The Threat of Dengue Fever in Bangladesh: Factors of Dengue Vector Abundance, Productivity, and the Role of Knowledge and Attitude in Disease Control in Dhaka, Bangladesh

By

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Abstract

Dengue is one of the fast growing arboviral diseases in the tropics. Because there is currently no cure or vaccine, dengue prevention requires a focus on effective vector control. Recognizing that previous studies on dengue have typically examined the effects of different factors on vector abundance or incidence of dengue cases separately, the present study adopts a holistic approach examining the climate-vector-disease relationships. My research investigated the effects of climatic factors on vector abundance and dengue cases; productivity of various containers of *Aedes* mosquitoes at household premises; and the prevailing knowledge, awareness, attitudes, and practices (KAAP) of community members regarding dengue and their willingness to pay (WTP) for vector control in Dhaka, Bangladesh.

An entomological survey was carried out in 727 randomly selected households in 12 wards of Dhaka city representing four urban ecological zones - to measure container productivity and mosquito density, the effects of household ecological factors, and human behavioural factors. In addition, a survey of 330 household heads was conducted to collect data on their KAAP. The container productivity was measured using the zero-inflated negative binomial model. Chi-square tests and multinomial logistic regression were then applied to investigate factors associated with WTP and other variables in the KAAP study.

The study found strong evidence for an increase in *Aedes* abundance during monsoon seasonal increases in temperature, relative humidity, and rainfall, with a subsequent increase in dengue cases. Container size, shade and type of water were found to be significant factors for pupae production. The *Stegomyia* indices varied significantly between urban zones, revealing paved and built areas with concentrated public/commercial services to have the highest mosquito density. The KAAP survey revealed that most respondents knew about dengue and its severity but were

unaware about the types of mosquito which carried dengue virus (DENV). Household income, knowledge of the effects of land-use and seasonality on dengue, and the usage of electronic gadgets were found to be significantly associated with the WTP for controlling dengue vectors.

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Dedication

Written with profound respect for the people of all walks of life who treat, manage and prevent infectious diseases all over the world.

To my parents, the two most generous and enlightened people I have known in my life. I could not have done it without you.

To my husband, who is kind, loving, understanding and very supportive.

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Table of Contents

List of Tables

List of Figures

Chapter 1 – Introduction

1.1 Background and Context

1.1.1 Dengue as an Emerging Infectious Disease Globally

Global health initiatives have enjoyed many significant successes in recent years, but new threats are arising in the form of emerging and re-emerging diseases - particularly vector-borne infectious diseases. Unless drastic changes are made in the form of upgrading health care systems, economic and social development, and coping with changing climatic conditions, the world will face a serious health crisis (Seipel, 2005). Though pathogens are the vital cause of infectious diseases, they are not exclusively responsible for outbreaks; rather the driving forces are rooted in the environmental, social, economic, and political frameworks of our society. Globalization through intense travel, trade, and migration - as well as the great speed and efficiency of modern air travel - have the potential to make future outbreaks far worse than at any point in human history (WHO, 1999a; Gordon, 2000; Heymann, 2000; Seipel, 2005).

Researchers have noted the difficulty in linking climate change to health outcomes and instead typically attempt to link current or historical weather patterns and disease incidence. Harper (2012) in this context asserted that it is too early to identify or predict the isolated consequences of climate change on infectious diseases, especially considering the many other social, political, ecological, and economic factors impacting at play. In the case of dengue, considering that the vector mosquitoes are cold-blooded with physiologic functions affected by ambient temperatures, global warming is likely to drive further geographic expansion and increasing abundance of the dengue vectors with a corresponding increase in dengue incidence (Ooi & Gubler, 2009). However, current mathematical models which find significant correlation between climate change and dengue incidence have been overly simplistic, limiting their analyses to temperature (Jetten & Focks,1997; Patz et al., 1998) and humidity (Hales et al., 2002) alone. Even if ambient temperature has important effects on vector biology and virus development in the mosquito, this meteorological variable does not function independently. The factors governing dengue transmission dynamics are complex and include environmental, viral, human, and vector components. It is therefore critical to public health efforts to understand how all these factors work in tandem to shape the dynamics of dengue transmission.

Dengue fever (DF) has been known in South-East Asia for centuries, with the causative mosquito-borne DENV being first identified in 1903. Fifty years later, a new, more severe form of the disease known as Dengue Haemorrhagic Fever (DHF) emerged. From the 1970s onwards, it was assumed that the *Aedes aegypti* and *A. albopictus* mosquito vectors spread through the trade in automotive tires and other commodities containing mosquito eggs (Racaniello, 2004), causing DF and DHF to become endemic in more than 128 countries (Brady et al., 2012). Estimates suggest that 96 million people are infected with DENV and develop DF every year, with a further 294 million DENV infections remaining asymptomatic (Bhatt et al., 2013).

In past few decades, DF/DHF has emerged as one of the most important mosquito-borne viral infectious diseases worldwide. The rapid geographic expansion of both the DENV and the mosquito vectors (mostly *Aedes aegypti*), combined with the lack of effective mosquito control, has resulted in frequent and recurrent epidemics. These features have placed an estimated 2.5-3 billion people at risk of acute illness each year (Gubler 1998; Halstead 2007). Many parts of the world have now become hyperendemic for DENV, and the virus has begun to spread as far afield as Europe and North America (Rodhain, 1996). It has been suggested that based on current seasonality and geographical heterogeneity, southern Europe has a risk of dengue outbreak as it can support the vector population and spread the DENV if introduced during summer (Liu-

Helmersson et al., 2016). The trend overall indicates an increased incidence of DF/DHF throughout the world.

An extensive global literature survey has revealed that rainfall, temperature and humidity are the most important explanatory variables in the transmission of dengue disease (Koopman et al., 1991; Herrera-Basto et al., 1992; Hales, Weinstein &Woodward, 1996; Hales et al., 1999; Gubler et al., 2001; Hales et al., 2002; Depradine & Lovell, 2004; Cazelles et al., 2005; Kuhn et al., 2005; Brunkard, Cifuentes & Rothenberg, 2008). A considerable number of studies have further confirmed the correlation between dengue prevalence and social, economic, infrastructural, and ecological variables (Chan et al., 1999; WHO 1999b; Guha-Sapir & Schimmer, 2005). Many social factors such as housing, water storage, and waste disposal have been linked to dengue vector abundance and dengue incidence encompassing the social-environmental behaviour and practices (Sampaio, Kligerman & Júnior, 2009; Banu et al., 2011; Schmidt et al., 2011). However, since interactions between these factors and their effects upon dengue vector abundance and incidence are complex, research results have hitherto produced mixed inferences.

The changing human environment leading to various complex conditions and social structures may aggravate dengue transmission. For example, it was observed that the rapid urbanization along with the water storage crisis is associated with dengue incidence and prevalence (Nagao et al., 2008). The altered environment in present-day world, especially in the micro-level: human habitat (household and neighbourhood), has become a preferred habitat and breeding site for some *Aedes* mosquitoes (WHO, 2009).

The rapidly-changing human environment, even at the smallest individual level, has a significant impact on the spread and incidence of dengue. In Bangladesh in particular, rapid urbanization, industrialization and water-storage crises have led urban dwellers to store large volume of stagnant water in open containers, providing a rich breeding ground for *Aedes* vector mosquitoes.

The complexity of DENV transmission is well established in the literature noting that transmission to humans take place through the bite of container inhabiting *Aedes* mosquitoes (Banu et al., 2012; Dhar-Chowdhury et al., 2016a). Understanding how the production and density of the mosquitoes are affected either through the containers and/or household ecological factors has been recognized as a very important task. In this complex transmission process, vector control becomes crucial as no vaccines or pharmacological treatment for DF/DHF yet exists. Given the significant impact of individual lifestyle choices upon disease transmission, vector control depends greatly on community members' knowledge of, and attitudes towards the disease transmission process and effective countermeasures to vector breeding (Paz-Soldán et al., 2015; Elsinga et al., 2018).

There is a general lack of knowledge regarding the dynamics of community practices, the effectiveness of State and other institution-based disease control programs, vector ecology and landscape, and socio-economic and political factors (Caprara et al., 2009; Arunachalam et al., 2010) with regard to dengue transmission, especially in developing countries. It is apparent that there are gaps in our understanding of the complexity of DF and DHF transmission within a system characterized by diverse ecological conditions (i.e. landscape and land cover), dynamic climate variability, and human behavioural factors. Human alteration of the environment and their knowledge, attitude, and practices concerning DF and DHF prevention and control also contribute to dengue transmission.

Studies hitherto have focused on the aforementioned factors on an individual basis, without due consideration for the complex interactions between them. A holistic approach accounting for all important variables and their interactions is necessary to fully understand a complex disease like dengue and to control its incidence and spread through a combination of policy initiatives and action programs such as vector control methods and future vaccination (Pang, Mak & Gubler, 2017).

1.1.2 Emergence of Dengue in Bangladesh

Dengue is not a new disease in Bangladesh, with evidence of earlier intermittent outbreaks of dengue-like fevers in Bangladesh in the 1960s known as "Dhaka Fever" (Rahman et al., 2002; Hossain et al., 2003; Banu et al., 2012; Sharmin et al., 2015). Since the 2000 outbreak, DF and DHF have been reported every year with widely varying numbers of cases and deaths - the majority of which were reported in the city of Dhaka (Banu et al., 2012; Ferdousi et al., 2015; Sharmin et al., 2015).

Countries bordering Bangladesh reported DF since 1945 in India (Sabin, 1952; Sharmin et al., 2015) and 1970 in Myanmar (Thu et al., 2004; Sharmin et al., 2015). Thus, since DENV and competent mosquito vectors were present in the region, the population of Bangladesh has always been at a risk of DENV infection since mid-1900s. It is assumed that the DENVs were likely the causes of "Dhaka fever" in 1964-65 (Aziz et al., 1967; Hossain et al., 2003; Sharmin et al., 2015).

The epidemic of 2000 is thought to have been caused by the introduction of a DENV strain from South-east Asian countries, especially Thailand (Podder et al., 2006; Sharmin et al., 2015), through population mobility and transfer of goods through trade/business and travel/tourism (Sharmin et al., 2015). In addition, emerging changes in human ecology, such as social and demographic changes, urbanization (Gubler, 2002; Banu et al., 2012; Li et al., 2014), land-use changes (Sarfraz et al., 2012), have further contributed to dengue spread.

