bangladesh, in 2000 and 2001. *The American journal of tropical medicine and hygiene*, *74*(2), 263-265.

Pongsumpun, P., Garcia Lopez, D., Favier, C., Torres, L., Llosa, J., & Dubois, M. (2008). Dynamics of dengue epidemics in urban contexts. *Tropical Medicine & International Health, 13*(9), 1180-1187.

Quintero, J., Carrasquilla, G., Suárez, R., González, C., & Olano, V. A. (2009). An ecosystemic approach to evaluating ecological, socioeconomic and group dynamics affecting the prevalence of Aedes aegypti in two Colombian towns. *Cadernos De Saude Publica, 25*(SUPPL. 1), S93-S103.

Rahman, M., Rahman, K., Siddque, A. K., Shoma, S., Kamal, A. H., Ali, K. S., ... & Breiman, R. F. (2002). First outbreak of dengue hemorrhagic fever, Bangladesh. *Emerging infectious diseases*, *8*(7), 738-740.

Scott, T. W., & Morrison, A. C. (2010). Vector dynamics and transmission of dengue virus: implications for dengue surveillance and prevention strategies. *Dengue virus* (pp. 115-128) Springer.

Spiegel, J. M., Bonet, M., Ibarra, A., Pagliccia, N., Ouellette, V., & Yassi, A. (2007). Social and environmental determinants of Aedes aegypti infestation in Central Havana: results of a case–control study nested in an integrated dengue surveillance programme in Cuba. *Tropical Medicine & International Health, 12*(4), 503-510.

Spigel, J., Bennett, S.,Hattersley, L. et al. (2005). Barriers and bridges to prevention and control of dengue: The need for a social-ecological approach. *Ecohealth, 2*, 273-290.

Tana, S., Abeyewickreme, W., Arunachalam, N., Espino, F., Kittayapong, P., Wai, K., . . . Sommerfeld, J. (2012). Eco-Bio-Social research on dengue in Asia: General principles and a case study from Indonesia. *Ecohealth Research in Practice* (pp. 173-184) Springer.

Tran, H. P., Adams, J., Jeffery, J. A. L., Nguyen, Y. T., Vu, N. S., Kutcher, S. C., . . . Ryan, P. A. (2010). Householder perspectives and preferences on water storage and use, with reference to dengue, in the Mekong Delta, southern Vietnam. *International Health, 2*(2), 136-142.

Wagatsuma, Y., Breiman, R. F., Hossain, A., & Rahman, M. (2004). Dengue fever outbreak in a recreation club, Dhaka, Bangladesh. *Emerging infectious diseases*, *10*(4), 747.

Waltner-Toews, D., Kay, J. J., & Lister, N. E. (2008). *The ecosystem approach: complexity, uncertainty, and managing for sustainability* Columbia University Press.

Waltner-Toews, D. (2001). An ecosystem approach to health and its applications to tropical and emerging disease. *Cad Saúde Pública, 17*, 7-36.

Wilcox, B. A., Gubler, D. J. (2005). Disease Ecology and the Global Emergence of Zoonotic Pathogens. *Environmental Health and Preventive Medicine, 10*, 263–272.

Wilcox, B. A., Gubler, D. J., HF, Mayer, K., & Pizer, H. (2008). Urbanization and the social ecology of emerging infectious diseases. *The Social Ecology of Infectious Diseases,* 113-137.

Wilcox, B. a., & Colwell, R. R. (2005). Emerging and Reemerging Infectious Diseases: Biocomplexity as an Interdisciplinary Paradigm. *Ecohealth, 2*(4), 244-257.

World Health Organization. (2005). *Declaration of Alma-Ata, 1978* World Health Organization.

CHAPTER NINE

CONCLUSIONS

9.1 Major Findings of the Research

My research has sought to develop a model of dengue transmission in the city of Dhaka, Bangladesh, which incorporates all major socio-economic and socio-ecological risk factors at multiple scales. In this thesis, I have asserted that gaining a full understanding of the dynamics of dengue transmission requires the adoption of a transdisciplinary, 'Ecohealth' perspective in place of traditional reductionist approaches.

Understanding the relationships between socio-economic and ecological changes and the spread of dengue virus is critical to predicting future outbreaks and developing effective interventions to prevent them. Such efforts in Bangladesh have been hampered by a lack of reliable data, stemming from the country's limited and inefficient surveillance system (Islam et al., 2006). This has lead to a number of problems, including i) discrepancies in numbers of reported cases between official and non-government sources; ii) a limited understanding of the dengue disease transmission; and iii) inadequate vector control programs (Haque et al., 2009). Generating a reliable database and creating a conceptual framework through vigorous entomological, serological and socioeconomic surveys is therefore a matter of great urgency if Bangladesh is to establish a reliable surveillance system and effective, sustainable disease prevention and control measures.

From a long-term perspective, there is no clear evidence as to whether dengue prevalence in Bangladesh has declined. A persistently high rate of dengue infection is being influenced by the lack of knowledge and awareness of the eco-bio-social factors that can prevent and control dengue spread. The high infection rate is also being affected by serious deficiencies in the capacity of local communities to participate effectively in the development and planning of community health programs. Previous research efforts in Bangladesh have lacked the direct and effective involvement of the local communities in identifying and addressing dengue health problems, and a transdisciplinary approach (Lebel, 2003; Charron, 2012) was not adopted prior to this research.

It was expected that a multi-scale, eco-bio-social analysis of dengue prevalence in Bangladesh would provide a useful case study that could be applied to similar developing countries in the Southern and Southeast Asian regions. The specific objectives of my thesis were to:

1) Identify socioeconomic and ecological factors influencing dengue vector abundance in the city of Dhaka;

2) Examine the seroprevalence of dengue virus and socioeconomic risk factors.

3) Evaluate spatial dimensions of dengue vector abundance and its association with seroconversion.

4) Assess the role of knowledge, risk perceptions and attitudes, and practices in dengue transmission.

The temporal and spatial scale of a complex problem relates to the specific social-ecological system context and the nature of the drivers impact the system (Nayak, 2012). While it is essential to identify key individual factors driving disease transmission, such reductionist thinking can be limiting and misleading. A better, holistic understanding of an epidemiological system can be gained by i) shifting the epistemological paradigm from systematic science (e.g. a biomedical lens) to a pluralistic epidemiology (i.e. ‘system thinking’) (Miller et al., 2008); ii) adopting a transdisciplinary research framework in dengue transmission investigations; iii) approaching local communities and biophysical environments as integrated urban ecological (IUE) systems (Picket et al., 1997); iv) recognizing the daily livelihood and security concerns facing impoverished and marginalized peoples; and v) fostering greater intersectoral and multi-level cooperation and collaboration between government health authorities (Berkes, 2010). Such considerations have led me to formulate my central thesis that '***obtaining an accurate model of dengue transmission may not be possible using a purely reductionist approach. It is also necessary to consider the complex interactions between various key factors, including the effects of human choices and actions.***'

The findings of the present study strongly support the above assertions and the stated *thesis* which are synthesized in Table 9.1. Consistent with these assertions, my research strives to explain the social-ecological factors, dynamics, and structures underpinning the epidemiology of dengue in the city of Dhaka. DF, DHF, and DSS have evolved in concert with the various ecological and social shifts in Bangladesh since the mid-1960s, with the first major breakout occurring in 2000. Before this time, dengue was not considered endemic to Bangladesh except for a few sporadic cases since 1965 (Yunus et al., 2001).

The presence of dengue in Bangladesh was not confirmed until 1996-97, when a joint WHO-Integrated Control of Vector-Borne Diseases study found an incidence rate of 13.7% in a sample of 225 people. As a result, the people, government, and medical establishment in Bangladesh were ill-acquainted and ill-equipped to diagnose, treat, and prevent cases of dengue (Yunus et al., 2001). Throughout the 1950s and '60s, the demographics and economy of Bangladesh were typical of a closed, developing agriculture-based country. For example, the population of Dhaka rose from only 417,000 in 1950 to almost 2.1 million in 1975 (Ahmed, 2012). With the advent of increased globalization in the 1990s, Dhaka - along with similar cities in South Asia - has undergone rapid socio-economic, demographic, and ecological transformation. With a demographic growth rate of 7%, the city's population reached 2.5 million in 2000, while its GDP growth rate increased from 3.6% in 1972 to 5.1% in 1990 (Rahman and Yusuf, 2010).

The 2000 dengue outbreak in Dhaka, Chittagong and Khulna resulted in a total of 5,551 cases (4,385 DF, 1,166 DHF), 93 of which were fatal. Inadequate training, lack of specialized knowledge, and the absence of national guidelines for clinical management of dengue syndrome resulted in this high fatality rate.

Following the outbreak, research was conducted only to confirm the presence of dengue, and despite the increasing circulation of dengue virus in Bangladesh, little reliable data on the disease is available in this region (Karim et al., 2012; Islam et al., 2006; Pervin et al., 2004; Rahman et al., 2002). In the absence of scientifically-designed surveillance systems (Mahmood & Mahmood 2011), institutional responses to the DF and DHF epidemics of 2000 and 2002 relied on information available through mass media and local public health concerns expressed through elected officials (such as City Mayors and Ward Councilors) and public health personnel. Epidemic prevention and control measures therefore took the form of *post-facto* interventions carried out in response to public or political pressure placed on the concerned authorities.

Official data published by the Directorate of Health Services, Government of Bangladesh, have revealed fluctuating numbers of dengue cases between 2000 and 2006, ranging between 483 in 2003 and 6,132 in 2002. Although the number of deaths due to dengue infection has declined in recent years, it has remained a major public health concern due to the potential for another large-scale epidemic. Therefore, there has been an urgent demand for better understanding of dengue epidemiology and more effective measures for preventing and controlling the disease. Such measures must address three major difficulties: i) public health policy and practices largely focused on treatment and patient care rather than dengue control and prevention; ii) the non-existence of active disease surveillance systems in the country; and iii) deficiencies in intersectoral collaboration among government departments and other concerned stakeholders.

Knowledge of dengue transmission in Bangladesh is still limited due to the small number of studies that have been attempted and policy prioritization of clinical patient-care approaches. In addition, previous studies followed a small-scale, cohort disciplinary approach. One of the most complete profiles of dengue vector abundance and dengue cases in Dhaka was made by Ali et al. in 2003. Their study reported that households with recent dengue illness were more likely to have *Aedes albopictus* larvae present in the home compared with disease-free households. Furthermore, they cited that the presence of *Aedes aegypti* in these household premises and the homes of neighbors (within 50 meters) was not associated with dengue illness. A major weakness of this study was that it focused only on self-reported cases of dengue. Following the 2000 epidemic, Poddar et al. (2006) identified DENV-3 as a responsible serotype based on only 18 samples from two hospitals in the city. Via clinical and laboratory observations on 105 clinical samples from two Dhaka city hospitals, Pervin et al. (2004) established the association of dengue haemorrhagic manifestations with different dengue virus serotypes. In 1996-87, Hossain et al. (2003) tested 225 serum samples from febrile patients and blood donors and discovered dengue antibodies, revealing that dengue transmission was ongoing in the city well before 1996. A handful of studies (Karim et al., 2012; Hashizume et al., 2012) performed time-series analyses of climate variability and dengue transmission in Dhaka; however, none of the studies conducted city-wide serosurveys or accounted for the role of local knowledge, perception, attitude, and practices on dengue transmission. To my knowledge, the current study is the first attempt to apply a transdisciplinary methodology to dengue epidemiology by integrating entomological, serological, and community/social factors into a holistic social-ecological system perspective. Table 9.1 summarizes the study's main findings corresponding to each of the four stated objectives.

Table 9.1: A synthesis of main findings corresponding to research objectives

Research Objectives	**Main Findings**
To identify socioeconomic and ecological factors influencing dengue vector abundance in the city of Dhaka	There was no significant difference among the high, medium, and low socio-economic status zones in terms of positive containers by householders as well as pupae per person indices Out of 35 different types of identified positive containers from *Aedes* infested households, 9 were found to be most productive for pupae of vector mosquitoes Two variables (i.e., purpose of storing water and income) were significant predictors of possession of containers categories by householders When the function of the containers was assessed, ornamental containers was the most important category associated with the number of pupae in the households
To examine the seroprevalence of dengue virus and socioeconomic risk factors in the city of Dhaka	Seroprevalence was high among the high, medium, and low socio-economic status zones Age and number of indoor potted plants were associated significantly with seroprevalence as well as seroincidence Seroconversion was high among children in the city of Dhaka.
To evaluate spatial dimensions of dengue vector abundance and its association with seroconversion	*Aedes aegypti* habitats and urban land cover/ landuse in the city of Dhaka are correlated. *Stegomyia* indices were considerably higher in the central business and residential zone (CBR) than in established residential and newly built residential zones Dengue seroprevalence across the city of Dhaka was high among all urban ecological zones (IUE). In all three IUE zones, seroprevalence concentrated in the area with more intense commercial activity, the main bus stations, transportation routes, schools and colleges, and community centers My results point to eco-spatial heterogeneity in the explanatory factors of dengue seroconversion. In the CBR zone, multiple microenvironmental factors, namely, participation in public gathering, travel during last six months, outdoor potted plants, and fever within last six months, were found to be correlated with seropositivity Overall, these results underscore the important role on dengue transmission, of public spaces and socioeconomic activities where human movement is intense, possibly more important than the households

Research Objectives	Main Findings
To assess the role of risk knowledge, perceptions and attitudes, and practices in dengue transmission	A comparative assessment of the public and experts' knowledge and perception of dengue-disease-risk has revealed significant gaps in the perception of: (a) disease risk indicators and measurements; (b) disease severity; (c) control of disease spread; (d) responsible institution to intervene. It further identifies misconceptions in public perceptions regarding: (a) cause of dengue disease; (b) dengue disease symptoms; (c) dengue disease severity; (d) dengue vector ecology; and (e) dengue disease transmission Most community members heard about dengue and knew that mosquitoes act as the primary vector of its transmission. In contrast, overwhelming majority was unaware that *Aedes* mosquitoes prefer to lay their eggs in water containers The respondents in age group 45-60 were more likely to have positive attitudes towards undertaking precautionary measures to prevent dengue than the respondents in age groups less than 25 years These findings confirm existence of misconceptions and considerable knowledge gaps about dengue transmission in the local communities that could be improved by formulating interventions targeting special subgroups of the population

Overall, the results of this research clearly establish the fact that formulating an effective explanatory model of dengue transmission would not be possible using a purely reductionist approach. Rather, it is an utmoast necessary to consider the complex interactions between ecological and social variables at multiple scales. However, this research also validates that the role of human *agency* in resource use and management play key roles in dengue transmission in the Bangladesh context. The aspects of human autonomy in making personal and collective choices that affected risk exposures can be cited here as effective examples. In the city of Dhaka, the dwellers' choice in the use of various types of water containers has profound effect upon the development of mosquito breeding sites in the households. As well, the choices made for the duration of storing water have similar impacts. In addition, this empirical research has revealed that human activities in terms of their movements and interactions affect seroconvertion among the population. In sum, this research successfully underscores the significance of studying interfaces between ecological and social spheres for understanding dengue transmission.

9.2 Contributions of Present Research

This thesis adopted an Ecohealth approach and social-ecological system perspective to explain dengue disease transmission and emergence in the context of a developing country mega-city, using Dhaka, Bangladesh as a case study. Tools and methods from various disciplines, including entomology, virology, sociology, social anthropology, ecology, were applied to formulate hypotheses and to collect empirical data on *Aedes* mosquitoes, human blood samples, and perceptual / socioeconomic characteristics of dengue transmission.

While disciplinary investigations can provide breadth and depth to fields that are inherently coherent, they can exclude vital information when the system under study involves elements from multiple disciplines such as biology, ecology, and sociology.

Thus the main contributions of this thesis lie in revealing the vital role of these interfaces in understanding dengue transmission in a developing mega-city. The specific contributions of my thesis are summarized in Table 9.2.

9.3 Reflections on Dengue Transmission Research

The WHO/TDR and IDRC initiatives in Latin America and Asia since the beginning of this millennia to understand the transmission of dengue and to address the problem effectively laid the foundation for a new approach to relationships between disease and broader socio-economic and ecological domains. My research has not only extended dengue transmission research, adopting an Ecohealth approach, to the geographical territory of South Asia, namely Bangladesh, it also demonstrates a 'show case' of integration between entomological, serological, and social-ecological spheres to explain dengue transmission process.

Table 9.2: Summary of contributions by knowledge, research and policy domain

Specific contribution domain	**Details of contribution**
Knowledge domain	My research outcomes will help to enhance the knowledge of dengue transmission scenarios in the context of developing countries, especially in South and South-east Asian countries
	The major contribution of this research findings is validating the role of human as a host and as an 'agency' (i.e., how their choices and preferences) help to play a role in disease transmission
	This research has also contributed in understanding the role of coupled socio-economic and biophysical systems together in disease transmission and emergence
Research domain	This is the first major research on understanding dengue transmission in the city of Dhaka by using transdisciplinary research design. The research design involves city-wide population serosurvey, entomological survey, socio-demographic survey, and KAP survey of the community members
	To confirm dengue cases, the gold standard Plaque Reduction Neutralization Tests have been performed on selected serum samples and to address the issue of cross-reactivity, I have confirmed the absence of any other flaviviruses (e.g., JEE, WNV) in the collected serum samples
	The sample size considered in this research is representing the whole city and conclusions drawn from this research has future research, practice/action and policy implications
Policy and action domain	This research showed that human living conditions, lack of intersectional collaborations contribute to the *Aedes* mosquito abundance dynamics. Research findings contributed in laying the ground of policy needed to enhance refuse collection, education campaign, and intersectoral collaboration

In order to achieve this goal, disciplinary tools and methods were used in a manner that enabled me and the research team to transform such systematic knowledge into newer integrative explanations of the issues and problems. This generated transdisciplinary knowledge involving further various stakeholders in society including policy and decision makers, as well as local community members.

My explorations into attitude, perception, and knowledge and the associated practice regarding dengue among the local community members have revealed that the conventional acedmic frameworks are inadequate to capture the real-world agony, sufferings, and grievance of the disadvantaged segments of population (i.e. the poor, women, marginalized groups, ethnic minorities). I observed very closely in the field of Bangladesh how challenging and difficult to make a daily living by these groups. The priority of health and disease issues remains at the bottom and until lives are threatened by emergencies, diseases like dengue fever are generally not addressed with any proactive measure. As a result of such avoidance of addressing diseases either with any preventive measures or at early stage, numerous misconceptions have evolved among them. A general failure to address inequity and social injustice issues by the prevailing institutions is associated with the perception, knowledge, and practice of the disadvantaged concerning dengue and other infectious diseases. Therefore, the conventional interventions, relying heavily on disciplinary knowledge and sectoral programming, are not likely to reach out these groups. My understanding of effective prevention and control of dengue in a city like Dhaka is deeply embedded in the need for an integrative approach involving pluralistic knowledge that exists in the scientific and social domains.

9.4 A Critical Evaluation and Limitations of the Research

Despite increasing acceptance in the literature that urban living itself is a determining factor of health and infectious diseases (Katz, 2012), experts and policy makers still approach many health problems on a disease- or population-specific basis. However, urban development oriented initiatives have bypassed some critical local issues to take on far more technically manageable “vertical” public health efforts that do not always necessarily align with local priorities or disease burden (Shiffman, 2006). My research revealed repeatedly that the effects of poor urban governance in the developing countries are major factors in the transmission of infectious diseases like dengue. Deficiency in public participation in decision-making, in transparency and accountability by the political and bureaucratic elites is the prime cause of such deficiency. The study of the relationship between urban governance and dengue disease transmission although was beyond the scope of present research, further research specifying political and governance structure and their effects on disease transmission will assist in improving our understanding in this area.

Considering participation of stakeholders’ as well as local community members as a fundamental pillar of application of ecohealth, the present research on dengue disease transmission was required to explore meaningful engagement of participants. The discourse of participatory research that evolved from the work of Robert Chambers and his followers (Chamebrs, 1994; Mukherjee, 1993) has advocated that local participation in research would only bring out meaningful results only when local community ‘people’ get the position first by being empowered as the driver of the research. Thus, the local community members set the research agenda, identify the problem, decide on method on approach and take part on deciding on conclusions in a truly participatory research. The present exploratory research on dengue transmission in the city of Dhaka could not be implemented as a truly participatory research (from the notion of Chambers) due to two primary reasons: i) dengue epidemic is a relatively new phenomenon in Bangladesh and therefore, local knowledge and awareness level are limited, ii) dengue disease transmission knowledge, similar to other infectious diseases, falls under the rubric of scientific paradigm, thus a specific type of knowledge. Lessons learned from the present research suggest that a future participatory research on dengue disease would be more successful if the research design considers the disease not merely from the perspective of health and disease, but incorporates the disease-livelihood-development nexus (Katz, 2012).

Entomological data was only collected at a single point in time, and was not tracked over a number of seasons. As this is the first study of *Aedes* pupal productivity in Dhaka, future research projects will doubtless be able to fill these gaps in the data. Generalizations of socio-demographic, economic and infrastructural homogeneity across an entire city must be made cautiously, but in this particular context I believe my assumptions to be valid. However, one limitation of the applied approach was that only household water containers were considered as potential *Aedes* habitats; a more thorough investigation would also factor in non-household containers.

In pre-monsoon serosurvey of June-July of 2012, the team succeeded in collecting 1,125 serum samples from 635 households. The serosurvey team attempted to revisit the same individuals during the post-monsoon serosurvey in November-December of 2012 with the aim of tracking seroconversion trends within the city, but due to high residential mobility and attrition, we were only able to collect 600 paired serum samples from 386 households, significantly decreasing our sample size.

I performed PRNT on 100 randomly selected samples from 899 IgG positive samples during pre-monsoon 2012 serosurvey, and on 50 randomly selected samples from 942 IgG positive samples during post-monsoon 2012 serosurvey. Therefore, considering the degree of margin of error in sample-based inferences, any generalizations should be made with caution.

In my attempt to delineate the Integrated Urban Ecological Zones (IUEZ) in Dhaka, I had to rely on an aggregate of land-cover and land-use-based classifications for administrative units (i.e. Wards). This was due to the fact that the initial study design used SES indicators for each selected Ward. In IUE Zoning, a preferred method would be to classify the entire city based on land-cover and land-use characteristics, and then delineate the boundaries of the distinct IUE zones. Future research should consider such a methodological approach to ensure further specificity in the geographical boundaries of the IUE zones.

My study aimed to capture the perspectives of various community members and other stakeholders concerning dengue disease, its vector, and practices for controlling and preventing the disease. The variety of interviewees was therefore quite wide, including local residents, local government personnel, local leaders, city authorities, local and city health workers, regulators and legislators, and policy makers. Due to limited time and scope of the study, I could encapsulate only a limited number of local, city and national stakeholders, leaving several other important actors for further study.

Due to time and resource constraints, only three of the six main principles of the Ecohealth approach could be covered: system thinking, transdisciplinary research, and participation. Further studies should therefore be pursued to examine gender, sustainability and knowledge-to-action factors affecting dengue transmission in Dhaka.

9.5 Future Research Directions and Policy Recommendations

The thesis is grounded in 9 months of field work conducted over 3 years in Dhaka, Bangladesh and 16 months of laboratory work in Winnipeg, Canada. It is the first such study to adopt a transdisciplinary lens in analyzing entomological, serological, socioeconomic, and behavioral data. Hence, my thesis work is primarily intended to fill certain critical knowledge gaps, with practical issues such as policy and disease control strategies being peripheral to the research. Nonetheless, some of my findings may have direct policy implications, particularly in the areas of health policies, urban development, and environmental management. Also, to the best of my knowledge, this research was the first population survey-based dengue transmission study in Bangladesh, and I was only able to investigate a limited number of hypotheses concerning disease transmission dynamics. Many relevant questions and hypotheses remained undressed, and should form the basis for future research projects.The six main topics relevant to policy and future research are as follows:

9.5.1 Identification of circulating serotypes

It is vital to identify multiple and sequential infections by the four dengue virus serotypes in people living in dengue hyperendemic regions, due to the lack of cross-protective neutralizing antibodies. Seroepidemiological studies have shown that secondary infection is a major risk factor for the development of DHF and DSS through antibody-dependent enhancement (Halstead et al., 1970; Monath & Heinz, 1996). Co-circulation of multiple dengue virus serotypes has been reported from many parts of the world (Bharaj et al., 2008). Therefore, it is vital for patient management and future epidemiological investigations that methods for rapid detection and differentiation between primary and secondary dengue virus infections are developed.

From literature on dengue in Bangladesh, it is evident that although all 4 dengue serotypes were prevalent during the 2000 outbreak, DEN-3 was the predominant serotype (70.5%) and was associated with the more severe clinical manifestations of the disease. Following the 2000 epidemic, there was a cyclical pattern of dengue outbreaks in Dhaka;

however, no current surveillance programs can identify the circulating serotypes. Establishing such a system would be a vital task for any future research study.

9.5.2 Monitoring and active surveillance system development

Determining the relationships between environmental changes, socio-ecological changes and the spread of dengue virus is critical to understanding its complex epidemiological system, developing predictive models, and undertaking appropriate interventions. Such efforts in Bangladesh have been constrained by the lack of reliable data, stemming primarily from the country's limited and inefficient surveillance system (Islam et al., 2006). This deficiency has lead to several problems, including: i) discrepancies in reported dengue cases between official and non-government sources; ii) a limited understanding of the dengue disease transmission; and iii) inadequate vector control programs in Bangladesh. Generating a reliable data base through vigorous serological surveys is therefore an urgent need in Bangladesh, particularly in order to develop effective disease management policies (Haque et al., 2009).

9.5.3 Addressing misconceptions and awareness gaps through risk communication

Since a large majority of community members tended to underestimate the risk associated with vector borne diseases like dengue, a large-scale disease prevention campaign is required. Such a campaign should clearly describe the prevalence and seriousness of mosquito-borne diseases in Dhaka and similar cities, and offer clear advice on how they can be avoided or eliminated - especially without resorting to the usage of bed nets and mosquito coils. Dengue risk communication strategies need to describe the transmission process, the role of *Aedes* mosquitoes in transmission, and the importance of stagnant water to their life cycles.