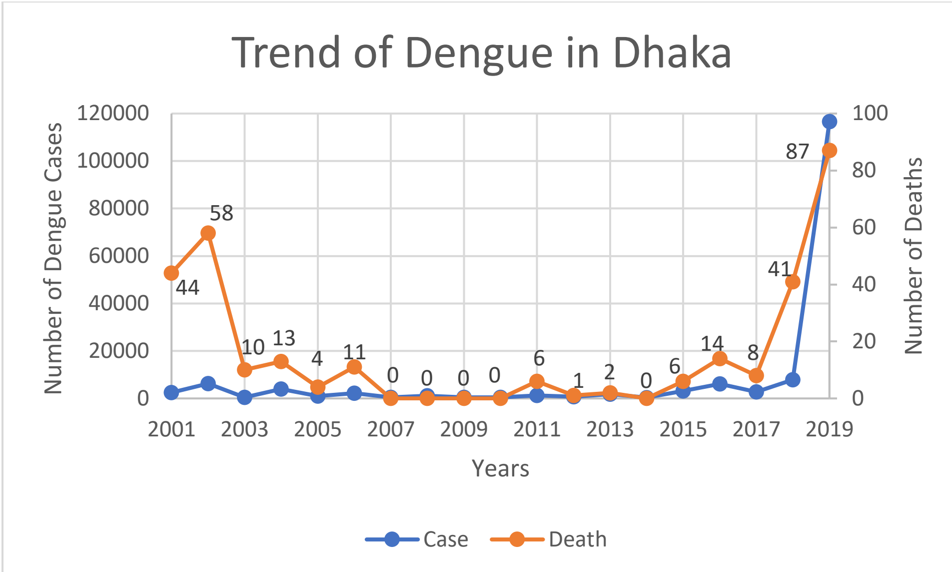

Figure 1.1: Trend of dengue cases and number of deaths in Dhaka, Bangladesh, 2001-2019. (Source: Directorate General of Health Services (DGHS), Bangladesh, 2001-2013; Dhaka Tribune, 2019; Shirin et al., 2019)

The first epidemic of DHF in Bangladesh occurred in 2000, when a total of 5,551 DENV infections and 93 deaths were reported mostly in three large cities (Dhaka, Chittagong, and Khulna) and 17 other towns (Paul et al., 2018; Sharmin et al., 2015; Yunus et al., 2001; Yunus, 2000). Mortality rates have decreased significantly since the outbreak of 2000; however, a sizeable population is still infected with DENV every year (Figure 1.1). The trend in dengue cases and deaths over the period of 2001-2019 in Dhaka is illustrated in Figure 1.1. Due to unavailability of data for year 2000 for the city, both the reported cases and number of fatalities were excluded. Though the dengue incidences have decreased over the years till 2015, it has followed cyclical and fluctuating patterns since 2001. It is evident from Figure 1.1 that the number of deaths has decreased dramatically – from 44 deaths in 2001 and 58 deaths in 2002 to no deaths in 2014. It then started increasing, resulting in 41 deaths in 2018 and an estimated number of 87 deaths in 2019. There was an astronomical increase in reported dengue cases and in the number of deaths in

2019. A total of 80,040 dengue cases were reported officially between January 1 and September 13, 2019 with a total of 60 deaths due to DHF and shock syndrome (Dhaka Tribune, 2019). Based on these numbers, considering dengue peak season between June and October (monsoon season), we estimated that the number of cases would likely to increase to 116,559 by the end of 2019 with an estimated death toll of 87. Thus, the evolution and prevalence of dengue over the past few decades invite extensive study in order to better understand the best means to control and prevent dengue in Bangladesh and especially Dhaka.

1.2 Statement of the Problem and Rationale of the Study

A critical review of the literature examining the relationship between climate variability, urban ecological factors, dengue vector abundance, and dengue disease occurrence has revealed significant gaps in the current state of knowledge in the following areas:

- Most studies address climatic factors on an individual basis, overlooking many important confounders (non-climatic) of the climate-dengue relationship, largely influenced by the adoption of disciplinary lenses as well as the lack of data in many countries where dengue is endemic.

- The effects of climatic variability and seasonality on dengue transmission have generally been overlooked.

- Urban ecological systems are assumed to be homogeneous, while empirical evidence indicates otherwise (Cadenasso, Pickett & Schwarz, 2007).

- "Epistemological plurality" has been suggested to bridge social and biophysical sciences in order to better understand, for example, climate, history and human action (McIntosh, Tainter & McIntosh, 2000) and avoid the gaps associated with positivist-oriented disciplinary or reductionist approaches. However, it has not yet been applied to the epidemiology of infectious diseases like dengue, a full understanding of which requires a coupling between the social and bio-physical sciences.

While dengue vector abundance and dengue disease incidence are closely related to climate variability, vector productivity at the household level, and integrated urban ecological/functionality factors, these factors are usually studied separately. The interactions amongst these complex set of variables and their effects upon dengue vector abundance and dengue disease occurrence are still poorly understood.

According to Kates, Ausubel and Berberian (1985), the climate research community overwhelmingly favours the view that the atmospheric climate is only part of a larger *climatic system* which includes other environmental regions which participate in significant mass, momentum, and energy exchange throughout the year – for example, the upper layers of the ocean, sea ice, soil, and biotic cover. Multi-level ecology examines the climate system at a variety of scales, and is particularly relevant to the study of dengue vector dynamics. Vector mosquitoes breed prolifically in standing water found in and around households, creating a localized neighbourhood (micro-ecological) effect. The cumulative effect of multiple neighbourhoods spread out at the city level in turn creates a meso-level ecological effect. If the urban system is understood as a humid climate with layers of ecological impacts on habitat of vector and resulting in disease spread, the dynamics of the entire system can be more accurately understood.

The majority of studies on dengue determinants focus on climatic factors (e.g. temperature and rainfall) (Barclay, 2008; EurekAlert, 2009), but not climatic variability (i.e. year-to-year climate extremes as well as regular seasonal variability over the course of each year). These factors may also play a major role in dengue vector abundance and disease spread. These factors must be more closely studied – both conceptually and empirically.

Dengue is endemic in an estimated 128 countries in Asia, the Pacific, the Americas, Africa, and the Caribbean, with 50 to 100 million infections, 500,000 DHF cases, and 22,000 deaths – mostly of children – reported each year worldwide (CDC, 2016). Of these 128 countries, 36 were previously been classified as dengue-free by the World Health Organization and the US Centres for Disease Control. In total, these organizations estimate that dengue places over 3.9 billion people at risk (Brady et al., 2012).

Bangladesh, a country of 143,000 square kilometres with a population of more than 160 million, has been especially hard-hit by dengue outbreaks since the year 2000 (Yunus, 2000; Hossain et al., 2003). The first epidemic of DHF occurred in 2000 in the cities of Dhaka, Chittagong, and Khulna, resulting in a total of 5,551 reported infections and 93 patients' deaths (Yunus et al., 2001). Since then, major concern has been raised regarding the state of the country's disease management infrastructure and the need to better understand the dynamics of DENV transmission. However, Bangladesh's limited capacity to respond to the resurgence of dengue incidence and limited public disease control and prevention programs have left the country's citizens – especially those living in urban communities – extremely vulnerable (Rahman et al., 2002; Hossain et al., 2003). Only in the last decade dengue disease management issues have received significant public policy attention in Bangladesh (Islam & Hasan, 2009).

A study by Dhar-Chowdhury et al. (2014) identified numerous prevalent misconceptions among community members regarding dengue vector and its transmission. It further detected that there is a need for specific interference in controlling dengue and increasing awareness at the community level in Dhaka city. In a subsequent study, the authors (Dhar-Chowdhury et al., 2016b) registered that there were considerable gaps in disease-risk assessment, control and institutional involvement. As well, a holistic approach encompassing the climate-vector-disease relation has not yet been applied to the study of dengue in Bangladesh.

As only a few studies have yet examined the impact of climatic variability on dengue vector abundance and dengue disease occurrence in Bangladesh, it is critical to investigate this particular relationship, along with the multi-level societal and ecological factors. Such efforts in Bangladesh have been constrained by the lack of reliable data, primarily because the country has a very limited and inefficient surveillance system (Wagatsuma et al., 2004; Islam et al., 2006). Recognizing these gaps, my research aims to develop a reliable database by identifying the key factors of dengue vector abundance and dengue occurrence, as well as the relationships between dengue vector abundance, climatic variability and the multi-level social-ecological systems of Dhaka. Particular attention has been given to how planned and unplanned urban development impacts dengue vector habitat and breeding sites and thereby the state of human health.

My doctoral research is a subset of the International Development Research Centre (IDRC) Ecohealth Program-sponsored research project on “Climatic Variability, Social-Ecological Changes, and Dengue Disease in Bangladesh.” Methodologically, my research encompassed both post-positivist ‘scientific’ and ‘participatory’ research methods. Overall, the research contributes both to scholarly and applied issues within the development planning and public health sectors while filling the gaps in existing knowledge and contributing to better understanding of the climatic and multi-level social-ecological determinants of dengue disease occurrence in Bangladesh.

1.3 Research Objectives

The overall goal of my research is to identify the effects of climate variability and ecological factors on dengue vector abundance and dengue disease occurrence in the human population and determine the relationships between these factors in order to develop appropriate interventions to prevent and control dengue in Dhaka, Bangladesh. The specific objectives are as follows:

1. To determine the degree to which climatic variability and seasonality affect dengue vector abundance and dengue disease occurrence;

2. To identify the factors governing *Aedes* mosquito productivity at the household level;

3. To determine the degree to which integrated urban ecological/functionality factors (e.g. urban landscape and neighbourhood environment) affect dengue vector abundance; and

4. To identify the KAAP of the local community members regarding dengue vectors and the disease, influencing factors and their willingness to pay (WTP) for vector control measures.

1.4 Conceptual Framework

A conceptual framework is used in research in various ways, one of which is to outline possible courses of action. Frameworks are built from a set of concepts linked to a planned or existing system of methods, behaviours, functions, relationships, and objects. An interdisciplinary conceptual framework addressing the drivers of dengue transmission comprises the mental mapping of climatic factors, urban ecological/functionality factors, the interaction between the human population and the vector (the *Aedes* mosquito), and the continuous feedback loops between all these factors. Within this framework, climate is conceptualized as a system within the larger Earth system which encompasses the atmosphere, hydrosphere, and biosphere. My research is grounded in an epistemological plurality approach that treats the physical and biological spheres as a linked system in continuous interaction with human society. Climate variability is regarded as a component of the physical sphere and ecology that focuses on the interface between biological and physical spheres are seen in an integral manner, but with their distinctive role in affecting the disease occurrence coupled with human interface.

Traditional approaches to epidemiology assign greater importance to economic factors and community desires, whereas the ecosystem approach ascribes equal importance to environmental management, economic factors, and community desires (Lebel, 2003). This quest for infectious disease epidemiology further expanded while Caprara et al. (2009) introduced the ecological determinants affecting DF incidence in Brazil where climate, vector ecology and vector biology are sub components under an eco-biological system within their framework which focused mostly on the socio-economic and political elements. Based on the above-mentioned concepts, I prepared a framework by blending physical, biological and social spheres together, with an emphasis on their interactions.

As can be seen in Figure 1.2 (a), the physical and biological spheres intersect with each other, creating the integrated urban-ecological segment; which also includes part of the physical sphere - climate variability. The other circle representing social factors such as community practices also intersects with the other two circles, forming a common middle section representing vector abundance as a result of interacting urban-ecological systems. Climate change/variability is therefore regarded as a component of the physical sphere and ecology, acting as the interface between biological and physical spheres. Following Lebel (2003) and Caprara et al. (2009), the distinctive roles of these spheres in affecting disease occurrence are emphasized.

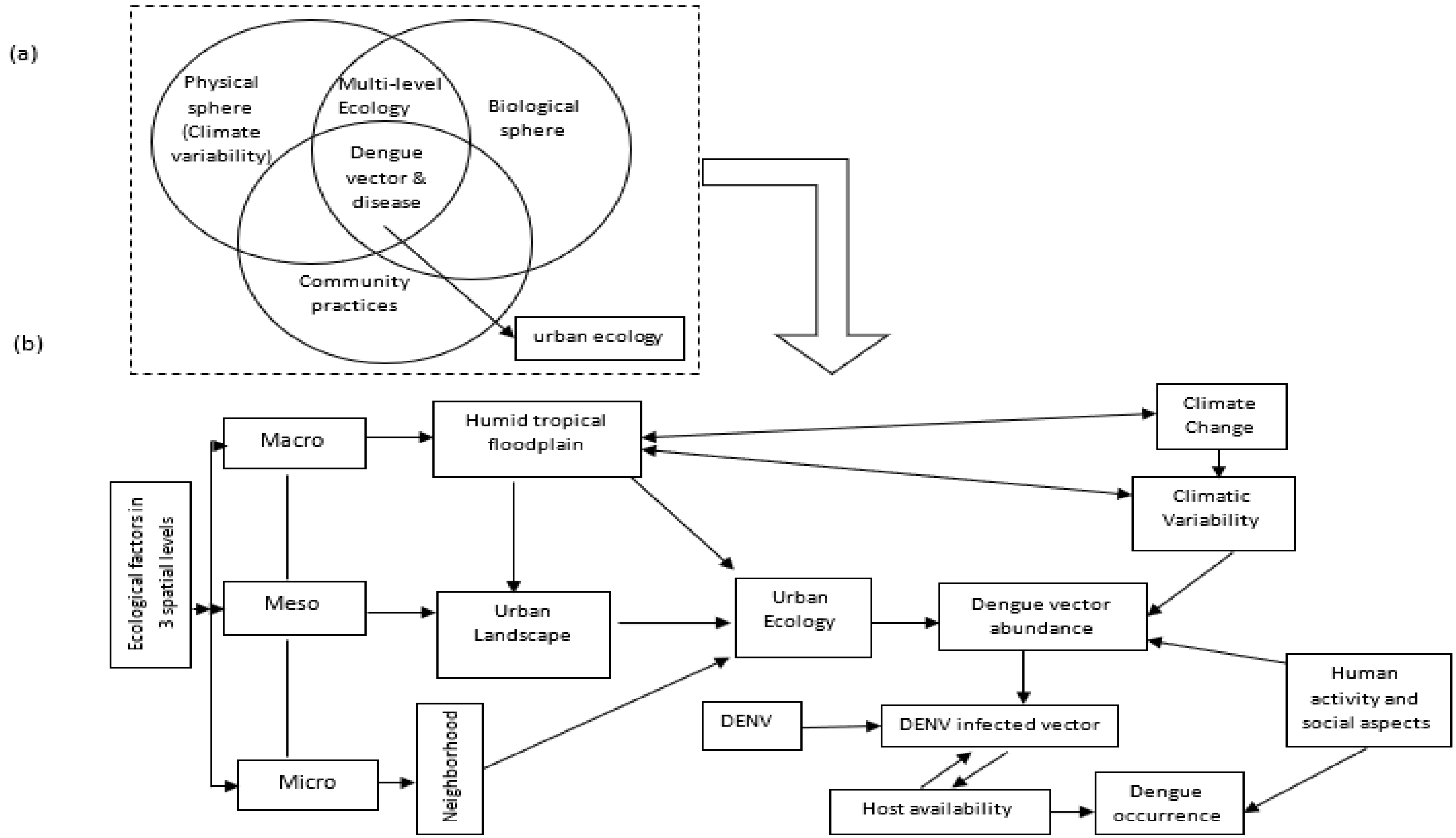

Figure 1.2: (a) Climate-ecological model for dengue vector abundance. (b) Conceptual framework showing relationships amongst climate, ecology and dengue vector abundance and dengue occurrence [both (a) and (b) are conceptualized after Lebel, 2003 & Caprara et al., 2009]. This diagram is a simplified version of an elaborated figure shown in Appendix 1.C.

Further branching out of the urban ecology/functionality, climate variability, and social components is shown in Figure 1.2 (b). This conceptual framework for the multi-level integrated urban ecological/functionality model has 3 scales/levels of ecological factors: 1) micro level – neighbourhood (residential, industrial/commercial and missed residential and commercial); 2) meso level – urban landscape (human settlements and built-up areas, water bodies, and vegetated areas); and 3) macro level – humid tropical flood plains.

My research covered mainly the microlevel and parts of meso level, examining how these factors interact with climate variability and seasonality to affect vector abundance and dengue disease incidence. The study also examined social factors such as community members' perception of climate change and variability, urban land-use, as well as their behavioural and attitudinal influence on vector abundance and dengue disease occurrence.

1.5 Philosophy and the Complex Systems Approach

General Systems Theory is concerned with the exploration of wholes and wholeness and places particular emphasis on connectedness and feedback within complex systems (Berkes, Colding & Folke, 2003). Complex systems organize around one of several possible equilibrium states or attractors. When a system experiences perturbation, internal feedback loops tend to return the system to equilibrium up to a certain threshold, which if exceeded may result in sudden and catastrophic changes. Such violent changes are rarely predictable. The disease epidemiology of dengue takes place within a complex environmental system which is subjected to constant threshold-exceeding changes due to climate change and regular seasonal variability, changing urban ecology, vector habitat and human behaviour; it is thus essential to understand these changes and their effect upon dengue transmission dynamics in order to develop effective intervention measures.

Traditionally, the concept of a linear relationship between one pathogen and one disease has dominated in the literature. Departing from such a reductionist approach, my study adopted a holistic approach encompassing both climatic and integrated urban ecological factors. Scientific approaches to epidemiology are very powerful and useful, but complex systems involving social-ecological factors cannot be properly understood from a purely mechanistic standpoint (Gallopin et al., 2001). Miller et al. (2008) introduced the concept of "epistemological pluralism" as a means of approaching interdisciplinary research in a holistic, integrated way, with multiple perspectives and approaches being applied to the same problem. The authors suggest that such an approach is very useful for managing 'social-ecological' systems as it recognizes and validates different perspectives, provides a more complete picture of complex systems, and takes negotiation and collaboration into account with respect to implementation (Miller et al., 2008). Following the notion of "epistemological pluralism" of Miller et al. (2008), my study adopts a 'pluralistic framework' combining climate variability, urban ecology, and human knowledge and behaviour in its examination of dengue vector abundance and dengue disease occurrence. The combination of these aspects better explains the 'climate-vector-host' triad while providing better understanding and integrated knowledge of dengue as a whole.

1.6 Research Approaches and a Prelude to Research Methods

This exploratory research attempted to determine the complex interactions between climate variability, integrated urban ecological factors, vector abundance and DF cases. It further examined the current state of KAAP of the community people and their willingness to fund to control dengue vector. The structure of the study is primarily based on the Mixed Methods approach (Creswell, 2003; Creswell, 2009), with a sequential explanatory design (Creswell et al., 2003).

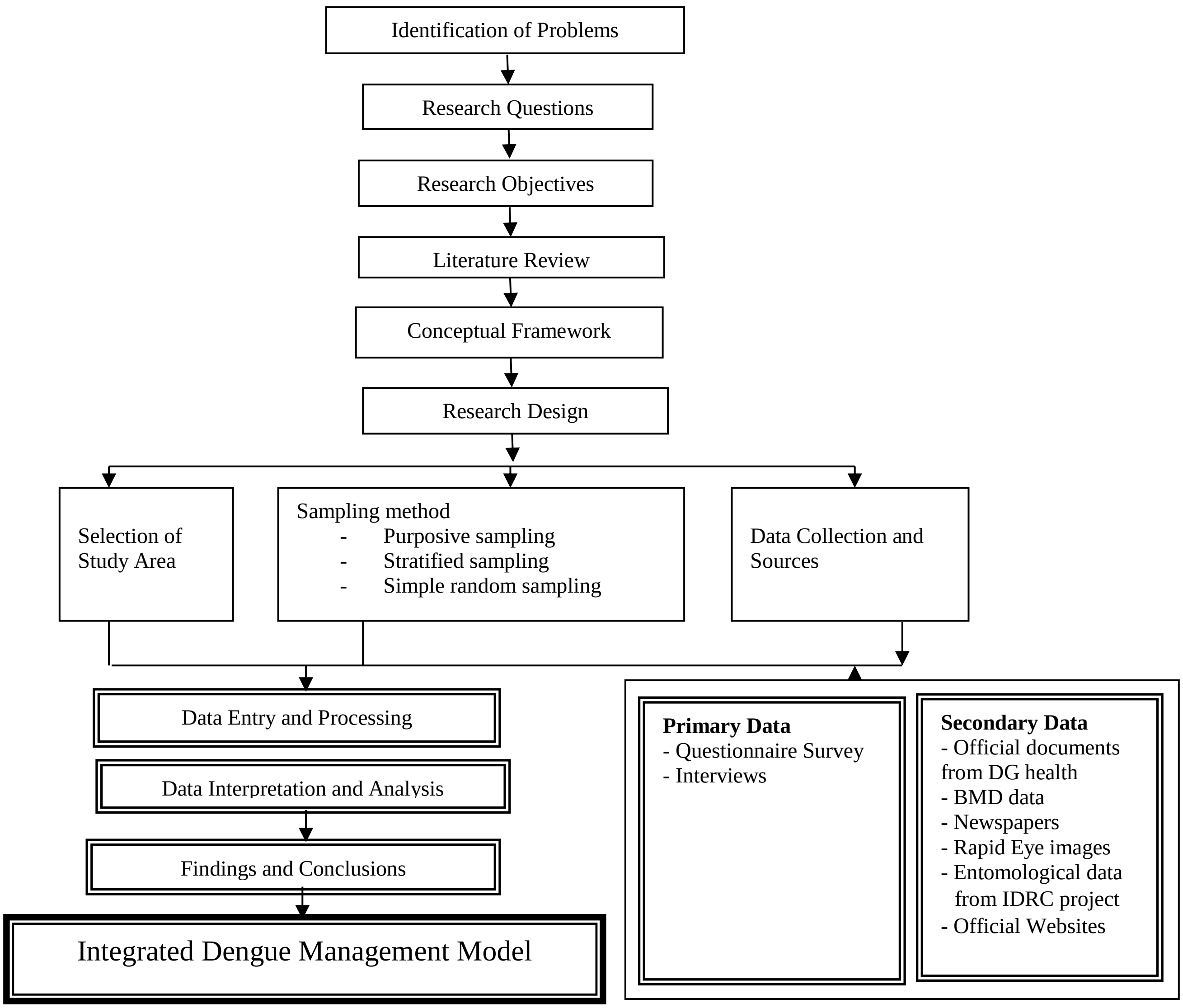

Figure 1.3: Research design framework

Quantitative data collection and pertinent analyses are followed by qualitative data collection, both of which are subsequently integrated to produce a more holistic analysis. Primary quantitative data were collected through a household questionnaire survey and secondary data from the IDRC 2013 entomological survey on dengue vector (*Aedes* mosquito), the Bangladesh Meteorological Department (BMD) (climate data), Rapid Eye images, several agencies of the Bangladesh Government and Dhaka City Corporation provided data for preparing multi-level urban ecology map, and data on vector and cases from the Directorate General of Health Services (DGHS). The data were analysed using Remote sensing, GIS, and statistical software, descriptive and analytical statistical methods and were validated using supplementary qualitative data. The primary data for the qualitative study were collected through direct observation and informal interviews with local community members.