The study revealed that in areas such as Dhaka where mild fever and other low-level vector-borne diseases are a daily occurrence, many people accept these risks as a routine part of life - especially as other problems (e.g. putting food on the table) are much more immediate and pressing. In other words, dengue is seen as an abstract risk to be dealt with should it ever occur, rather than one to be actively prepared for. Disease prevention campaigns should therefore focus on clearly explaining the immediate and serious impacts of dengue, and how they can easily be prevented with minimal financial investment.

In public health campaigns, too often communication is unidirectional, with scientifically sound information on disease and health issues being provided by the authorities to the public. Local needs and knowledge are generally ignored in such messages, and as a result, government recommendations are often only partially understood and implemented by the people. In an era where global environmental and public health risks from dengue and other emerging infectious diseases are continuously evolving, it is critical to reach out local community members and secure their cooperation. More importantly, flow of information and communication from local communities to public health officials and other government agencies in Bangladesh will require restructuring governance structure and institutions. Without making an arrangement for public servants to be accountable to the community members and the general public, effective reception of local communication by the government officials would unlikely to take place. Policy emphasis must therefore be given to the establishment and strengthening more democratic and accountable governance systems at all level. Newer and better communication strategies that engage both experts and the public interactively are required. In addition, community-sensitive health and livelihood issue programming is required to more successfully effect motivational and behavioral changes.

9.5.4 Intersectoral coordination for an integrated approach to dengue issues

The findings of this study revealed serious coordination deficiencies among the various government departments and ministries responsible for health, environment, infrastructure, and urban development. Such communication gaps create situations in which, for example, power supply disruptions cause water supply problems, in turn forcing people to store water in open containers. Such unforeseen consequences can create breeding grounds for *Aedes* mosquitoes and encourage the spread of dengue. In-depth study of such processes was beyond the scope this research, but further research should be undertaken in order to improve interdepartmental/intersectoral and develop effective strategies for dengue prevention and control.

9.5.5 Shift of policy-focus from patient-care to dengue prevention and control

Since the 2000 dengue outbreak in Dhaka and other cities of Bangladesh, serious concerns have been expressed by various stakeholders regarding the need for improved disease management strategies to reduce dengue morbidity and overall population health.

This need is particularly pressing as public health policies and practices in Bangladesh are primarily focused on patient care rather than disease control and prevention. Also, due to improvements in treatment since 2000, the mortality rate due to DF, DHF, and DSS has declined, creating a 'sense of complacency' among many stakeholders. Considering the very high seroprevalence rate among the population of Dhaka, it is likely that another large outbreak is imminent - along with the major social, economic and demographic costs this entails. By departing from the present 'post de facto' approach to dengue prevention and control, the Bangladeshi health authorities could formulate a sustainable dengue prevention and control program involving local communities and other stakeholders.

9.5.6 Linking human health to ecosystem health

In illustrating 'an ecosystem approach to health', Forget and Label (2001) and Lebel (2003) succinctly linked better environmental management to better health within a transdisciplinary and participatory research framework. Considering such association between environment and health, my research validates that dengue transmission and emergence and associated illness are the products of complex and dynamic interactions between determinants (or factors), and between individuals, socioeconomic conditions, and ecosystems (Charron, 2012). The City of Dhaka, its population, its socioeconomic conditions and the biophysical environment are currently undergoing a rapid pace of transformation. Without water, waste and other infrastructural management at various geographical scales, the reduction of dengue incidence will be a difficult task. Determining the processes of interactions among these variables and their outcomes is required in order to conceptualize how human health and ecosystem health are linked. Further research therefore needs to focus on feedback, uncertainty, and self-organization dimensions of Dhaka's social-ecological systems.

References

Ahmed, S. (2012). The redress of urban governance and marginality in Dhaka, Bangladesh. *Advances in Education in Diverse Communities: Research, Policy and Praxis, 8*, 511-533.

Ali, M., Wagatsuma, Y., Emch,M. (2003). Use of a geographic information system for defining spatial risk for dengue transmission in Bangladesh: role for Aedes albopictus in an urban outbreak. *American Journal of Epidemiology, 69*(6), 634-640.

Berkes, F. (2010). Devolution of environment and resources governance: trends and future. *Environmental Conservation, 37*(04), 489-500.

Bharaj, P., Chahar, H. S., Pandey, A., Diddi, K., Dar, L., Guleria, R., . . . Broor, S. (2008). Concurrent infections by all four dengue virus serotypes during an outbreak of dengue in 2006 in Delhi, India. *Virol J, 5*(1), 1-5.

Charron, D. F. (Ed.). (2012). *Ecohealth research in practice: Innovative Applications of an Ecosystem Approach to Health*. Ottawa, Canada: Springer.

Chambers, R. (1994). *The origins and practice of participatory rural appraisal*. *World development*, 22(7): 953-969.

Forget, G., Lebel, J.,(2001). (2001). An ecosystem approach to human health. *Int J Occup Environ Health, 7*(2 Suppl), S3–S38.

Halstead, S. B., Nimmannitya, S., & Cohen, S. N. (1970). Observations related to pathogenesis of dengue hemorrhagic fever. IV. Relation of disease severity to antibody response and virus recovered. *The Yale Journal of Biology and Medicine, 42*(5), 311-328.

Haque, U., Ahmed, S. M., Hossain, S., Huda, M., Hossain, A., Alam, M. S., . . . Haque, R. (2009). Malaria prevalence in endemic districts of Bangladesh. *PLoS One, 4*(8), e6737.

Hashizume, M., Dewan, A. M., Sunahara, T., Rahman, M. Z., & Yamamoto, T. (2012). Hydroclimatological variability and dengue transmission in Dhaka, Bangladesh: a time-series study. *BMC Infectious Diseases, 12*, 98-98.

Hossain, M. A., Khatun, M., Arjumand, F. et al. (2003). Serologica evidence of dengue infection before onset of epidemic, Bangladesh. *Emerging Infectious Disease, 9*(11), 1411-1414.

Islam, M. A., Ahmed, M. U., Begum, N., Chowdhury, N. A., Khan, A. H., Parquet, M. d. C., . . . Suzuki, Y. (2006). Molecular characterization and clinical evaluation of dengue outbreak in 2002 in Bangladesh. *Japanese Journal of Infectious Diseases, 59*(2), 85-91.

Karim, M. N., Munshi, S. U., Anwar, N., & Alam, M. S. (2012). Climatic factors influencing dengue cases in Dhaka city: a model for dengue prediction. *The Indian Journal of Medical Research, 136*(1), 32.

Katz, Rebecca, et al. "Urban Governance of Disease." *Administrative Sciences* 2.2 (2012): 135-147.

Lebel, J. (2003). *Health: an Ecosystem Approach*. Ottawa: International Development Research Centre.

Mahmood, B. A. I., & Mahmood, S. A. I. (2011). Emergence of Dengue in Bangladesh a major international public health concern in recent years. *Journal of Environmental Research and Management, 2*, 035-041.

Miller, T. R., Baird, T. D., Littlefield, C. M., Kofinas, G., Chapin III, F. S., & Redman, C. L. (2008). Epistemological pluralism: reorganizing interdisciplinary research. *Ecology and Society, 13*(2), 46.

Monath, T., Heinz, F., Flaviviruses, F. B., Knipe, D., & Howley, P.Fields Virology, 1996, 961-1034. *Lippinscott-Raven Publishers, Philadelphia*,

Mukherjee, Neela. (1993). *Participatory rural appraisal*. Vol. 1. Concept Publishing Company.

Nayak, P. K. (2012). Change and Marginalisation: Livelihoods, commons institutions and environmental justice in Chilika Lagoon, India.

Pervin, M., Tabassum, S., Ali, M., & Mammon, S. (2004). Clinical and laboratory observations associated with the 2000 dengue outbreak in Dhaka, Bangladesh. *Dengue Bull, 28*, 96-106.

Pickett, S. T., Burch Jr, W. R., Dalton, S. E., Foresman, T. W., Grove, J. M., & Rowntree, R. (1997). A conceptual framework for the study of human ecosystems in urban areas. *Urban Ecosystems, 1*(4), 185-199.

Poddar, G., Breiman. R. F., Azim, T.,Thu, H. M. et al. (2006). Short Report: Origin of dengue type 3 viruses associated with the dengue outbreak in Dhaka, Bangladesh, in 2000 and 2001. *American Journal of Tropical Medicine and Hygiene, 74*(2), 263-265.

Rahman, J., & Yusuf, A. (2010). Economic growth in Bangladesh: experience and policy priorities. *Journal of Bangladesh Studies, 12*(1).

Rahman, M. T., Tahmin, H. A., Mannan, T., & Sultana, R. (2002). Seropositivity and pattern of dengue infection in Dhaka city. *Mymensingh Medical Journal : MMJ, 16*(2), 204-208.

Shiffman, J. Donor funding priorities for communicable disease control in the developing world.*Health Policy Plan*. 2006, 21, 411–420.

Yunus, E. B., Bangali, A. M., Mahmood, M. A. H., Rahman, M. M., Chowdhury, A., & Talukder, K. (2001). Dengue outbreak 2000 in Bangladesh: from speculation to reality and exercises. *Dengue Bulletin, 25*, 15-20.

Appendix I

UNIVERSITY OF MANITOBA | Ethics
Office of the Vice-President (Research)

CTC Building
208 - 194 Dafoe Road
Winnipeg, MB R3T 2N2
Fax (204) 269-7173
www.umanitoba.ca/research

APPROVAL CERTIFICATE

October 25, 2010

IDRC

TO: **C. Emdad Haque**
Principal Investigator

FROM: **Brian Barth,** [redacted]
Joint-Faculty [redacted]d (JFREB)

Re: **Protocol #J2010:124**
"Climatic Variability, Social-ecological Changes, and Dengue Disease in Bangladesh: Development of an Integrated Ecohealth and Adaptive Management (IEAM) Approach"

Please be advised that your above-referenced protocol has received human ethics approval by the **Joint-Faculty Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement. This approval is valid for one year only.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, the auditor requires that you submit a copy of this Approval Certificate to the Office of Research Services, fax 261-0325 - please include the name of the funding agency and your UM Project number. This must be faxed before your account can be accessed.**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/ors/ethics/ors_ethics_human_REB_forms_guidelines.html) **in order to be in compliance with Tri-Council Guidelines.**

Bringing Research to Life

Appendix II

UNIVERSITY OF MANITOBA | Office of the Vice-President (Research and International)
Research Ethics and Compliance

Human Ethics
208 - 194 Dafoe Road
Winnipeg, MB
Canada R3T 2N2
Fax 204-269-7173

APPROVAL CERTIFICATE

February 28, 2012

MHRC, IDRC

TO: **Parnali Dhar Chowdhury** (Advisor C. Emdad Haque)
Principal Investigator

FROM: **Wayne Taylor, Chair** [redacted]
Joint-Faculty Research

Re: **Protocol #J2012:004**
"Understanding Dengue Transmission Dynamics through Ecohealth Approaches in Bangladesh"

Please be advised that your above-referenced protocol has received human ethics approval by the **Joint-Faculty Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement (2). This approval is valid for one year only.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, the auditor requires that you submit a copy of this Approval Certificate to the Office of Research Services, fax 261-0325 - please include the name of the funding agency and your UM Project number. This must be faxed before your account can be accessed.**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Quality Management Office may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba Ethics of Research Involving Humans.

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/orec/ethics/human_ethics_REB_forms_guidelines.html) **in order to be in compliance with Tri-Council Guidelines.**

umanitoba.ca/research/orec

Appendix III

বাংলাদেশ চিকিৎসা গবেষণা পরিষদ
Bangladesh Medical Research Council
BMRC

Ref: BMRC/NREC/2007-2010/ 310

Date: 23/06/2010

National Research Ethics Committee

Prof. Dr. G.U. Ahsan
Chairman
Deptt. of Public Health & Life Sciences
School of Applied Sciences
North South University
Dhaka.

Subject: Ethical Clearance

With reference to your application on the above subject, this is to inform you that your Proposal entitled **"Climatic Variability, Social-Ecological Changes, and Dengue Disease in Bangladesh: Development of an Integrated Ecohealth and Adaptive Management (IEAM) Approach"** has been reviewed and approved by the National Research Ethics Committee (NREC).