The Target Population of the research consisted of households within the defined territory of Dhaka City Corporation, while the Survey Population was limited only to households located in twelve selected wards of Dhaka City Corporation.

In my study, the impact of climate variability (temperature, rainfall and humidity), vector productivity by container type and size, the impact of household ecological factors and integrated urban ecological zones (IUEZ) on dengue vector abundance and DF occurrence, the KAAP of community members, and the methods currently used to control vectors along with WTP for controlling vectors were examined through a positivist, quantitative research lens. The "post-positivist" school of thought direct researchers to mitigate their personal biases by remaining emotionally detached and uninvolved with the objects of study and to test or empirically justify their stated hypotheses. Following this philosophy, the quantitative approach maintains the 'objectivity' of the research inquiry. In such cases, time and context-free generalizations are desirable and possible, and real causes of social scientific outcomes can be determined reliably and transformed into generalizations (Nagel, 1986). Conversely, the quantitative or *positivist* approach reflects a deterministic philosophy wherein outcomes are determined by the causes (Creswell, 2003).

According to Smith (1988), the quantitative research involves counting and measuring of events and statistically analysing the resulting body of numerical data. As quantitative research is deductive and particularistic, it is based upon the formulation research questions or hypotheses and verifying them empirically. Thus, this type of research is usually free of human biases (Frankfort-Nachmias & Nachmias, 1992). The knowledge generated through this lens was based on careful observation and measurement of the objective reality that exists in the study site - in this the city of Dhaka. This inquiry was conducted through the use of "surveys" (both primary and secondary) which included a cross-sectional study using household survey questionnaires and structured interviews conducted with sample of the population, and an entomological survey of households in the study site. These provided a quantitative description of trends, observations, experiences, attitudes, and opinions within the sampled population (Babbie, 1990).

Although positivist approaches in public health studies have been criticized as number-crunching exercises and can be ideologically problematic, a sense-datum experience provides this study with a statistical basis with which to understand and communicate observable and measurable phenomena. However, this kind of study may fail to fully capture the context of the environment within which the studied phenomena occur and may not encourage their continuous investigation. Consequently, the study complemented the quantitative data with a qualitative research component.

My research is focused on Bangladesh's urban communities and the climatic and socio-ecological factors which drive vector abundance and dengue disease occurrence within them. The various interactions between community members, groups, and organizations were taken into account, relying as much as possible on the participants' views and experiences (Creswell, 2003). Therefore, the research methodology aligns well with the 'social constructivist' perspective.

The 'social constructivist' school of thought uses qualitative tools which add an understanding of the subjective nature of community members as actors in the causal relationships that are pragmatic in the environment and society. It is defined as "a strategy of inquiry process to understand a social or human problem, based on building a complex and holistic picture, formed with words, reporting detailed views of informants and conducted in a natural setting" (Creswell, 1994: 1-2). This school of thought concedes that research is value-bound, that it is impossible to differentiate fully between causes and effects, that logic flows from specific to general (e.g. explanations are generated from the data), and that the human subject cannot be separated from the content of knowledge which determines the reality (Guba, 1990). This process includes open-ended questions so that participants can fully express their views based on historical and social experiences which best explain their local context (Creswell, 2003).

A qualitative research approach has several advantages over the quantitative approach: it is useful for describing complex phenomena as they are situated and embedded in the local contexts and more responsive and adaptive to local conditions. It also allows for the study of dynamic processes. The qualitative approach assumes that the human condition is a result of various conditions (social, economic, political, and environmental) that influence individual choices and behaviours, which cannot be interpreted by quantitative means. As qualitative approaches are responsive to local situations, conditions, stakeholders' needs, and the changes that occur over the course of the study, they allow shifts in focus and the incorporation of emerging new realities in the field (Johnson & Onwuegbuzie, 2004). Creswell (1994) sees the qualitative research approach as preferable because it emphasizes the *process* over products or outcomes, is concerned with meaning (i.e. how people make sense of their lives and experiences and the structures of their world), considers the researcher as a primary instrument for data collection and analysis while allowing to observe behaviour and conditions in a natural setting. However, qualitative field studies are typically time-consuming, and the results are more easily influenced by the researchers' personal biases.

Integrating quantitative and qualitative approaches allowed me to find statistical patterns within the climate-vector-disease relationships while at the same time capturing the perspectives of stakeholders whose lives are directly impacted by dengue. According to Creswell's (2009) classification, my research therefore falls into the 'pragmatic' school of thought, wherein researchers focus on the "research problem" and apply all approaches available in order to understand it (Creswell, 2009). The most prominent feature of the pragmatic worldview is the freedom of choice it affords researcher has to choose the methods, techniques, and procedures of investigation (Morgan, 1998).

Following this, the world or reality was not viewed as an absolute unity while conducting this research, rather emphasis was given on the social, cultural and other pertinent contexts of the research problem concerning the climatic and ecological aspects affecting vector abundance and DF incidence in the city of Dhaka, Bangladesh. Eventually, such efforts lead building an integrated urban socio-ecological systems model to facilitate explaining the dengue disease risk and determining the areas of interventions to prevent and control dengue.

1.7 Study Area and Selection of Study Sites

Located on the banks of the Buriganga River, Dhaka is the capital city of Bangladesh and the most significant urban centre in the country in terms of population density, urban development, and health issues. It has an area of 126.34 sq. km. (census 2011) (BBS, 2016), and with a population of 18.2 million, is ranked the 11th megacity in the world (UN, 2016). The Dhaka City Corporation (DCC) had 90 administrative “wards” (a local administrative unit) during the study period.

Dhaka experiences a hot, wet and humid tropical climate. The city has a distinct monsoonal 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 (BBS, 2001). Nearly 80% of the annual average rainfall of 1,854 millimetres (73 in) occurs between May and September (BBS, 2001). Lying on the lower reaches of the Ganges Delta, the city is particularly vulnerable to flooding during the monsoon season (BBS, 2001). The region is also particularly susceptible to cases of dengue and has experienced several epidemics since 2000.

The study area for my research is the Dhaka Municipal Corporation, where most reported cases of DF have been localized. Meteorological data were collected for the city as a whole as there was only one weather station available. For the study of *Stegomyia* indices [Household Index (HI), Breteau Index (BI), Container Index (CI), Pupae per person Index (PPI)], 12 wards [wards 13, 20, 25, 26, 35, 38, 40, 58, 60, 69, 76 and 78] were selected; whereas four wards [wards 20, 26, 60 and 69] were selected for the KAAP survey. Urban ecological zones are regarded as distinct areas of a city characterized by unique land and waterscapes and habitats which maintain a distinct ecological character in respect to biological, functional, and cultural diversity (Pickett & Cadenasso, 2006; Cadenasso, Pickett & Schwarz, 2007). Therefore, they are labelled as Integrated

Urban Ecological Zones (IUEZs). Four IUEZs were obtained following seven urban classification indicators as suggested by Cadenasso, Pickett, and Schwarz (2007). The above-mentioned wards were selected based on the IUEZs and the availability of entomological data. The land-cover and land-use data representing the functionality of the urban ecological areas were identified from the ancillary data collected from different government organization in Dhaka, and the entomological data was collected by the IDRC-sponsored dengue project in Bangladesh between August and September 2013.

Delineation of Urban Ecological Zones

A Rapid Eye image for the city of Dhaka ($23^{0}40^{/}09^{//}$N to $23^{0}54^{/}05^{//}$N and $90^{0}19^{/}45^{//}$E to $90^{0}30^{/}35^{//}$E) for 2013 was procured for identification of current land cover. Supervised classification with six training samples and four test samples for each of the categories of land cover was performed. The Maximum Likelihood classification technique was applied for the supervised classification. Land use data procured from the Dhaka City authority were overlaid with the classified land cover map. The land use classes from the ancillary data were then connected with the Rapid Eye classified imager through a *Spatial Join* operation in Arcmap 10.1. The average percentage of each land cover/use type for each of the 90 wards was determined by overlaying the ward boundaries on the land cover map and summarizing by zone in Arcmap 10.1.

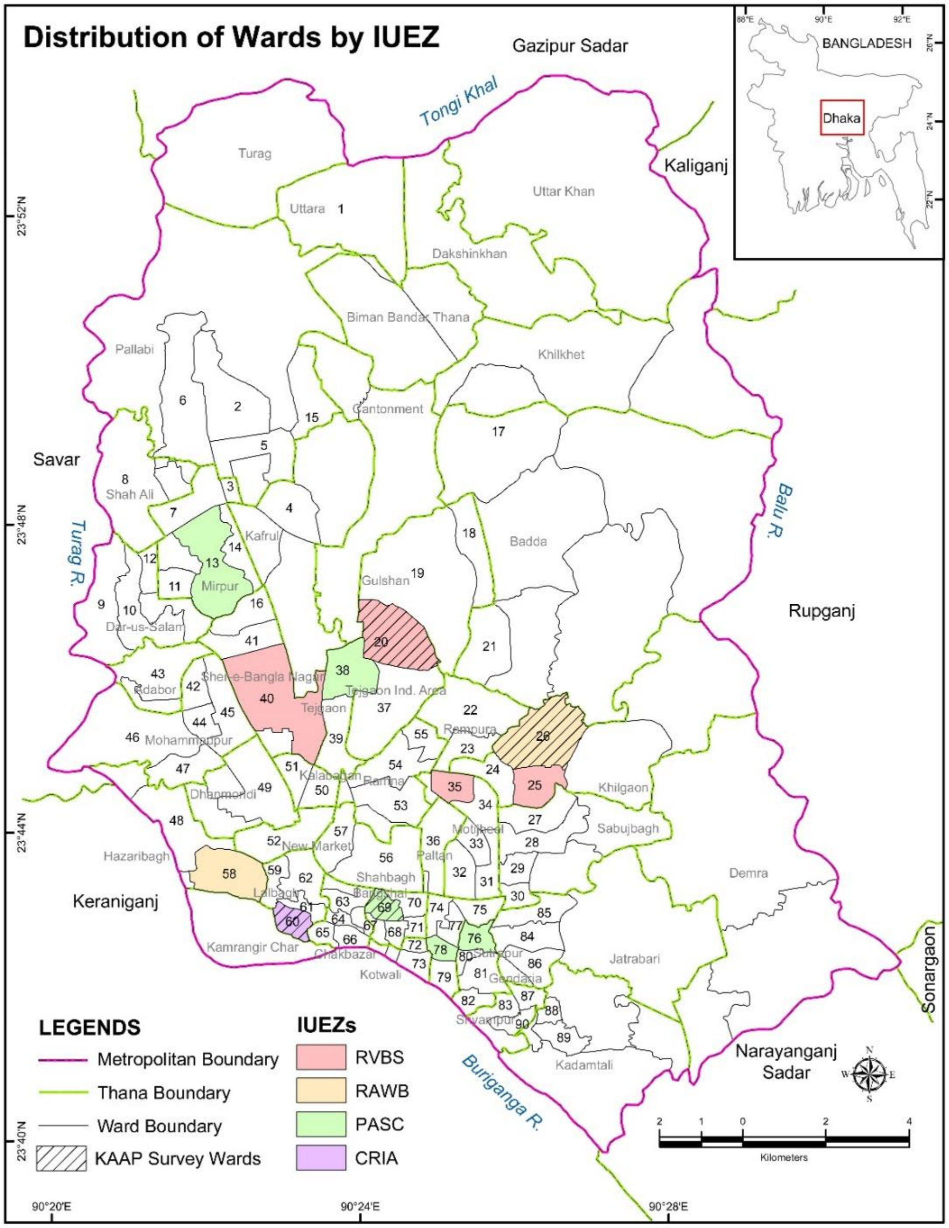

Figure 1.4: Location of sampled wards (n=12) by Integrated Urban Ecological Zone (IUEZ) for the 2013 entomological survey (in colour), and sampled communities (four wards) for the 2014 KAAP survey (patterned) in the Dhaka City Corporation (DCC) area.

The city was then classified into four Integrated Urban Ecological Zones (IUEZ): i) Residential, Vegetation and Bare Soil (RVBS), ii) Residential and Water-bodies (RAWB), iii) Paved/built Area, Services and Commercial Activities (PASC), and iv) Commercial, Residential and Industrial Area (CRIA) (Figure 1.5). This classification was based on seven indicators: bare soil and built area (building and paved area), water surface, vegetation, residential area, public services and commercial areas, commercial and industrial areas. The R function ***agnes*** from R-package ***cluster*** (Struyf, Hubert & Rousseeuw, 1997) was used for this purpose. The association matrix was based on chord distance (Legendre & Legendre, 2012) using the ***designdist*** function from the ***vegan*** R-package (Dixon, 2003) and Ward's as the clustering method (Struyf, Hubert & Rousseeuw, 1997). A dendrogram of the studied "*wards*" (administration unit) was produced and four urban zones were identified. For visualization purposes a PCA of the wards was also produced using the ***prcomp*** function in the statistical software R (R Core Team, 2019).

1.8 Organization of the Thesis

This thesis is divided into five chapters. This first chapter builds on the literature review, outlining knowledge gaps in previous studies on the effect of environment/climate, urban land-use, and human factors on dengue transmission; highlighting the importance of a holistic approach to studying the climate-vector-host-dengue nexus; and elaborates on the theoretical lens and research approaches used in this study. This introductory chapter is followed by three chapters addressing the four specific objectives of this thesis research. Chapter Three has been published, Chapters Fours has been accepted and Chapter Two is awaiting review.

Chapter Two is focused on the roles of changing climate and seasonality on vector abundance and dengue disease occurrence and understanding the complex interactions within the climate-vector-disease relationships. Chapter Three deals with the factors affecting vector (*Aedes*) productivity and includes an analysis of the effects of container types and sizes and other ecological factors at the household (micro) level. Chapter Four covers the effects of urban ecological zones and local knowledge, awareness, attitudes and practices on dengue control measures and the WTP for vector control. The effects of urban ecological/land-use change, human knowledge and interaction with the vector and DF/DHF occurrence are examined here, elaborating on how vector-host relations overlap with changing environmental conditions. The thesis concludes with a combined discussion and conclusion in Chapter Five which summarizes the findings of chapters Two, Three, and Four. This final chapter also provides a holistic framework for dengue transmission risk and dengue control strategies, based on the concept of climate-vector-disease relationships, while outlining the contribution of the thesis to the larger body of research on dengue as well as its limitations and recommendations for future research.

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Chapter 2 - Climate variability, dengue vector abundance and dengue fever cases in Dhaka, Bangladesh: a time-series study[1]

Abstract

Background: Previous studies on the relationship between climatic factors and dengue have typically examined the effects of climate on either vector abundance or incidence of dengue cases, with few explicitly examining the climate-vector-dengue incidence triad as a holistic framework. Adopting such a holistic approach, we studied the effects of climatic factors on vector abundance – and the subsequent effect on dengue cases – in Dhaka city, Bangladesh.

Methods: We examined the time-series of *Stegomyia* indices for *Aedes* mosquitoes, first in relation to temperature, rainfall and relative humidity for 2002-2013; and then in relation to reported dengue cases in hospitals/clinics throughout Dhaka. We analyzed these data at three sequential stages using generalized linear and additive models in which the factors depend linearly or non-linearly on some unknown functions. The effects of seasonality were estimated, and anomalies of temperature and rainfall were calculated from the available data.

Results: We found strong evidence for an increase in *Aedes* abundance during seasonal increases in temperature, relative humidity, and rainfall associated with the monsoon, as well as for a subsequent increase in dengue incidence. Results revealed that mean rainfall (MR) and lag mean rainfall (LMR) were significantly related to Container Index (CI) [p-values = 0.0356 and 0.0744],

[1] This chapter is being reviewed: Islam, S., Haque, C.E., Hossain, S., & Hanesiak, J. Climate variability, dengue vector abundance and dengue fever cases in Dhaka, Bangladesh: a time-series study. PLOS Neglected Tropical Diseases.

and that Breteau Index (BI) was significantly and positively related to mean relative humidity (MH) and MR [p-values = 0.0208 and 0.0157]. A highly significant relationship between dengue cases (CAS) and *Stegomyia* indices, i.e., House Index (HI), BI and CI [p-values = 0.005, <0.001, and <0.001] was also observed. In examining longitudinal (2001-2013) data to determine the association between dengue incidence and climatic factors, we found significant evidence of time lag between MR and CAS. As well, the relationships between CAS and mean temperature (MT), MH, MR and LMR were found to be significant [p-values = 0.0773, 0.0463, 0.0754 and 0.0279].

Conclusions: Our data suggest that climatic factors are significant predictors of vector abundance, and that *Stegomyia* indices are significant predictors of dengue incidence in the city of Dhaka, Bangladesh. These results provide a basis for developing an early warning system for dengue outbreaks, especially under changing climate conditions.

Keywords: Dengue, Climate, Rainfall, Temperature, Humidity, Vector, Linearity, Non-linearity, Bangladesh

2.1 Background

The potential impacts of climate change on human environments are significant and alarming, irrespective of whether or not these changes are anthropogenic. The Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) presents unequivocal evidence of global warming and a changing climate. The Report offers a number of global and regional future projections: it is "likely" that heat waves will become more intense and frequent, especially in large parts of Europe, Asia and Australia; "likely" that heavy precipitation events will become more frequent and "likely" to increase in areas affected by drought, and "likely" that disease epidemics – particularly vector-borne – will increase (IPCC, 2014). Dengue/Dengue Hemorrhagic Fever (DF/DHF) is one of the fast-growing arboviral diseases in the tropics, for which there is currently no cure or vaccine universally available. The rapid spread of both the dengue virus (DENV) and its mosquito vector (mostly *Aedes aegypti* and *Aedes albopictus*) in the past four decades poses an enormous risk to public health in tropical regions. Halstead (2007) and Gubler (1998) state that such projected emergences will place around 2.5-3.0 billion people at risk of acute illness every year as tropical diseases spread to new areas such as Europe and North America (Rodhain, 1996).

Disease epidemiology for emerging infectious diseases (EIDs) like dengue, is still a poorly-researched area of study, especially from an interdisciplinary perspective (Teixeira et al.2005; Moore, 2008; Brisbois & Ali, 2010; Laughlin et al., 2012). EIDs are still commonly understood as being only pathogen-driven or vector-driven. While some scholars account for the climatic factors in their analysis of arboviral disease epidemiology (Githeko et al. 2000; Semenza & Menne, 2009; Murray, Quam & Wilder-Smith, 2013; Lorenz et al., 2017), climatic factors and/or climate change are generally considered as a discrete and separate entity in explaining disease dynamics. In clarifying dengue disease epidemiology, some quarters even consider climatic aspects as unrelated factors (McMichael, Woodruff & Hales, 2006). In contrast, we argue that climatic factors should instead be considered as one of the principal determinants of the epidemiological complex encompassing vector ecology, pathogen biology, disease transmission, disease occurrence and prevalence, and disease control, prevention, and cure. Such an improved understanding of EIDs such dengue would enable us to more comprehensively map the process of disease occurrence and spread. This is especially vital for diseases such as dengue for which there is no known cure, and against which risk assessment, prevention, and control are the only countermeasures available.

The relationship between climatic conditions and DF/DHF incidence is complex. An extensive survey of the literature has revealed that rainfall, temperature and humidity are the most important explanatory variables in the transmission of dengue virus (DENV) through the means of vectors (*Aedes aegypti* and *Aedes albopictus*) and human hosts (Koopman et al., 1991; Herrera-Basto et al., 1992; Hales, Weinstein &Woodward, 1996; Gubler et al., 2001; Hales et al., 2002; Depradine and Lovell, 2004; Kuhn et al., 2005; Brunkard, Cifuentes & Rothenberg, 2008; Colón-González et al., 2013; Naish et al., 2014). However, the specifics of these interactions vary widely from region to region and remain largely inconclusive in the current literature.