You are requested to please note the following ethical guidelines as mentioned at page 2 (overleaf) of this memo-

[redacted]

(Prof. Harun-Ar-Rashid)
MD, MSc, MPH, PhD, FRCP Edin
Director

Mohakhali, Dhaka-1212, Bangladesh, Phone : 8811395, 8828396, Fax : 880-2-8828820
E-mail : bmrc@citechco.net

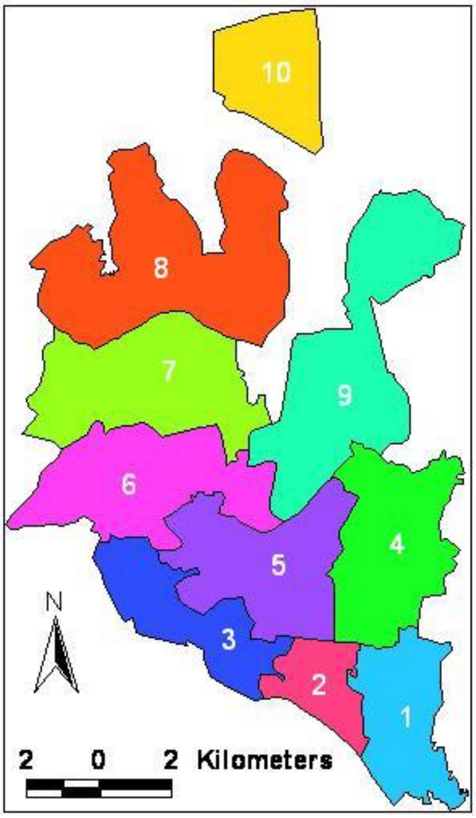
Page –2

THE ETHICAL GUIDELINES TO BE FOLLOWED BY THE PRINCIPAL/ CO-INVESTIGATORS

- ❒ The rights and welfare of individual volunteers are adequately protected.
- ❒ The methods to secure informed consent are fully appropriate and adequately safeguard the rights of the subjects (in the case of minors, consent is obtained from parents or guardians).
- ❒ The Investigator(s) assume the responsibility of notifying the National Research Ethics Committee (NREC) if there is any change in the methodology of the protocol involving a risk to the individual volunteers.
- ❒ To immediately report to the NREC if any evidence of unexpected or adverse reaction is noted in the subjects under study.
- ❒ This approval is subject to P.I.'s reading and accepting the BMRC ethical principles and guidelines currently in operation.

Appendix IV

Socio-Economic Status of Dhaka City Corporation wards



Prepared by
Md. Shamsuddoha
and
Md. Shahadat Hossain
for
Participatory Research and Development Initiative (PRDI)
Dhaka, Bangladesh

June 2011

Socio-Economic Status of Dhaka City Corporation wards

Background

Dhaka, the capital city of Bangladesh, is in a continuous process of urban expansion. Dhaka emerged as an important strategic and business center along the river Buriganga at the beginning of Muslim rule in 13th century. Since after liberation till today, capital city Dhaka accommodates major share of urban population. According to 2001 census, Dhaka Statistical Metropolitan Area (SMA) accommodates 10.7 million people, which is 37.45% of total urban population of Bangladesh (BBS, 2003). Dhaka entered the mega city list attaining the rank 25th in the year 1980 with a population of 6.6 million. It is predicted by United Nations that Dhaka would be the 6th largest mega city by the year 2010 and it would continue to uplift its position as second largest mega city of the world by the year 2015 (Islam, 2005). According to the population projection of Dhaka Metropoilitan Development Plan (DMDP, 1997), the population of Dhaka Mega City will be 15.57 million by the year 2015.

Mega city Dhaka is an agglomeration of Dhaka City Corporation, four other municipalities (Narayanganj, Tongi, Gazipur, and Savar), several cantonments, and a large number of rural settlements, stretches of agricultural lands, wetlands, rivers, and even part of the Modhupur forest. The gross density of population in the mega city area is only 6,000 persons/square km, but this figure hides the reality to a large extent. Less than 40 percent of the mega city area has been urbanized. The population density in urbanized areas is about 14,000/sq km. This is quite high, especially when most development is horizontal. By 2015, Dhaka's projected population of 19.5 million will fill most of the designated metropolitan area as a result of urban migration, extensions in the peripheries, and fresh urbanization. DCC comprises only 24 percent of the megacity, a total of 138 square km, but within this small area it has to accommodate a population of nearly 6 million, plus another million or so daily commuters.

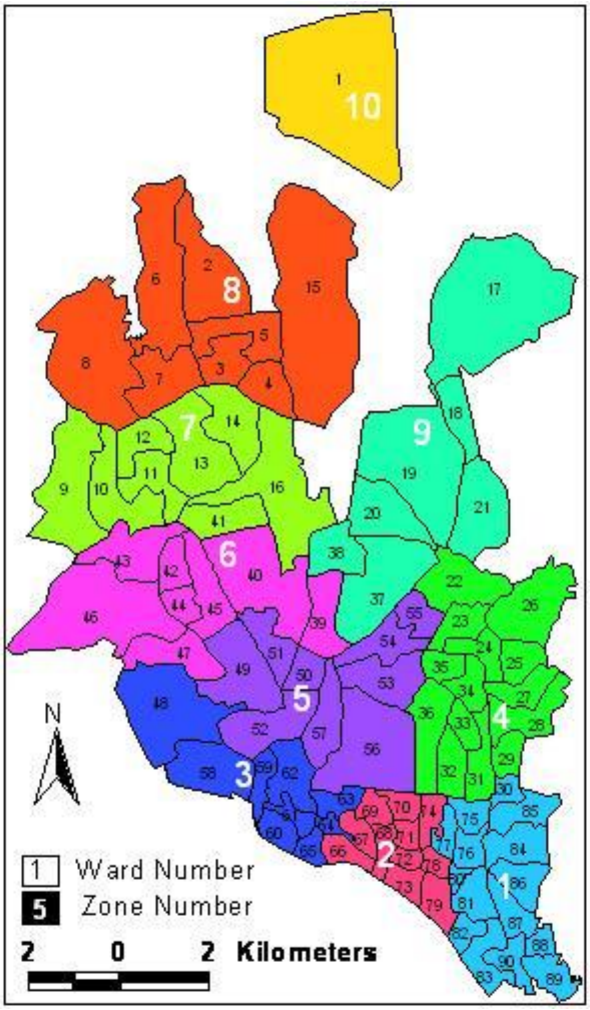


Figure 1. Wards and zones of DCC

Although the focus of this study is the area within the DCC limits, we cannot forget about the close interrelationship of DCC with the other municipalities, or with the surrounding region within the mega city. Indeed, Dhaka's functional hinterland is the whole of Bangladesh. The three basic premises with which planners and builders of cities normally deal are economy, efficiency, and beauty. A city should be a human settlement that is highly efficient, economically productive, and visually attractive. Today, an ideal city should demonstrate equity in access to resources and services, provide scope for democratic participation, and be environmentally and culturally sustainable.

Unfortunately, DCC does not present a good track record in any of these parameters. Ownership of urban land is highly unequal, with only 30 percent of the population controlling ownership or access to 80 percent of the residential land, while the other 70 percent have access to the remaining 20 percent.

Administrative wards of DCC

DCC is divided into 90 wards. The territory of DCC is divided into 10 administrative zones (Figure 1; Table 1). The Dhaka Metropolitan Development Plan (DMDP) has forecasted the average density of thegross built up urban areas would be 209 person /acre in the year 2015 but according to the census 2001 the average density of Dhaka city has already reached 214 person/acre. Prevailing density in some wards is more than three timesthan the average and some wards remain below the average density. It is revealed from the density scenario that the scope for consolidation in Dhaka City is still there in some wards where density is comparatively low.Redistribution of population and improvement of infrastructure can widen the scope of consolidation in densely populated areas where potential developable lands are available.

DCC has been planned for extension up to 1550 sq km calling Greater Dhaka, surrounded by the rivers of Turag, Shitalakha, Balur and Buriganga (Huda 2001).Economic indicator shows that the per capita income of the people of Bangladesh is nearly US$ 450. GDP is US$14.89 million. Around 55 per cent people live below the poverty line in Dhaka.

Table 1. Total wards with area of Dhaka City Corporation

Zone No.	**Ward No.**	**Area (sq.km)**
Zone-1	Ward 30	0.433
	Ward 75	0.672
	Ward 76	0.548
	Ward 77	0.431
	Ward 80	0.272
	Ward 81	0.543
	Ward 82	0.514
	Ward 83	0.576
	Ward 84	0.760
	Ward 85	1.087
	Ward 86	0.859
	Ward 87	0.857
	Ward88	0.538
	Ward 89	0.736
	Ward 90	0.935
	Total Ward :15	**Total Area: 09.761**
Zone -2	Ward 66	0.349
	Ward67	0.465
	Ward68	0.215
	Ward69	0.311
	Ward70	0.368
	Ward71	0.139
	Ward72	0.135
	Ward73	0.449
	Ward74	0.424

Zone No.	Ward No.	Area (sq.km)
	Ward78	0.274
	Ward79	0.364
	Total Ward: 11	**Total Area: 03.493**
Zone-3	Ward48	1.351
	Ward58	1.072
	Ward59	0.548
	Ward60	0.424
	Ward61	0.359
	Ward62	0.922
	Ward63	0.511
	Ward64	0.178
	Ward 65	0.457
	Extension Area	1.810
	Total Ward:09	**Total Area: 07.632**
Zone-4	Ward22	1.808
	Ward23	0.856
	Ward24	0.825
	Ward25	1.015
	Ward26	1.927
	Ward27	0.865
	Ward28	1.016
	Ward29	0.591
	Ward31	0.966
	Ward32	1.315
	Ward33	0.380
	Ward34	0.812
	Ward35	0.511
	Ward36	1.035
	Extension Area	2.559
	Total Ward: 14	**Total Area: 16.481**
Zone-5	Ward49	2.340
	Ward50	0.619
	Ward51	0.868
	Ward52	1.897
	Ward53	1.744
	Ward54	1.149
	Ward55	0.769
	Ward56	2.082
	Ward57	1.952
	Total Ward: 09	**Total Area: 13.420**
Zone-6	Ward39	1.374
	Ward40	3.661
	Ward42	0.712
	Ward43	2.469
	Ward44	0.629
	Ward45	1.561
	Ward 46	5.582

Zone No.	Ward No.	Area (sq.km)
	Ward 47	1.362
	Total Ward: 08	**Total Area: 17.360**
Zone-7	Ward9	1.615
	Ward10	1.669
	Ward11	1.133
	Ward12	1.697
	Ward13	1.817
	Ward14	1.948
	Ward16	2.084
	Ward41	1.528
	Total Ward: 08	**Total Area: 13.491**
Zone-8	Ward2	3.048
	Ward3	1.101
	Ward4	1.339
	Ward5	1.344
	Ward6	3.029
	Ward7	1.875
	Ward8	3.776
	Ward15	5.806
	Total Ward: 08	**Total Area: 21.318**
Zone-9	Ward17	5.475
	Ward18	1.496
	Ward19	5.298
	Ward20	1.729
	Ward21	1.449
	Ward37	3.075
	Ward38	1.219
	Extension Area	7.246
	Total Ward: 07	**Total Area: 26.987**
Zone-10	Ward1	8.945
	Total Ward: 01	**Total Area: 08.945**
	Total Ward: 90	**Total Area: 138.888**

Materials and methods

Using DELPHI method, ten experts from different disciplines who have adequate knowledge about the DCC wards' overall SES standing were selected and interviewed in July 2011 (Table 2). Standard questionnaire with a set of pre-defined criteria were provided to the experts to rank the wards on the Socio-Economic Status(SES) scale. After criteria-wise response, the experts gave the overall rank of the wards as High, or Medium, or Low on a relative scale for each ward.

Table 2. Experts list (interviewees)

Sl	Name	Designation	Organization	Contact
1	Md. GolamRahmanMiah	Chief Estate Officer	Dhaka City Corporation	

Sl	Name	Designation	Organization	Contact
2	KaziHasibaJahan	Geographer	Urban Planning Department, Dhaka City Corporation,	
3	Khalil Ahmed	Senior Assistant Secretary & Executive Magistrate	Dhaka City Corporation	
4	Md. Akthar Mahmod	Associate Professor	Department of Urban & Regional Planning, Jahangirnagar University	
5	Dr. M. Khabir Uddin	Professor	Department of Environmental Sciences, Jahangirnagar University	
6	Ar. Sayeed Parvez Reza Latif	Managing Director	Artisan Apartments LTD., Artisan Technological Service LTD., Artisan Architects Engineers & Development LTD.	
7	Dr. Md. Saiful Alam Siddiquee	Professor	Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET)	
8	Suman Kumar Mitra	Assistant Professor	Dept. of Urban and Regional Planning, Bangladesh University of Engineering and Technology (BUET)	
9	Dr M Asaduzzaman	Research Director	The Bangladesh Institute of Development Studies (BIDS)	
10	Professor Dr. Ainun Nishat	Vice Chancellor	BRAC University	
11	Mr. Quamrul Islam Chowdhury	Chairman	Bangladesh Fedaration of Environmental Journalist Bangladesh	

Criteria used for ranking:

1. Ward Number
2. Zone Number
3. Municipal property tax rates
4. Real estate property value
5. Rate of property rent
6. Proximity to types of markets and shopping areas
7. Types of predominant residence, building structure etc.
8. Proximity to public services and types of amenities
9. State of transport and other infrastructure,

Results and observations

Table 3. Socio-economic status of DCC wards and zones

Socio-Economic Status	Ward No. (total)	Zone No. (total)	Remarks
High	1,3,18,19,20,22,23,32,38,49,50,53,54,57 (14)	4,5,9,10 (4)	
Medium	2,4,5,6,7,8,17,21,24,25,26,27,28,29,31, 33,34,35,36,37,39,40,41,42,43,44,45,46, 47,51,52,55,56,59,60,61,62,63,64,65 (40)	3,4,5,6,7,8,9 (7)	
Low	9,10,11,12,13,14,15,16,30,48,58,66,67,68 69,70,71,72,73,74,75,76,77,78,79,80,81, 82,83,84,85,86,87,88,89,90 (36)	1,2,3,7 (4)	

Conclusive remarks

Dhaka will remain the most important urban agglomeration in the country and one of the largest in the world. Given the political system, economic situation, and environmental condition, it is impossible to restrict migration into Dhaka, and therefore the city is likely to continue to grow rapidly for the foreseeable future. There are many other issues to be tackled that concern the future of Dhaka. A number of the issues are deconcentrating Dhaka's population by accelerating growth of existing satellite towns and establishing new satellites; discouraging new investments in DCC area; improving transportation between the central city and other towns in the vicinity; government support for housing for the poor; construction of link roads, bypass roads and flyovers; and adoption of local area planning process with participation of community members. It is essential to carefully review the issues and determine the total commitment for implementation. Finally, the planning and development process of Dhaka cannot reach its desired objectives without direct and total participation of its residents. Equally important is efficient city administration, including planning, development, and service delivery.