A number of studies have examined relationships between DF and DHF cases and social, economic, and infrastructural variables, while others have focused on understanding dengue transmission processes through vector ecology (WHO, 1999; Guha-Sapir & Schimmer, 2005). As reflected in mixed research findings, interactions between these factors and their effects on vector abundance and dengue disease occurrence are complex and involve multidimensional dynamics. Although literature on the bivariate relationship between dengue vectors (i.e. *Aedes* mosquitoes) and climatic factors; DENV and climatic factors, and DF/DHF and climatic factors is extensive, studies examining all three variables concurrently, using a multivariate approach, are relatively scarce. Our study aims to fill in these gaps in the literature, in the context of Dhaka, the capital of Bangladesh.

To our knowledge, the present research is the first study of its kind in South Asia to consider the climate-vector-disease relationships for dengue. It attempts to determine the effects of climatic variability (focusing on three climatic factors – temperature, humidity and rainfall as well as seasonality at large) on dengue vector abundance and dengue disease occurrence in the city of Dhaka, Bangladesh. The specific objectives of the study are: 1) to examine the relationship between climatic factors and dengue vector abundance; 2) to examine the relationship between DF/DHF cases and vector abundance; 3) to examine the relationship between climatic factors and DF/DHF cases; and 4) to map the patterns in seasonality and climate anomaly, along with their effects on DF/DHF cases.

2.1.1 Temperature and Dengue

The relationship between DENV infection, DF and DHF incidence and temperature follows a complex, non-linear trend. Most studies on dengue have been conducted in tropical areas where the annual temperature patterns were similar and disease transmission occurs at an optimal temperature range of 20-35°C (Kuno, 1995; Wu et al., 2010; Yu et al., 2011). However, vector breeding and disease transmission are dependent on many other socio-economic and human behavioral factors. It is also critical to distinguish between outside and ambient temperature when examining dengue vector breeding conditions. For example, in sub-tropical regions, breeding can still occur at sub-optimal outside temperatures (i.e. during the winter) if the ambient (indoor) temperature is higher and heating and standing water are available (Kuno, 1995). Conversely, even if the outside temperature is optimal, if the ambient temperature in buildings is lower due to air conditioning, the vector may not breed or multiply sufficiently to cause an outbreak. Especially, the breeding patterns of *Ae. aegypti*, the major vector for dengue, may not necessarily correlate with outdoor temperature, but rather ambient temperature.

Both the ambient temperature and seasonality play a crucial role in *Aedes* mosquito breeding and the spread of DENV. In a study conducted in Bangkok, Thailand, Kuno (1995) observed that *Ae. aegypti* mosquitoes could transmit DENV only if the ambient temperature was above 20°C. Indeed, dengue transmission usually declines with the approach of seasonally cold temperatures. For example, a recent epidemic in Australia ended when winter temperatures reached 14-15°C (Kuno, 1995). It was registered in Thailand that the extrinsic incubation period for *Ae. aegypti* (approximately 11-14 days) with an elongated time range at a lower ambient temperature in turn decreases dengue transmission (Kuno, 1995). It is rather the lowest daily temperature which influences the extrinsic incubation period. It has been suggested that ongoing global warming of the atmosphere may change seasonal patterns and annual average temperatures and consequently allow the spread of the dengue vector (and the disease itself) into temperate regions such as the mid-latitude and northern parts of Europe and North America (Ward & Burgess, 1993; Liu-Helmersson et al., 2014; Nazerath et al., 2014). This risk may even amplify further due to higher adaptive capacity of *Ae. albopictus* mosquitoes to colder climates.

Previous studies in various countries reported a positive association between temperature, mosquito density, and dengue transmission (Nagao et al., 2003; Chakravarti & Kumaria, 2005; Nakhapakorn & Tripathi, 2005; Thammapalo et al., 2005; Bangs et al., 2006; Arcari, Tapper & Pfueller, 2007; Jury, 2008; Beebe et al., 2009; Johansson, Cummings & Glass, 2009a; Johansson, Domnici & Glass, 2009b; Hii et al., 2009; Hsieh & Chen, 2009; Lu et al., 2009; Tseng et al., 2009; Tipayamongkholgul et al., 2009; Wu et al., 2009; Wu et al., 2010; Yu et al., 2011; Colón-González et al., 2013; Banu et al., 2014; Naish et al., 2014). Wu et al.'s (2007) study in Taiwan was the only exception, reporting a negative correlation. As higher temperature favors DENV replication, vector breeding and feeding frequency of mosquitoes, rising temperature may enhance dengue transmission within a range of 20°-35°C. However, the impact of increased temperature on dengue outbreaks was not immediate in any of the studies examined. Various lag times were reported between temperature rise and the onset of dengue outbreaks, ranging from 4 to 16 weeks (Arcari, et al., 2007; Wu et al., 2007; Hii et al., 2009; Hsieh & Chen, 2009; Lu et al., 2009; Hu et al., 2010; Yu et al., 2011) – corresponding to the total life cycle for *Ae. aegypti* including the extrinsic incubation period. Studies have also found that temperature may alter the length of the extrinsic incubation period by affecting viral replication (Wu et al., 2010). This means that rising temperatures can simultaneously enhance viral replication and shorten the vector's extrinsic incubation, resulting in enhanced transmission of dengue.

Increases in temperature during the monsoon season have been correlated with DENV infection rates and DF and DHF incidence in various parts of the tropical world. A study in Taiwan (Wu et al., 2009) calculated that the risk of DF transmission increases by a factor of 1.95 for every 1°C increase in monthly average temperature. A separate study in Taiwan (Tseng et al., 2009) revealed that a 1.8°C increase in temperature in the country would increase the probability of dengue infection by 87% in the case of high infection rates and 12% for low infection rates. However, the authors of the latter study caution that these figures are likely inaccurate when applied to regions where temperatures exceed 30°C, as such temperatures may not be favorable for vector survival (Yu et al., 2011).

Some contemporary researchers have suggested other contributing factors to dengue transmission, such as regional physiography, altitude, and vegetation. For instance, a study in Puerto Rico (Johansson et al., 2009b) found that the cumulative effects of temperature on dengue incidence are highest in the cooler and wetter mountainous areas (Johansson et al., 2009b). Research conducted in Indonesia (Arcari et al., 2007) and Thailand (Thammapalo et al., 2005) found similar regional variation. In addition, a Taiwanese study concluded that the incidence of DF was negatively associated with monthly temperature variation, which might be due to higher average temperatures in cities (Wu et al., 2007).

2.1.2 Rainfall and Dengue

The relationship between dengue incidence and rainfall is dependent on numerous complexly - interlinked factors. The dengue epidemiology literature reveals that dengue outbreaks in most countries coincide with the wet season and increased precipitation in general (Nagao et al., 2003; Chakravarti & Kumaria, 2005; Nakhapakorn & Tripathi, 2005; Arcari et al., 2007; Su, 2008; Hii et al., 2009; Hsieh & Chen, 2009; Johansson et al., 2009a; Johansson et al., 2009b; Yu et al., 2011; Colón-González et al., 2013; Naish et al., 2014). In this regard, Kuno (1995) noticed a positive association between rainfall and larval density and dengue incidence that has since been documented in many tropical countries. However, this causal pathway cannot be universally generalized, as dengue outbreaks follow different climatic patterns in certain regions. In places where dengue epidemics were recorded, the amount of rainfall or larval indices was unusually low and no positive association was found for the transmission (Norman, Theodre & Joseph, 1991; Biswas et al., 1993). For example, in India outbreaks generally coincide with the post-monsoon season following a period of decreasing rainfall (Chakravarti & Kumaria, 2005). An outbreak of dengue in Singapore also exhibited no positive correlation with rainfall (Kuno, 1995). These observations indicate that a single-factor causal relationship between rainfall and dengue is insufficient to explain all outbreak patterns.

2.1.3 Relative Humidity and Dengue

Despite great interest within the research community in the association between climatic factors and dengue incidence, research on relative humidity as an important climatic factor has been relatively scant. Furthermore, the results of those studies which have been conducted have been inconsistent and inconclusive. An Indonesian study (Halide & Ridd, 2008) revealed that the most important predictive factor for dengue outbreaks in that country was relative humidity, with a 3-4 month lag time (Halide & Ridd, 2008). This research revealed that low relative humidity during September and October is usually followed by a dengue outbreak early the following year. It is thus highly probable that if seasonal conditions (average temperature and humidity) are shifted due to climate change, seasonal incidences of dengue will be shifted as well. As noted above, certain studies have identified a reverse association between relative humidity and dengue incidence with a two-month lag (Wu et al., 2007). It was mentioned in Halide and Ridd (2008) that people store water during dry periods when relative humidity is low, resulting in high dengue incidence as the water storage containers become breeding grounds for vector mosquitoes.

Conversely, the Nakhapakorn and Tripathi (2005) study in Thailand observed that dengue mostly occurred in high-humidity environments, while Tipayamongkholgul et al.'s (2009) study registered a consistently negative correlation between the local relative humidity and dengue outbreaks with 3-4 month lag time (Tipayamongkholgul et al., 2009). Nonetheless, despite the small number of studies which have addressed the subject, it is clear that relative humidity does play a significant - if not completely understood - role in dengue transmission (Naish et al., 2014).

2.1.4 Dengue in Bangladesh

Bangladesh is situated in the tropical monsoon climate zone. Dhaka -- the capital city – and other major urban centers experience a hot, wet and humid tropical climate. Bangladesh has a country-wide monsoon mean temperature of about 29°C (Shahid, Harun & Katimon, 2012), which falls within the optimal range for both mosquito breeding and dengue transmission (Watts et al., 1986; Rueda et al., 1990; Kuno, 1995; Wu et al., 2010; Yu et al., 2011). The major cities of Bangladesh (a country with a population of about 160 million in an area of 143,000 km^2) have experienced a major resurgence of dengue since 2000 (Yunus, 2000; Hossain et al., 2003). The first epidemic of DHF occurred in 2000 in the cities of Dhaka, Chittagong and Khulna. During this dengue epidemic, a total of 5,551 infections were reported and 93 patients died (Yunus et al., 2001). Since then, serious concern has been expressed regarding the lack of understanding of the dynamics of dengue transmission and the urgent need for improved disease management. Hossain et al. (2003), after analyzing samples from febrile patients between 1996 and 1997, suggested that dengue transmission was ongoing in the country well before 1996 (Hossain et al., 2003). The

Sharmin et al. (2015a), and Morales et al. (2016) studies noted that dengue could be traced back to 1964 in Bangladesh [then East Pakistan] before the major outbreak took place in 2000. According to Sharmin et al. (2015a), the 2000 outbreak resulted from a virus strain originating in Thailand. They also added that dengue cases remain underreported in the country as rural people only visit hospitals in the most severe cases. Rahman et al.'s (2002) research indicated some degree of correlation between the DF/DHF outbreak in 2000 and monsoon seasonal conditions as the outbreak started in late June 2000, peaked in September (during the rainy season) and decreased in the dry winter season of the same year.