References

Huda, K.M.N., 2001. Feasibility study for solid waste management to control environmental hazard and pollution in Dhaka City Corporation.Paper Presented to the First Meeting of the Kitakyushu Initiative Network Kitakyushu, Japan. 20-21 November 2001.

BBS, 2003. Population Census 2001: National Report (Provisional), Dhaka: Bangladesh Bureau of Statistics.

DMDP, 1997. Dhaka Metropolitan Development Plan (1997-2015) Volume I & II", Dhaka: Dhaka Metropolitan Development Planning (DMDP), RajdhaniUnnayanKartripakha (RAJUK).

Islam, N. 2005. Dhaka Now: Contemporary urban development. Dhaka: Bangladesh Geograpical Society (BGS).

Appendix V

Table: Percentage distribution of Landuse/Land cover variables by ward, city of Dhaka, 2012-13

Ward No	Bare Soil	Coarse Vegetation	Industrial	Paved	Public Service and Commercial	Residential	Water Bodies	Building Ratio	Total
13	1.4134	5.4671	0.2809	24.382	2.3511	66.0341	0.0713	68.6660	100.00
20	1.4134	5.4671	0.2809	24.3820	2.3511	66.0342	0.0713	60.4560	100.00
25	0.1956	6.6559	0.2227	10.7864	1.6395	78.538	1.9619	80.4002	100.00
26	3.36	3.7069	0.0167	2.0213	0.3224	85.0331	5.5395	85.3722	100.00
35	0	6.9148	0.2353	26.3927	2.5704	62.7328	1.154	65.5385	100.00
38	0.0307	0.201	0.0556	45.829	0.9849	52.8246	0.0742	53.8651	100.00
40	0.378	15.8452	0.0433	36.5413	2.2964	41.4895	3.4062	43.8293	100.00
58	0.2277	2.2075	2.3724	14.1373	1.4369	62.7711	16.8471	66.5804	100.00
60	0.2519	1.4706	0.4784	25.1487	2.0608	61.6633	8.9263	64.2025	100.00
69	2.4074	2.1291	0.6922	35.7607	6.1236	52.887	0	59.7028	100.00
76	7.166	8.8453	0.2738	34.4679	6.1373	43.1097	0	49.5208	100.00
78	0	1.4938	0.0925	47.0677	7.0684	44.2776	0	51.4385	100.00

Appendix VI

Entomological Survey Instruments 1

OUTLINE OF THE QUESTIONNAIRE

Section 1	Survey Information
Section 2	Demography and Household Composition
Section 3	Housing Characteristics
Section 4	Water Supply, Storage and Usage
Section 5	Waste Disposal
Section 6	MEASURES TO PREVENT MOSQUITO BITE
Section 7	HOUSING CHARACTERISTICS CHECKLIST

SECTION 1: SURVEY INFORMATION

Team# ____________
Date ____________
Ward# ____________
Grid Cell Number________________
Household Address ____
Contact Number_________________________
Start time____________________ End Time_______________________

SECTION 2: DEMOGRAPHY AND HOUSEHOLD COMPOSITION

2.1 Head of Household (Specify Name)____________________________________

2.1.1 Sex:	☐ Male	☐ Female		2.1.2 Age (Year) ▶		______
2.1.3 Religion	☐ Muslim	☐ Hindu	☐ Buddhist	☐ Christian	☐ Others	☐ None
2.1.4 Educational Status						

2.1.6 Occupation	☐ Unemployed	☐ Daily Laborer	☐ Public service holder
	☐ Self-employed	☐ Housewife	☐ Private service holder
	☐ Business person	☐ Student	☐ Skilled/semi-skilled workers
	☐ Professional	☐ Others (please specify)	______________

2.2 Respondent (If different from 2.1) (Specify Name)__________________________________

2.2.1 Sex:	☐ Male	☐ Female		2.1.2 Age (Year) ▶		______
2.2.3 Religion	☐ Muslim	☐ Hindu	☐ Buddhist	☐ Christian	☐ Others	☐ None

2.1.4 Years of schooling ▶		2.1.5 Highest Degree attained ▶	

2.2.6 Occupation	☐ Unemployed	☐ Daily Laborer	☐ Public service holder
	☐ Self-employed	☐ Housewife	☐ Private service holder

	☐ Business person	☐ Student	☐ Skilled/semi-skilled workers
	☐ Professional	☐ Others (please specify)	________________________

2.3. 1 How many people normally live in this house_______________
2.3.2 How many people slept in your house last night__________________
2.3.3 What is the average monthly income for your household (Give range)_______________
2.3. 4 How many people are away from home during the day______________

SECTION 3: HOUSING CHARACTERISTICS

3.1	Do you own or rent the residence?	☐ Own	☐ Rented
3.2	For how many years have you been living in this neighborhood?		
3.3	For how many years have you been living in this residence?		
3.4 How many units are there in this apartment____________ 3.5 How many floors___________________			

SECTION 4: WATER SUPPLY, STORAGE AND USAGE

4.1	What is/are your source/s of water supply? (Multiple answers are acceptable)	
	☐ Piped water to house	☐ Piped water to community
	☐ Hand-pumped tube-well	☐ Deep tube-well
	☐ Open source (pond/lake/ditch/canal/river)	☐ Vehicular supply (from municipality)
	☐ Others	

4.1.1	Do you face any water supply problem?	☐ Yes	☐ No
	If yes, please specify what types of water supply problems do you face.		
4.2	Do you store water?	☐ Yes	☐ No

4.3	For which purposes do you store water?			
	☐ Washing	☐ Cleaning	☐ Drinking	☐ Shower
	☐ All of these	☐ Others		

4.4 If you store water, how frequently do you empty the following containers?

Container Size	Number	Type	Lid?	Frequency					
				Daily	Alternate day	Weekly	Fortnightly	Monthly	More …
Large (>300L)			☐	☐	☐	☐	☐	☐	☐
Medium (30-300L)			☐	☐	☐	☐	☐	☐	☐
Small (<30L)			☐	☐	☐	☐	☐	☐	☐

4.5	Where is the toilet located?			
	☐ Inside house	☐ Outside house	☐ Community toilet	

SECTION 5: WASTE DISPOSAL

5.1	How do you dispose-off the organic waste?

	Disposal method	Frequency		
		Daily	Alternate day	Other (pls specify)
	☐ municipal or private pick up	☐	☐	
	☐ Empty in a specific location on property	☐	☐	
	☐ Empty in a specific location off property	☐	☐	
	☐ No fixed pattern of disposal	☐	☐	
	☐ Other	☐	☐	
5.1.1	If NOT disposing waste in a designated facility, what are the reasons for not using designated facilities?			
5.2	What do you do with the solid waste (plastic/tin cans/jars/bottles, broken cups/plates or other utensils, coconut shells, tires of wheels etc.)?			
	Disposal method	Frequency		
		Daily	Alternate day	Other (pls specify)
	☐ municipal or private pick up	☐	☐	
	☐ Empty in a specific location on property	☐	☐	
	☐ Empty in a specific location off property	☐	☐	
	☐ No fixed pattern of disposal	☐	☐	
5.2.1	If NOT disposing waste in a designated facility, what are the reasons for not using designated facilities?			

SECTION 6: DO YOU USE ANY OF THE FOLLOWING MEASURES TO PREVENT MOSQUITO BITE ?

☐ REPELLENT
☐ COIL
☐ AEROSOL
☐ BED NET
☐ INSECTICIDE TREATED CURTAINS
☐ WINDOW SCREENS (NET MADE)
☐ COVERING CONTAINERS
☐ WASHING AND CLEANING CONTAINERS
☐ EMPTYING WATER OF THE CONTAINERS
☐ WASTE MANAGEMENT IN THE HOUSE
☐ MOSQUITO BAT
☐ OTHERS (SPECIFY)____

SECTION 7: HOUSING CHARACTERISTICS CHECKLIST				
7.1	What is the type of your residence?			Number of Floors
	☐Independent House	☐Multi-story Building	☐High-rise Apartment	
7.2.	Please indicate the building materials of your residence.	Thatch	CI Sheet	Masonry
	Wall	☐	☐	☐
	Roof	☐	☐	☐
7.3	If the residence is a multi-story or high-rise apartment, do you have an elevator?	☐Yes	☐No	

7.4	Which floor is the unit on____________	
7.5	How far is the nearest household in meters?	
7.6	Are there points of mosquito entry into the residence beside windows and doors? If yes, please specify___________________________	
7.7	Are the windows properly screened?	

7.8 Is there open green space attached to your residence?				
		☐Yes	☐ No	Specify the green space__________________

7.9 Is there any open water source (pond, lake, ditch, canal & river) within sight of the residence?						
	☐ Pond	☐ Lake	☐ Ditch	☐ Canal	☐ River	☐ Other
Distance (m)						

7.10	Do you have vegetation (natural or cultivated on ground soil) in your residence?	☐ Yes	☐ No
7.11	Do you have roof-top gardens with potted plants ?	☐ Yes	☐ No

7.12 If yes, what type of vegetation (natural or cultured grown on ground soil) is there in your homestead?

- ☐ Grass
- ☐ Shrubs/bushes
- ☐ Vines
- ☐ Orchards
- ☐ Trees
- ☐ Roof top garden
- ☐ Other

ANOTHER TEAM WILL COME TO YOUR HOUSEHOLD FOR BLOOD SAMPLE COLLECTION TO DETECT DENGUE FOR FREE. WILL YOU OR ANY OTHER PERSON IN YOUR HOME IS WILLING TO GIVE BLOOD FOR FREE DETECTION OF DENGUE?

Appendix VII

Entomological Survey Instruments 2

IMMATURE AEDES SURVEY FORM

Date of Survey__DAY___/_MONTH_/_YEAR_____ TeamNo:______Ward:________Grid Cell No.:______________

Entomology Technician:____________________________ Research Fellow:__________________________

Start time:________________ End Time:_______________Owner/Resident's Name:___________________________

**Household Address:____

How many people slept last night in this house____________

Container specific data										Larval counts				Pupal count	
Container type [A]	Container quantity	Water capacity volume (L)	Water volume (F=full; 3/4,1/2, 1/4, SC=scantly)	Type of water (1=tap, 2=rain, 3=tubewell, 4=ring well, 5=other)	Vegetation (0=none; 1=nearby; 3=under)	Container location (I=inside; O=outside)	Container sheltered from Rain (N=no; Y=yes)	Shade (0=none;1=partial; 2=full)	Intervention/Covered [B]	Sample ID Number [C] (ward – grid#- container type – 1..2..3)	Absolute number	Estimated number present		Absolute number	Estimated number present

NOTE: when containers appear to be emptied frequently; ask the respondent how often the water is removed and DO NOT count larvae or pupae in containers that are emptied every three days or less, count as wet containers.

[A] Container code:

A1=Water tank
A2=Cement pot
A3=Clay pot
A4=Ceramic pot
A5=Aluminum pot
A6=Glass bottle
A7=Plastic bottle
A8=Plastic mug
A9=Earthen jar (Motka)
A10=Clay pitcher
A11=Tin/metal can
A12=Metal pan
A13=Metal bucket
A14=Plastic bucket
A15=Plastic bags
A16=Animal bowl
A17=Flag stand hole
A18=Metal drum
A19=Plastic drum (sealable)
A20=Money plants tub
A21=Flower tub & tray
A22=Coconut shell (dry or green)
A23=Plant axil
A24=Tree hole
A25=Bamboo stamp
A26=Dried gourd shell
A27=Tires
A28=Battery shell
A29=Vehicle parts (specify)
A30=Cement mixer
A31=Musical instrument
A32.1= **A32.2=** **A32.3=**
Other……..............................Other…………..................Other…………..................

[B] Intervention:0=None **1=**Completely covered**2=**Frequentlyemptied (greater than 3 days) **3=**Cleaned **4=**Other (specify)

[C]Sample ID numbers should consist of the ward number, followed by grill cell number, followed by the container code with sequential suffices for each replicate of the infested container (e.g., if two infested Tin/Metal cans from Ward 12 were detected at the household with a grill cell number 123, the correct ID sample numbers would be 12-E25-A11.1 & 12-E25-A11.2).