Studies on the relationship between climate and dengue transmission in Bangladesh have primarily focused on patients in hospitals and clinics (Rahman et al., 2002; Hossain et al., 2003; Banu et al., 2014; Sharmin et al., 2015a), and only a few investigations have hitherto been carried out in the country (Hashizume et al., 2012; Karim et al., 2012; Sharmin et al., 2015b). In a rare study on climate-dengue case relationships in Bangladesh, Hashizume et al. (2012) conducted a time-series analysis of the trend between hydroclimatological variability and DF cases, and found a positive association between DF cases with high as well as very low river levels with varying weekly time lags of 0-19 weeks (Hashizume et al., 2012). Banu et al. (2014) found that that the emergence of dengue cases had been significant during the period of 2000-2009 and that temperature (maximum) and humidity were positively associated with DF transmission in Dhaka city with a lag of 4 months. The researchers also predicted that dengue cases could reach as high as 16,030 by 2100 with a 3.3°C temperature rise. The aforementioned studies, however, were limited in scope as they looked only into the relationship between weather and hydrological factors (i.e. water level in rivers) and dengue cases, ignoring critical vector and host-related factors such as vector density, population immunity, and human behavior (Banu et al., 2014).

By taking a wider scope, several recent dengue studies in Bangladesh have emphasized the importance of macro-level meteorological, climatic, demographic, and socioeconomic factors in the spread of dengue. Sharmin et al.'s (2015b) investigation of Dhaka city revealed that a combination of high mean temperature and low temperature fluctuation were significant predictors for dengue outbreaks, with a one-month lag. The authors also identified a growing population as a significant factor in increasing dengue risk. However, no consideration was given to the critical role of vector mosquitoes. Sharmin et al.'s (2015a) study of Bangladesh as a whole indicated that dengue risk in a city like Dhaka was tied not only to poor intervention, uncontrolled urbanization, environmental changes, changing human mobility, and economic factors, but also (and more significantly) rising temperatures and rainfall (Sharmin et al., 2015a). Karim et al. (2012), examined the influence of climatic factors on dengue cases in the city of Dhaka, and found that rainfall, maximum temperature, and relative humidity could explain 61% of the variability in reported dengue cases with a two-month lag period (Karim et al., 2012). The study revealed that the arrival of the monsoon season, with a peak in August, was sufficient to explain most of the reported dengue cases in the City. Again, the role of vector mosquitoes in dengue transmission was not considered. A recent investigation in the city of Dhaka revealed that both *Ae. aegypti* and *Ae. albopictus* larval populations peaked in July at the height of the monsoon (Ahmed et al., 2007).

In studies on dengue in Bangladesh, we argue that the focus has generally been on two-dimensional relationships either between climate factors and vector abundance or between vector abundance and dengue cases. For instance, Sharmin et al. (2015a), Sharmin et al. (2015b), and

Karim et al. (2012) investigated the effect of climate factors on dengue cases, revealing linear and complex relationships among them. The effects of climate factors on propagation of *Aedes* have rarely been studied in Bangladesh, and those rare studies that have been conducted have only considered two-dimensional relationships (Ahmed et al., 2007). No studies in Bangladesh have as of yet addressed the climate-vector-disease relationships under one holistic research framework. We therefore assert that considerable gaps still exist in our understanding of the complex climate-vector-disease relationships and how these relationships are being affected by confounding factors such as urbanization and human behavior. As there is not yet a cure or vaccine for dengue, it is vital to improve our understanding of risk factors in order to effectively control and prevent the spread of the disease in developing countries like Bangladesh.

Finally, the existing literature on climate-dengue relationships primarily focuses on the relationships between climate change and dengue incidence/occurrence, rarely addressing related factors such as climate variability, seasonality and climate change which can profoundly affect vector abundance and dengue disease occurrence. The latter also are impacted by geographic location and social factors. There is also a conspicuous dearth of interdisciplinary, holistic research on the dynamics and complex interactions within the climate-vector-disease relationships, and such limitations pose serious obstacles to disease prevention and control efforts.

2.2 Materials and Methods

2.2.1 Study Area and Design

The city of Dhaka is the most important urban center of Bangladesh. Considering its socioeconomic, political and demographic significance, pivotal standing in terms of population health risk to infectious diseases, and recurring number of dengue cases, the Dhaka City Corporation (DCC) was chosen as the study area for this investigation. Located on the banks of the Buriganga River, Dhaka has an area of 126.34 square kilometers (census 2011) (BBS 2016) and ranks 11th among global mega-cities with a population of 18.2 million (UN, 2016). The city experiences a hot, wet, and humid tropical climate with 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. Nearly 80% of the annual average rainfall of 1,854 millimeters (73 in) occurs between May and September (BBS, 2010).

2.2.2 Data Collection Techniques

The meteorological data required for the study included temperature, humidity and rainfall on daily, monthly and yearly time scales. These data were obtained from the Bangladesh Meteorological Department (BMD) in Dhaka for the 1985-2014 period. The time-series data for Household Index (HI), Breteau Index (BI) and the Container Index (CI) for *Ae. aegypti* larvae for the city of Dhaka were obtained from the Directorate General of Health and Services (DGHS) of the Government of Bangladesh for the 2002-2013 period. The larval data from entomological surveys were available only for seven years: 2002, 2003, 2004, 2005, 2009, 2012 and 2013. These surveys were carried out during the same period of each year, namely during June-October months.

However, we noticed that the geographic areas surveyed by the DGHS varied from year to year. In order to maintain consistency and ensure comparability, we selected only those areas within which data collection was repeated for at least five years. We re-calculated all indices (HI, BI and CI) for the city of Dhaka based on DGHS datasets by considering only areas of repeated surveys. Since no data were available for certain years (i.e., 2006, 2007, 2008, 2010, and 2011), these missing data were denoted as "missing at random". Following Little and Rubin (2002) and Weerasinghe (2010), these missing data were imputed by applying the Spline Interpolation Method (see R-package "imputTS") (Moritz & Bartz-Beielstein, 2017) and the regression imputation method (Buuren, 2012) (Table 1). All statistical analyses were performed using Microsoft Excel and the Statistical Software R (R Core Team, 2019).

2.2.3 Statistical Analyses

We applied various statistical techniques to identify interactions within the climate → vector → disease relationship. This relationship has not been previously studied to a significant extent, especially in the South Asian context, and thus the constituent dynamics are not fully understood. Our novel approach is to first analyze the effects of climatic variables on vector abundance, then subsequently analyze the effect of vector abundance on dengue incidence, conceptualizing this pathway as a step-by-step process. In addition, we also analyzed seasonality factors that may affect disease patterns over the years. The meteorological, entomological and dengue case data were analyzed in three stages:

Stage 1: Analysis of climate factors vs. vector indices: First, we calculated the mean temperature (MT), mean humidity (MH), mean rainfall (MR), and lag mean rainfall (LMR). We then attempted to find relationships between each of the indices (CI, BI and HI) and the climate factors (MT, MH, MR, and LMR). The following Generalized Additive Model (GAM) (Wood, 2006) was used:

$$g(Index_{it}) = \beta_0 + \beta_1 f(MT_t) + \beta_2 f(MH_t) + \beta_3 f(MR_t) + \beta_4 f(LMR_t) + error_t, \text{ ---------------------- } (1)$$

where g is the link function; β_0 is the intercept; β_1, β_2, β_3 and β_4 are the coefficients of MT, MH, MR and LMR respectively; i is HI, CI or BI; t is time; and f is the unknown smooth functions of climatic factors.

Stage 2: Analysis of vector abundance vs. dengue case incidence: Here, we emphasized examining the relationship between vector abundance (by using HI/BI/CI) and dengue cases. Since our response (dengue cases) was represented by counts, the following Poisson regression model was used to model vector abundance vs. dengue case incidence:

$$\log(\mu_t) = \beta_0 + \beta_1 HI_t + \beta_2 BI_t + \beta_3 CI_t, \text{ ---------------------------- } (2)$$

where μ_t is the mean case count with respect to time t

Stage 3: Analysis of climate factors vs. dengue case incidence: the following four steps were followed to determine the relationship between climate factors and dengue cases:

i) We examined the relationship between dengue cases (CAS) and climatic factors for specific months over the twelve-year study period (2001-2013), using a generalized linear model.

ii) Dengue case data for Dhaka city were plotted against the climate data variables (temperature, rainfall and humidity) from the BMD for the period of 2001-2013 in order to map seasonal variations in dengue cases.

iii) To determine the relationship between dengue cases and climatic factors (MT, MH, and MR), we fitted the following Poisson regression model:

$$\mathrm{Log}(\mu_t) = \beta_0 + \beta_1 MT_t + \beta_2 MH_t + \beta_3 MR_t \text{ ---------------------------- } (3)$$

iv) We calculated the annual mean of temperature and rainfall for the period 1985-2013. This was used as the 'climate normal' baseline for the study. Then the yearly anomaly was found by subtracting the baseline mean of temperature or rainfall from the data for each individual year. This can be expressed as follows:

Expected year's anomaly $_{(1985\text{-}2013)}$ = Yearly mean of the expected year $_{(2001\text{-}2013)}$ – Climate normal $_{(1985\text{-}2013)}$ ……………………………(4)

The data obtained from relation (4) were then plotted to show the climate anomaly over the 2001-2013 period. This depicted the changes in dengue disease occurrence along with the annual anomaly over the years for the 2001-2013 period.

2.3 Results

Based on the three stages discussed in the previous section, we present our results below:

In stage one, we examined the effects of climatic factors on each of the *Stegomyia* indices (CI, BI and HI) for the city of Dhaka over the 2002-2013 period, based on observed (by BMD and DGHS) and our imputed meteorological and entomological data (Table 2.1).

Table 2.1: Vector indices and climatic variables for specific months (2002-2013).

Years	**Months**	**%CI**	**%BI**	**%HI**	**MT (°C)**	**MH (%)**	**MR (mm)**	**LMR (mm)**
2002	Aug	7.49	15.28	14.25	28.6	81	8.77	14.39
2003	Aug	16.31	16.84	8.74	29.4	78	6.52	6.16
2004	Jun	29.91	32.54	14.04	28.5	81	15.87	5.23
2005	Sep	15.7	13.91	10.47	28.9	81	17.13	11.65
2006	Aug	8.11	14.69	8.49	29.1	77	5.39	10.68
2007	Aug	13.61	39.14	10.73	29.1	80	16.29	24.29
2008	Aug	26.46	71.07	15.58	28.8	81	10.29	18.16
2009	Jun	40.91	94.29	21.43	30.2	74	5.67	5.42
2010	Aug	51.56	96.59	26.65	29.5	78	10.97	5.39
2011	Aug	54.36	81.7	29.45	28.5	82	13.19	11.48
2012	Sep	45.6	57.33	28.01	29	79	2.70	9.10
2013	Oct	21.47	30	20.53	27.2	78	4.23	5.73

Results of our univariate analysis revealed that there is a non-linear relationship between CI and mean rainfall (MR) or lag mean rainfall (LMR). We used a smoothing method based on cubic splines to estimate the functional coefficient for the regression model (1).