**Household selection process: Travel to the approximate center of the grid and the household to be sampled is determined by selecting a random number (from 1 to 6). If the household selected is an apartment block/complex, select additional random numbers for the floor and unit to be sampled.

Adult mosquitoes observed: Yes or No

If yes, locations of observation………………………………………………………………

Notes:

Appendix VIII

Lab Processing Protocol

INVENTORY AND CROSS CHECK ALL SAMPLES TO PUPAL SURVEY FORMS

Note: Pupal collections will now be separated from larvae in the field

Most containers will have both larva and pupae so you will usually get 2 vial (1 larva/1 pupae)

- Transfer pupae from pupal only samples TO EMERGENCE CONTAINERS LABELED AS ‘P’ (e.g., ward-grid cell number-container type – ‘P’)

- Place pupal samples in a secured location separately from other sources of pupae (see 4). When adults emerge from these pupae they will be counted as pupae.

Note: Larva samples for all containers will also be collected and will be labeled as in above but with the last letter – “L”

Samples collected as larva can consist of 1) larva only or 2) larvae/recently emerged pupae

1) For samples with only larvae – kill immediately with formaldehyde and place these samples in a secure location, separate from pupae

Count total number of larva and identify all III and IV instars and record as larvae

2) If samples contain recently emerged pupae, remove these pupae and place them in separate emergence container. Use the sample ID number but include he designation of “L” instead of “P” and keep these pupae separate from number 2 (pupal survey pupae) (pupae separated in the field)

When adults emerge they will be counted as larvae [because this is what they were when collected; So add these to the larval total]

All tasks except identification of killed larva must be done on the same day the samples arrive.

3) Double check that final number of pupae and larva match those on pupal survey forms

4) Remove adults from emergence containers at least daily and do the pupae only and larval pupae separately in space and time.

5) Report all errors or inconsistencies to supervisor (e.g., labeling errors missing samples, etc.)

6) Separate (from one container) pupae from larvae in the field

7) Record all data as before by add “L” after container type for samples with larvae

and add “P” to the label for pupae only vial (e.g., 38- X2 Y4-A27-P (pupae only)

38-X2Y4 – A27 – L (larva)).

Appendix IX
Selected entomological variables (Monsoon 2011)

Distribution of selected entomological variables by different SES wards/zones

Different SES wards/zones	Number of wet containers (%)	Number of positive containers (%)	Number of containers with pupae (%)	Number of houses surveyed (%)	Number of positive houses (%)	Number of houses with pupae (%)	Total larvae (%)	Total pupae (%)	% of MPCs
High	248 (19.4)	78 (15.8)	20 (20.6)	134 (16.2)	42 (19.0)	17 (20.7)	770 (21.1)	101 (18.4)	14.0
Medium	470 (36.8)	180 (36.5)	33 (34.0)	317 (38.4)	77 (34.8)	30 (36.6)	1,216 (33.2)	176 (32.0)	38.3
Low	560 (43.8)	235 (47.6)	44 (45.4)	375 (38.4)	102 (46.2)	35 (42.7)	1,681 (45.8)	273 (49.6)	47.7
Total	**1,278**	**493**	**97**	**826**	**221**	**82**	**3,667**	**550**	**371**

Distribution of selected entomological variables by selected 12 wards

Ward Number and Name (SES)	Number of total containers inspected (%)	Number of wet containers (%)	Number of positive containers (%)	Number of containers with pupae (%)	Number of house surveyed (%)	Number of positive houses (%)	Number of houses with pupa	Total larvae	Total pupae	% of MPC	Total Larvae/ pupae from MPCs
13 : Mirpur Pierbag (L)	102	93	43	10	60 (7.3)	19 (8.6)	09/19	303	32	8.0	241/29
20 : Mahakhali (H)	149	124	41	10	67 (8.1)	19 (8.6)	07/19	402	62	7.5	289/37
25 : Goran Khilgaon (M)	119	93	22	03	73 (8.8)	11 (4.9)	03/11	174	06	3.8	101/06
26 : Banashree (M)	130	108	57	12	63 (7.6)	22 (9.9)	11/22	347	79	12.6	305/48
35 : Malibagh (M)	115	91	38	03	65 (7.9)	19 (8.6)	03/19	231	13	7.3	143/07
38 : Nakhalpara (H)	148	124	37	10	67 (8.1)	23 (10.4)	10/23	368	39	6.5	311/38
40 : Monipuripara	104	93	42	06	53 (6.4)	16 (7.2)	06/16	338	35	9.7	313/35
58 : Hazaribagh (L)	136	112	14	00	69 (8.3)	09 (4.0)	00/09	78	00	2.7	53/00
60 : Lalbagh (M)	97	85	21	09	63 (7.6)	09 (4.0)	07/09	126	43	4.8	103/39
69 : Chankharpul (L)	141	126	66	10	83 (10.0)	25 (11.3)	10/25	473	86	14.5	400/76
76 : Sutrapur (L)	151	137	80	17	80 (9.7)	31 (14.0)	09/31	571	90	15.4	425/41
78 : Narinda (L)	109	92	32	07	83 (10.0)	18 (8.1)	07/18	256	65	7.0	206/41
Total	**1,501**	**1,278**	**493 (100)**	**97**	**826 (100)**	**221 (100)**	**82**	**3,667**	**550**	**75.2**	**2,890/397**

Appendix X
Selected entomological variables (Dry Season 2012)

Distribution of selected entomological variables by different SES wards/zones

Different SESW	Number of total containers inspected (%)	Number of wet containers (%)	Number of positive containers (%)	Number of containers with pupae (%)	Number of houses surveyed (%)	Number of positive houses (%)	Number of houses with pupae (%)	Total larvae (%)	Total pupae (%)
High	135	98	9	3	100	5	3	89	12
Medium	311	200	19	7	236	14	6	217	25
Low	255	165	25	10	210	20	8	117	54
Total	701	463	53	20	546	39	17	423	91

Distribution of selected entomological variables by selected 12 wards

Ward Number and Name (SES)	Number of total containers inspected (%)	Number of wet containers (%)	Number of positive containers (%)	Number of containers with pupae (%)	Number of house surveyed (%)	Number of positive houses (%)	Number of houses with pupa	Total larvae	Total pupae
13 : Mirpur Pierbag (L)	58	34	4	1	51	4	1	21	1
20 : Mahakhali (H)	68	57	3	1	50	2	1	40	3
25 : Goran Khilgaon (M)	71	41	4	2	56	3	2	16	12
26 : Banashree (M)	61	35	1	1	50	1	1	10	1
35 : Malibagh (M)	38	18	5	0	31	4	0	30	0
38 : Nakhalpara (H)	67	41	6	2	50	3	2	49	9
40 : Monipuripara	71	53	4	1	53	3	1	102	2
58 : Hazaribagh (L)	14	10	2	1	12	2	1	16	16
60 : Lalbagh (M)	70	53	5	3	46	3	2	59	10
69 : Chankharpul (L)	59	33	3	1	48	2	1	5	1
76 : Sutrapur (L)	57	34	5	4	48	4	3	13	20
78 : Narinda (L)	67	54	11	3	51	8	2	62	16
Total	**701**	**463**	**53**	**20**	**546**	**39**	**17**	**423**	**91**

Appendix XI
Selected entomological variables (Monsoon 2012)

Distribution of selected entomological variables by different SES wards/zones

Different SESW	Number of total containers inspected (%)	Number of wet containers (%)	Number of positive containers (%)	Number of containers with pupae (%)	Number of houses surveyed (%)	Number of positive houses (%)	Number of houses with pupae (%)	Total larvae (%)	Total pupae (%)
High	174	133	52	23	155	47	22	861	296
Medium	420	277	99	54	366	80	43	1319	598
Low	409	278	107	61	377	95	55	1527	496
Total	**1003**	**688**	**258**	**138**	**898**	**222**	**120**	**3707**	**1390**

Distribution of selected entomological variables by selected 12 wards

Ward Number and Name (SES)	Number of total containers inspected (%)	Number of wet containers (%)	Number of positive containers (%)	Number of containers with pupae (%)	Number of house surveyed (%)	Number of positive houses (%)	Number of houses with pupa	Total larvae	Total pupae
13 : Mirpur Pierbag (L)	99	70	31	20	85	27	17	426	167
20 : Mahakhali (H)	76	54	18	06	72	18	6	243	54
25 : Goran Khilgaon (M)	106	59	22	12	100	20	11	581	92
26 : Banashree (M)	76	49	19	13	76	19	13	335	96
35 : Malibagh (M)	86	55	19	07	81	17	7	200	27
38 : Nakhalpara (H)	98	79	34	17	83	29	16	618	242
40 : Monipuripara	90	64	26	20	66	17	11	54	379
58 : Hazaribagh (L)	67	51	07	05	64	7	5	80	9
60 : Lalbagh (M)	62	50	13	2	43	7	1	149	4
69 : Chankharpul (L)	71	44	15	11	68	14	10	296	162
76 : Sutrapur (L)	95	67	36	15	85	29	13	529	86
78 : Narinda (L)	77	46	18	10	75	18	10	196	72
Total	**1003**	**688**	**258**	**138**	**898**	**222**	**120**	**3707**	**1390**

Appendix XII

Serological Survey Instruments
HOUSEHOLDQUESTIONNAIRE

Participant ID: □□□□ Date of interview : ___/___/___ (D/M/Y)

Interviewer name:

Section A: Socio-demographic information

1. ParticipantName :
2. Age (years): □□
3. Sex (1=Male, 2=Female): □
4. Address :House: Street:

Moholla: P.O.:

Ward: Mobile no.:

5. Educational level: □
   (Primary = 1, Secondary = 2, Higher secondary = 3, Undergrad = 4, Grad = 5)
6. Your occupation : □□

1=Businessman
2=Small business
3=Manager
4=Accountant
5=Clerk
6=Messenger
7=Driver / Helper
8=Sweeper/Ward boy/cleaner
9=Other
10=Rickshaw/Push-cart puller
11=Day laborer
12=Skilled laborer(tailor,plumber,transport mechanic etc.)
13=Farmer
14=Officer in any Organization
15=Teacher
16=Clergy
17=Garments worker
18=Maidservant/servant
19=Landlord
20=Hawker
21=Professional (doctor, engineer, lawyer, architect, etc.)
22=Barber/hair dresser
23=Fisherman

24=Mill/factory worker
25=Electrician
26=Craftsman not laborer not elsewhere classified
27=Security forces (Army, police, Private security etc.)
28=Unskilled laborer
29=Cook
30=Line man(gas, T&T, WASA etc.)
31=Sales man / woman
32=Paramedic(nurse, /FWV/MA/SACMO)
33=Municipality Health worker(MHW), HA, FWA
34=Trained TBA
35=Untrained TBA
36=Termination attendant
37=Allopath quack/pallichikitshok
38=Pharmacist
39=Traditional practitioner(aurbed, Kabiraj, religious practitioner)
40=Homeopath practitioner
88=Don't know

7. Location of your occupation:
8. Role in your occupation:
9. Number of hours spent at occupation per week: □□
10. Number of hours spent in doors per day: □□
11. Total number of people in your house: □□
12. Number of adults in your house: □□
13. Information of adults in your house: (According to descending age order)

Serial	Name	Sex (M/F)	Age(years)	Educational Level	Occupation	Location of occupation	Role in your occupation
I.							
II.							
III.							
IV.							
V.							

(Primary = 1, Secondary = 2, Higher secondary = 3, Undergrad = 4, Grad = 5)

14. Number of children in your house: □□

15. Information of children in your house: (According to descending age order)

Serial	Name	Sex (M/F)	Age (years)	School going (Y/N)	Location of school	Number of hours spent in school per week

I.						
II.						
III.						
IV.						
V.						

16. What is your total household income (Taka/month)?□
    1. <5,000
    2. 5,000-10,000
    3. 10,000-15,000
    4. 15,000-20,000
    5. 20,000-25,000
    6. >25,000

17. Appearance in public gathering places:

    a. Where? ☐ Botanical Garden ☐Recreational Park ☐Mosque ☐Restaurant ☐Other (specify):

    b. How often? ☐ Daily ☐ Weekly ☐ Monthly
    c. How many hours per week? □□

    d. Is it? ☐ Indoor ☐Outdoor

18. Standing water inspection:
    a. Number of standing water vessels inside home: □□
    b. Number of standing water vessels outside home: □□

    c. Is there any water tank outside home? ☐Yes ☐No

    If yes, is it covered?
    d. Number of potted plants indoor: □□
    e. Number of potted plants outdoor: □□
19. Your residence:

    a. Is there any Trees/vegetation nearby?☐Yes☐No
    b. Number of doors?
    c. Number of windows?
    d. What number of doors kept open during day? □□
    e. What number of windows kept open during day? □□

20. Do you use any mosquito control measures? ☐Yes ☐No

If yes what type?
☐ Bed net ☐ Mosquito coil☐ Mosquito repellent cream
☐ Spray☐ Others please specify:

21. Did you travel outside your home within last 6 months? ☐Yes ☐No

    If yes, a. Location:
    b. How long you stayed there? (Days) □□
    c. What you did there?

Section B: Illness history

1. Did anyone of your family suffer from febrile illness in last 6 months?
   ☐Yes ☐No

2. Did it require hospitalization?☐Yes ☐No

If yes, 1. Date of admission ___/___/___

3. Brief Description illness:

4. Diagnosis:

Days hospitalised: ☐☐

Outcome: ☐ Cured ☐ Not cured☐ Complicated☐ Dead

5. Did anyone of your family missed work for illness? ☐Yes ☐No

If yes, 1. How many days?☐☐ From ___/___/___ To___/___/___
2. Was he/she suffering from fever that time?☐Yes☐No

Appendix XIII

Dengue IgG ELISA Worksheet **Date:**_______________ **Lot#** **Plate #**

	1	2	3	4	5	6	7	8	9	10	11	12
A	Blank											
B	Pos											
C	Neg											
D	Cal1											
E	Cal2											
F	Cal3											
G												
H												

Incubation Times:

Time Kit Removed from Fridge: __________________

Pre-soak plate ☐

Sample 1 hours at RT _______________ to _______________

1. Wash plate ☐

Conjugate 30 minutes at RT _______________ to _____________

2. Wash plate ☐

Substrate ~ 10 minutes at RT _______________ to _______________

<u>Dengue ELISA IgM Worksheet</u> **Date:_______________ Lot# Plate #**

	1	2	3	4	5	6	7	8	9	10	11	12
A	Blank											
B	Pos											
C	Neg											
D	Cal1											
E	Cal2											
F	Cal3											
G												
H												

<u>Incubation Times:</u>

Time Kit Removed from Fridge: __________________

Pre-soak plate ☐

Sample 1 hour at RT _______________ to _______________

1. Wash plate ☐

Sample 1 hour at RT for Ag Binding ________________to______________

2. Wash plate ☐

Conjugate 30 minutes at RT _______________ to _____________

3. Wash plate ☐

Substrate ~ 10 minutes at RT _______________ to _______________

Appendix XIV

Summary of Post-Monsoon 2013 Serosurvey Results

A follow up serosurvey was conducted during the post-monsoon season of 2013 (i.e. November 2013). The primary purpose of the 2013 serosurvey was to identify new cases who were seroconverted in the year of 2013. An analysis of 2013 serosurvey data was beyond the scope of this thesis research; however, a basic analysis of all age groups with IgM seropositivity was performed to provide a summary and a comparative perspective. Of 1125 subjects enrolled at baseline (pre monsoon 2012) and 1065 subjects enrolled in post monsoon 2012 seroconversion study, a total of 817 (53.24%) subjects were found to be living in the same location as of 2012 and were eligible for a third blood sample draw. These 817 study participants tested for DENV antibodies with IgM ELISA (age range, 01–85 years). IgG ELISA tests were performed only on previously negative samples. The young age group (23-33) has the highest percentage of IgM seropositivity in 2013, indicating a recent exposure to DENV (Figure XIV.1).

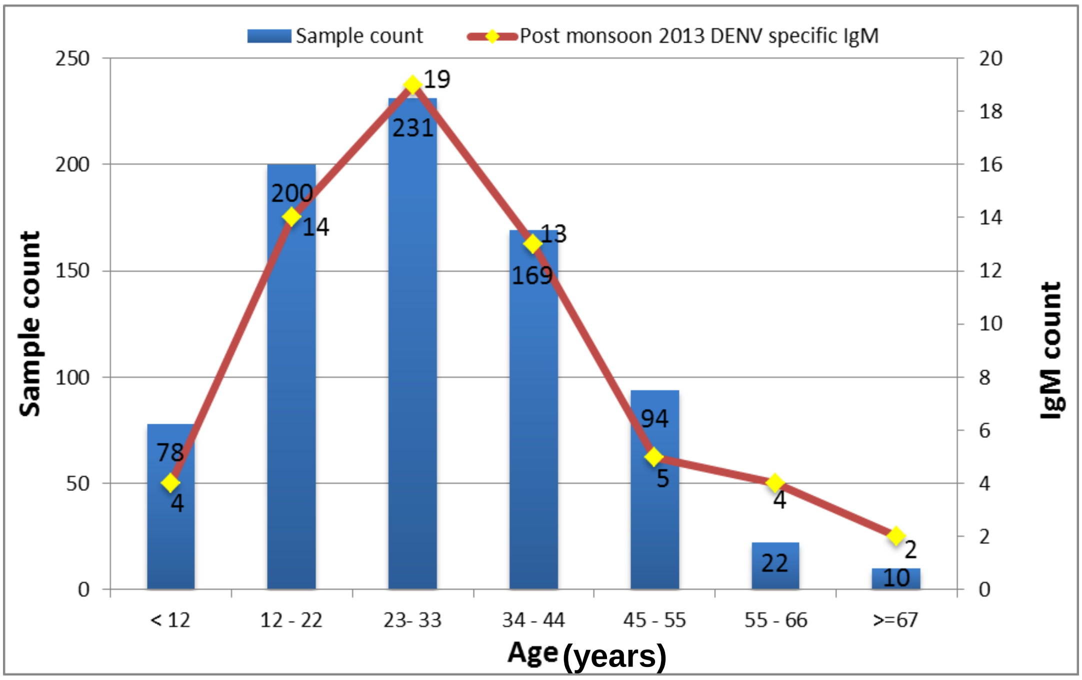


Figure XIV.1: DEN specific IgM seroprevalence during post monsoon 2013 by age groups in Dhaka

During 2013 post monsoon serosurvey, out of 817 subjects, a total of 65 samples (7.9%) were IgM positive. During post monsoon 2012, out of 600 paired sera, only 56 (9.3%) were IgM positive. A comparative analysis of IgM seropositivity between 2012 and 2013 for various age groups is presented in Figure XIV.2. It is apparent from Figure XIV.2 that seropositivity has been consistently high among children groups (i.e., <12 years). During 2012, 18% IgM seropositivity were found compared to 6.5% IgM seropositive samples in the aged group (56-66 years). In the analysis of 2013 seroconverted cases, only one person, a 16 year old male, was found to be positive during both 2012 and 2013 post monsoon seasons. The IgM index value of this person was higher in 2013 (4.5) compared to 2012 (1.8).

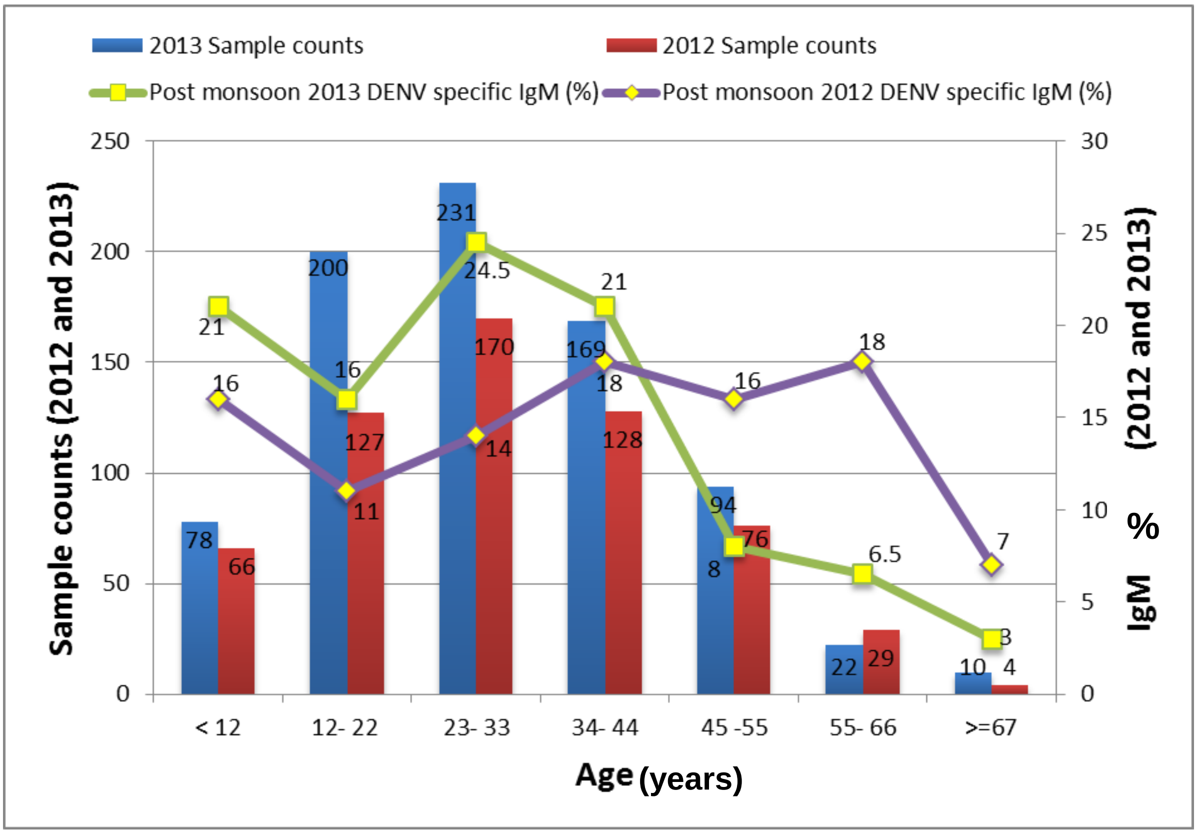


Figure XIV.2: DEN specific IgM distribution during post monsoon 2012 and post monsoon 2013 by age groups in Dhaka

Appendix XV

PRNT Worksheet

Sample Numbers:Virus: **Titre:**

Cell Culture	
Date	
Time	
Number of Plates	
First Overlay	
Date	
Time	
Number of Plates	
Volume Solution A	
Volume Agar	
Second Overlay	
Date	
Time	
Volume Solution A	
Volume Neutral Red	
Volume Agar	
Results	
Total Incubation Time	
Virus Titre	
Back titration 100 PFU/ml	
Back titration 10 PFU/ml	
Back titration 1 PFU/ml	

Number of plaques per serum dilution with __________ virus

Sample	20	40	80	160	320	640

Appendix XVI

KNOWLEDGE, ATTITUDE AND PRACTICE QUESTIONNAIRE

OUTLINE OF THE QUESTIONNAIRE

SECTION 1:	KAP SURVEY INFORMATION
Section 7	Knowledge about Mosquito Ecology
Section 8	Mosquito/Vector Control Practices
Section 9	Knowledge about Dengue and its Vector
Section 10	Attitude towards Dengue Control
Section 11	Individual Health
Section 12	Social Relations and Networking
Section 13	Other social concerns
Section 14	Gender equity & Decision Making

SECTION 1: KAP SURVEY INFORMATION

Team# _____________

Date _____________

Ward# _____________

Community Name _____________

Grid Cell# _____________

Household Address ____

SECTION 7: KNOWLEDGE ABOUT MOSQUITO

7.1 Can you recognize different types of mosquito?	☐Yes	☐No

7.2 How many types (with names if possible) of mosquito do you see in your residence?__________________

7.3 Where do you see the mosquito resting/hiding at your residence?________________________

7.4 Do mosquito bite more during day time?	☐Yes	☐No

7.5 If yes, is the mosquito striped one?	☐Yes	☐No

7.6 During what season do you see more mosquitos?

7.7 Where do mosquito generally lay their eggs (multiple response)?			
	☐ Clean water	☐Dirty water	☐Any water
	☐ On wet clothes	☐ Plants	☐Waste bins
	☐Don’t know	☐ Others (pls specify)	

7.8 Have you ever seen larvae/pupae/eggs in your residence?	☐Yes	☐No

7.9 If yes, where?	____

SECTION 8: VECTOR CONTROL PRACTICES

8.1 What do you do to reduce the nuisance of mosquitoes?			
	☐ Indoor spraying	☐ Covering the water containers	☐ Cleaning rubbish
	☐Putting chemicals in water	☐Using electronic gazettes	☐Bed net
	☐Nothing	☐Others	

8.1.1 What are the main reasons for you to take such measures?
8.1.2 If the answer is ‘*Nothing*’, what are the reasons for such inaction?
8.2 What does the government do to control mosquitoes according to your knowledge? (multiple answers)

	☐Spraying	☐Fogging	☐Cutting plants
	☐Checking the water containers	☐Educating people	☐Nothing
	☐Others (pls specify)		

8.3 When did a health inspector last visit your locality/neighborhood?			
	☐Last month	☐Two to six months ago	☐six to twelve months

			ago
	☐More than a year ago	☐Never	☐ Do not remember

8.4	Is there any community effort to clean the neighborhood environment?		
	☐ Yes	☐ No	☐ Do not know

8.5	If yes, what does the community do to clean the neighborhood environment?	
	☐ Eliminate breeding places	☐Visit households to ensure program implementation
	☐ Others (pls specify)	

8.6	What can you do to prevent mosquito breeding in your house?	
	☐ Covering all the water containers	☐Changing water once a week
	☐Eliminating stagnant water	☐Brushing and cleaning inner surface of containers
	☐ Putting chemicals into the water container	☐ Removing larvae
	☐ Others (pls specify)	

8.7	What can you do to prevent mosquito breeding around/outside your house?		
	☐Covering all the water containers	☐Eliminating stagnant water	
	☐Putting chemicals into the water container	☐ Removing larvae	
	☐Removing rubbish	☐Others	

8.8	Do you participate in such community activities to control mosquitoes?	☐Yes	☐No

8.9	What should Government do for improving mosquito control?		
	☐ Checking water containers	☐ Spraying	☐Fogging
	☐Cutting plants	☐ Educating people	☐Nothing
	☐ Others (pls specify)		

SECTION 9: KNOWLEDGE ABOUT DENGUE AND ITS VECTOR

9.1	Have you ever heard about dengue?	☐Yes	☐No

9.2	If yes, from where have you heard about dengue? (multiple answer)			
	☐ Television	☐Radio	☐Newspaper	☐Health worker
	☐Friend/Peer	☐Neighborhood	☐Posters	☐ Hospitals
	☐Others (pls specify)			

9.3	Is dengue a serious or mild disease according to your opinion?		
	☐Serious	☐Mild	☐Do not know

.

9.4	Have you ever received suggestions on dengue prevention and control activities?	☐Yes	☐No

9.5	How does dengue spread from one person to another? (multiple answer)			
	☐ Mosquito	☐ Direct contact	☐Water	☐Flies
	☐Dirty environment	☐Rats, birds, pigs and other animals		
	☐Others (pleasespecify)			

9.6	Can dengue be prevented?	☐Yes	☐No	☐Uncertain	☐Do not know

9.7	How dengue can be prevented?	☐ Yes	☐No	☐Uncertain	☐ Do not know

SECTION 10: ATTITUDE TOWARDS DENGUE CONTROL

(Interviewer informs the purpose and attitude scales before interviewing)

	Strongly agree	Agree	Unsure	Disagree	Strongly Disagree

		5	4	3	2	1
10.1	Dengue is a serious concern for your family, especially during rainy season					
10.2	Your family takes precautionary measures during the season					
	10.2.1 If the response is ≥ 4, then what type of precaution do you take?					
10.3	It is necessary to clean water containers in and around the house once a week					
10.4	Women are mainly responsible for cleaning water containers in household					
10.5	Men should clean large containers in households					
10.6	Men should make decision for spending money to control mosquitoes in household					
10.7	It is difficult to remove mosquito breeding places					
10.8	It is necessary for neighbors to cooperate to prevent dengue					
10.9	Only families with dengue should participate in dengue prevention					
10.10	Government has taken necessary steps to prevent dengue					
10.11	Government should penalize households with mosquito larvae					
10.12	Health workers are solely responsible for removing mosquito breeding sites					
10.13	We have received sufficient support from community health workers					
	10.13.1 If the response is ≥ 4, then what kind of support did you receive?					
10.14	We get support from community leaders and organizations (clubs, NGOs, CBOs) to prevent and control dengue					

10.15	What should the Government do to prevent and control dengue? (multiple answer)		
	☐ Checking water containers	☐Spraying	☐Fogging
	☐Cutting plants	☐ Educating people	☐ Nothing
	☐ Others (pls specify)		

10.16	What should the community leaders and organizations (clubs, NGOs, CBOs) do to improve dengue prevention and control?

SECTION 11: INDIVIDUAL HEALTH (MENTAL HEALTH)

11.1	Thinking about your daily life here, that is your living conditions, way of life, and so forth, how satisfied are you with your life here? Would you say				
	☐ Very satisfied	☐Satisfied	☐ Dissatisfied	☐ Very Dissatisfied	☐No answer

11.2	Do you think you have control over the things that happen in your daily life here? Would you say				
	☐Not at all	☐Very Little	☐Somewhat	☐ A lot	☐No answer

11.3	Would you say what happens to you in the future depends mainly on you, or mainly on Allah?		
	☐ Mostly on you	☐Mostly on Allah	☐ No answer

11.4	Compared to your life today, do you think your living conditions will be better, worse, or about the same in one or two years from now?			
	☐ Yes	☐ No	☐Not sure	☐ No answer

SECTION 12: SOCIAL RELATIONS AND NETWORKING

	Strongly agree	Agreed	Unsure	Disagree	Strongly Disagree
	5	4	3	2	1
12.1 In my family, there are tensions and stress generated from our relationships	☐	☐	☐	☐	☐
12.2 In my neighborhood there are tensions and hostility	☐	☐	☐	☐	☐
12.3 In my workplace there are tensions and hostility among the colleagues, senior offices and subordinates	☐	☐	☐	☐	☐

12.4 I consult with social and neighborhood issues with				
☐Neighbors	☐ Community leaders	☐Relatives	☐Friends	☐ Others

12.5 The following people consult with me about social and neighborhood issues				
☐Neighbors	☐Relatives	☐ Friends	☐ Distant Community	☐ Others

12.6 Are you involved with any social or creative activities?				
☐ Sports	☐ Singing	☐ Acting	☐Dancing	☐
☐Writing	☐ Political	☐ Indoor Games	☐ Outdoor adventurous activities	
☐Other				

SECTION 13: OTHER SOCIAL CONCERNS

13.1 What are the main problems that you face in your neighborhood now?

13.2 What are the main concerns that you hove regarding			
	☐ Your family	☐ About your community/ neighborhood	☐About your region (i.e. district)

Section 14	**Gender equity & Decision Making**

14.1 Who is responsible for cleaning household?

14.2 Who cleans drainage?

14.3Who is responsible for managing water storage containers?

14.4 Whose task is water collection and/or storage?

14.5 Who is responsible for waste disposal?

14.6 Are there any wage earning women in the household?

14.7 Who decides how money is used for family matters?

14.8 Is any of your family a member of community group or club? Is so, whom?

14.9 Who owns the property of your family?

14.10Who is responsible for health decisions?

14.11 Who is responsible for mosquito control decisions?

Appendix XVII

FGD Guideline

Q1. Have you ever heard about dengue?
Q2. If yes, what do you know about dengue and its symptoms?
Q3. How many mosquitoes you can identify in your neighborhood?
Q4. Where do mosquitoes breed?
Q5. Do you think that dengue mosquitoes bite during daytime?
Q6. Do you think dengue is a severe disease?
Q7. Do you take any precautionary measures for dengue control?
Q8. Do you store water?
Q9. What is your idea about dengue prevention?
Q10. Does government take any action for dengue prevention?

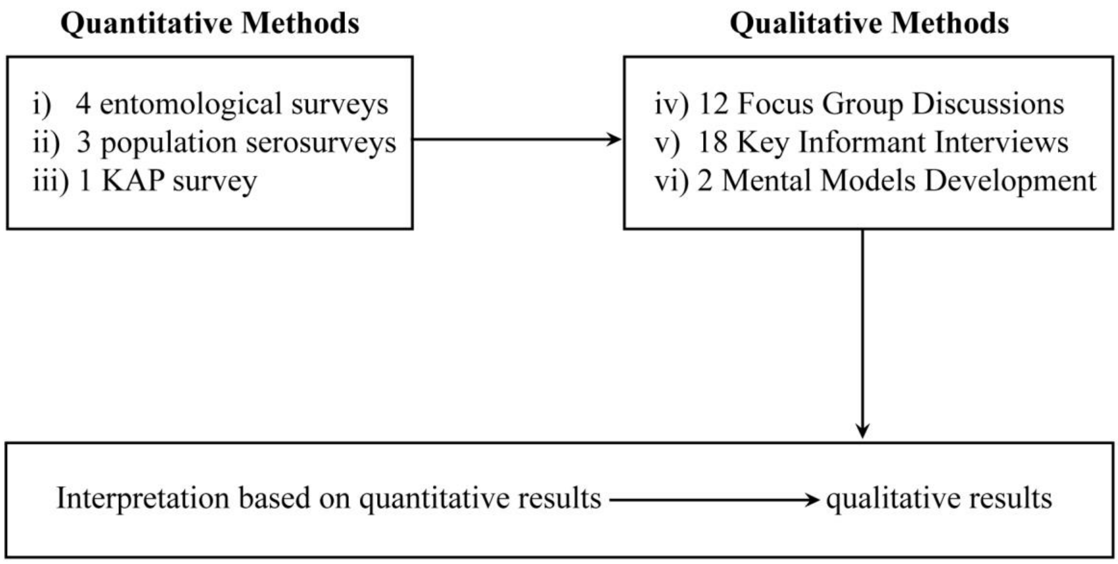
Appendix XVIII

KII Guideline

Q1. What is your idea about dengue in your locality?
Q2. What do you know about dengue and its symptoms?
Q3. Do you think that there are lots of mosquitoes in your neighborhood?
Q4. Do you think that there are effective garbage collection program in your neighborhood?
Q5. Do you think that fumigation is necessary to combat *Aedes* mosquitoes?
Q6. Do you think dengue is a severe disease?
Q7. Do you take any precautionary measures for dengue control?
Q8. Is there any power cut problem in your neighborhood?
Q9. What is your idea about dengue prevention?
Q10. Does government take any action for dengue prevention?

Appendix XIX

Explanatory Mixed Method Research Design (After Creswell and Plano, 1994)



Appendix XX
News and Media Coverage of the Research

IDRC | CRDI Canada

ABOUT US PROGRAMS THEMES REGIONS FUNDING

Home > IDRC > News

News

URL: http://www.idrc.ca/EN/Misc/Pages/NewsDetails.aspx?NewsID=643

PARNALI DHAR-CHOWDURY

Parnali Dhar-Chowdhury working with focus groups on an ecohealth approach to dengue fever control in Bangladesh

IDRC awardee receives Sanofi Pasteur Award for Communicable Disease Epidemiology

08/05/2014

Dengue fever, a serious mosquito-borne disease, is sweeping into new parts of the globe. Currently, there is no specific treatments, effective vaccines or vector control mechanisms to prevent the disease's spread.

University of Manitoba PhD candidate and IDRC awardee Parnali Dhar-Chowdhury was awarded the Sanofi Pasteur Award for her work that tested a community-based approach to prevent and control dengue fever. The Sanofi Pasteur Award for Communicable Disease Epidemiology recognizes the importance of applied epidemiology in the field of communicable diseases. Chosen out of 1,000 candidates, Dhar-Chowdhury was recognized for her work on understanding dengue transmission in Bangladesh using an ecohealth approach.

Dhar-Chowdhury credits IDRC's financial and technical support with enabling her to complete her field work in Bangladesh. "The support that I received [...] allowed me to complete the social, developmental, and epidemiological aspects of my research," she says. "An IDRC senior program officer helped me to nail down my research methodology. IDRC also facilitated contact with a Bangladeshi NGO, which provided me easy access to local communities."

Dhar-Chowdhury received her award at the 16th International Congress on Infectious Diseases (ICID), in Cape Town, South Africa, where she highlighted the interdisciplinary nature of her work.

"My transdisciplinary research focuses on both the clinical and societal aspects of dengue transmission. The recognition through this award shows the significance of transdisciplinary research in infectious diseases like dengue," says Dhar-Chowdhury.

Dhar-Chowdhury's research was carried out with funding from an IDRC Doctoral Research Award. These awards are available to Canadian students studying international development and provide development-related research funding.

Learn more about Parnali Dhar-Chowdhury's research by visiting her multimedia website, Dengue in Bangladesh.

Watch Parnali Dhar-Chowdhury talk about her field work in Bangladesh on YouTube.

URL: http://www.idrc.ca/EN/Misc/Pages/NewsDetails.aspx?NewsID=643

http://www.youtube.com/watch?v=1VvQ36J_5mo

Appendix XXI

Image 3.1: Entomological field research team in Dhaka

Image 3.2: Men Focus Group Discussion meeting in Dhaka

Image 3.3: Women Focus Group Discussion meeting in Dhaka

Image 3.4: Present researcher with NGO field assistants in Dhaka

Image 3.5: Present researcher meeting with experts and health specialists

Image 3.6: Present researcher in a Focus Group meeting with health workers

Image 3.7: Present researcher in a Focus Group meeting with local community leaders

Image 3.8: Present researcher interviewing a physician in Dhaka

Image 3.9:Focus Group Discussion meeting among experts to formulate Mental Models

Image 3:10: Focus Group Discussion meeting among community members to formulate Mental Models

Image 4.1: Field entomologist collecting immature *Aedes*

Image 4.2: Laboratory technicians identifying *Aedes* species

Image 4.3: Discarded containers located outdoor

Image 4.4: Ornamental containers used for decorating houses produce highest number of pupae

Image 4.5: Field investigators counting pupae and filling in PSF

Image 4.6: People store water in plastic containers indoor

Image 4.7: Entomological survey team in Dhaka

Image 4.8: In low SES households, water is stored inside kitchens due to anticipated power cuts


Image 5.1: Present researcher interviewing a woman household head


Image 5.2: Field nurses collecting blood sample from a household member


Image 5.3: Ornamental containers found in many houses with seroconverted person


Image 5.4: *Epipremnumaureum* plants are grown in glass and/or plastic containers


Image 7.1: Present researcher interviewing a local ward councilor


Image 7.2: Present researcher interviewing a policy maker – a key informant – in Dhaka