The results of the fitted model (1) showed that neither mean temperature (MT) nor mean humidity (MH) were significantly associated with CI. However, MR and LMR were found to be positively associated with CI (Table 2.2). The adjusted $R^2 = 0.79$ means that the fitted model can explain 79% of the variability in CI due to MR and LMR.

To check the normality of the error term in the fitted model (1), we drew the autocorrelation (ACF) and partial autocorrelation plots (PACF) of residuals. The PACF plot (not shown) indicated that the residuals in the fitted model were "white noise"; that is, the errors were normally distributed.

Table 2.2: Statistically significant association of climate variables with the *stegomyia* indices.

	Association with CI		Association with BI	
Variables	MR	LMR	MH	MR
p-value	0.0356*	0.0744**	0.0208*	0.0157*

Note: * significant at 0.05. ** significant at 0.10.

We fitted the same model (1) when the response was BI. Both MT and LMR showed positive relationships with BI but were not significant. However, the results indicated that BI was significantly related to MH and MR (Table 2.2). The MH was negatively related to BI, meaning that as MH increases, BI - and thus vector density - decreases. The adjusted R^2 value= 0.72 means that the fitted model can explain 72% of the variability in BI associated with MH. We checked the model assumption using ACF and PACF plots, which revealed that the residuals were just "white noise".

We fitted the same model (1) again when the response was HI, revealing that there were positive relationships between HI and MT, MR and LMR, and a negative relationship with MH. None of the climatic factors were significantly related to HI. The above findings reveal how dengue vector abundance and distribution are impacted by temperature, rainfall, and relative humidity. As the vector is a means rather than a final phenomenon in terms of dengue disease, it is critical to extend our examination to the relationship between dengue and the *Stegomyia* indices.

In stage two, univariate data analysis revealed that the number of dengue cases was non-linearly related to each of the indices BI and CI. A cubic spline method was used to estimate the functional coefficient of the model (2). The results indicated that there were highly significant relationships between dengue cases (CAS) and the indices (HI, BI and CI) (Table 2.3). It is evident from the results that CI was the most significant variable among the indices. The adjusted R^2 value of 0.489 showed that the model could explain about 49% of the variability in dengue cases accounted for by the indices. We examined the ACF and PACF plots of standardized Pearson residuals of fitted model (2), which revealed that the residuals behaved as "white noise".

Table 2.3: Statistically significant association of dengue cases with the *stegomyia* indices and climate variables.

	Association with CAS						
Variables	HI	BI	CI	LMR	MH	MR	MT
p-value	0.005*	<0.001*	<0.001*	0.0279*	0.0463*	0.0754**	0.0773**

Note: * significant at 0.05. ** significant at 0.10.

In stage three, we examined the relationship between dengue cases (CAS) and climatic factors (MT, MH, MR and LMR) by applying the following four steps:

Firstly, we checked the univariate relationship between CAS and each of MT, MH, MR and LMR, which revealed a non-linear relationship with MT and LMR. The cubic spline method was used to estimate the functional coefficients of the model (2). We present below the results from the estimated model, which reveal the relationships between dengue cases and climatic factors for the study period (i.e. 2002-2013) for specific monsoon months, encompassing June to August.

Results from the fitted model (2) indicate that there are significant relationships between CAS and each of MT, MH, MR and LMR (Table 2.3). It is evident from these results that MH and LMR are highly significant and MR is negatively related to dengue cases. The adjusted R^2=0.93 means that the model can explain about 93% of the variability in dengue cases resulting from climatic factors. We examined the ACF and PACF plots of standardized Pearson residuals for the fitted model (2), which indicated that the residuals behaved as "white noise".

Secondly, the raw temperature, humidity and rainfall data were plotted in Figure 2.1 to determine their effects on dengue cases over a thirteen-year period (2001-2013). Figure 2.1(a) indicates that dengue cases follow a cyclical pattern, with a sharp rise (of more than 3000) in the second year of the study (2002). It is also evident from Figure 2.1(a) that the number of dengue cases peaked every other year until 2008, after which the peaks occurred every two years. Figure 2.1(b) reveals that temperature followed a similar pattern over the same 13-year period, with a peak of 30°C (monthly average temperature) during months of July/August of most of the years and a low of 16°C (monthly average temperature) in early 2003. Figure 2.1(c) shows the monthly average humidity pattern over the 13-year study period, which was cyclical with consistent yearly peak of 80-85%. Finally, Figure 2.1(d) also depicts a yearly cyclical and seasonal pattern of the rainfall. The average monthly rainfall for the aforementioned period varies between 10-15 mm with occasional departures; for example, the peaks in 2004, 2006, 2007 and 2009 with highest peak in 2004 having more than 25mm monthly average rainfall.

Overall, all the climatic factors show a yearly cyclical pattern in average monthly temperature, humidity, and rainfall, as shown in Figures 2.1(b), 2.1(c), and 2.1(d), respectively. Figure 2.1(a) shows that dengue cases also follow a seasonal pattern, with incidences being highest during the monsoon season and lowest during the pre-monsoon season (January-April) in alternating years.

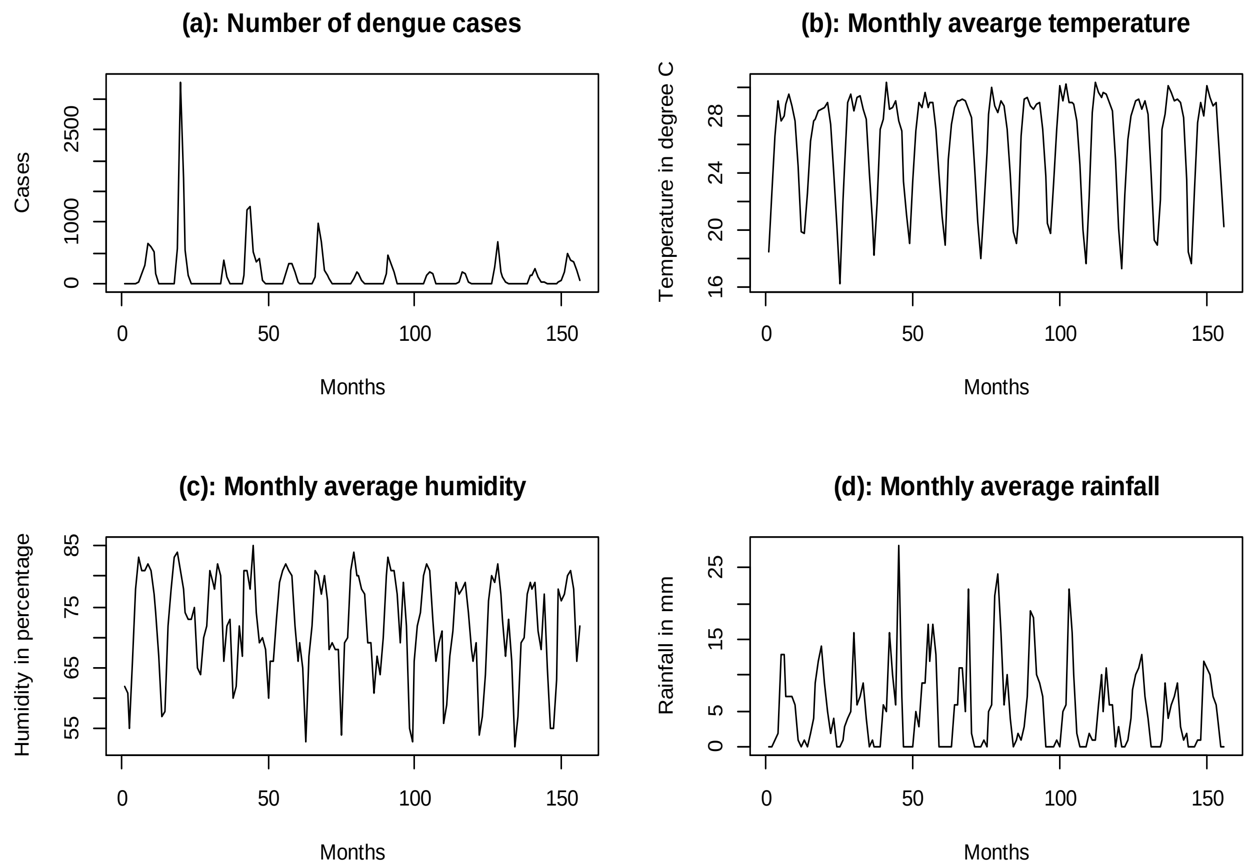

Figure 2.1: Seasonal pattern for the 13-year period (2001-2013) of study: (a) monthly number of dengue cases; (b) monthly average temperature; (c) monthly average humidity; and (d) monthly average rainfall.

The autocorrelation and partial autocorrelation plots of dengue cases, monthly average temperature, monthly average humidity and monthly average rainfall for the 13-years period are shown in Supplementary Figure 2.1. Supplementary Figure 2.1(b) shows that there is a significant correlation at lag 1 and 2 followed by correlations that are not significant. This pattern indicates an autoregressive term of order 2. Other Figures clearly indicate the seasonal behavior of the monthly temperature, humidity and rainfall.

Thirdly, when we checked the ACF and PACF plots of the residuals for the 13-year period to determine seasonal variations in the climatic parameters (Supplementary Figure 2.2), we found an autoregressive pattern of order 1. To account for this, we fitted the count time series regression model (3) using the R-function *tsglm* from the *tscount* R-package.

From the fitted model output, the estimated coefficient and its standard error for temperature were found to be 0.10 and 0.003, respectively. The confidence interval for this estimate is (0.10, 0.11) which did not include zero. This means that the temperature is significant at a 5% level; that is, temperature plays a significant role in the number of dengue cases in the city of Dhaka. Since the estimate is positive, the number of dengue cases increases as the temperature increases, while adjusting for humidity and rainfall. For humidity, the estimate is 0.23 and the standard error is 0.002. The confidence interval for this estimate is (0.22, 0.24) which did not include zero. This means that humidity is also significant at the 5% level and plays a significant role in the number of dengue cases in the city of Dhaka. As the estimate is positive, the number of dengue cases increases as humidity increases, while adjusting for temperature and rainfall. For rainfall, the estimate is -0.10 and the standard error is 0.002. The confidence interval for this estimate is (-0.10,

-0.09) which does not include zero. This means that rainfall is significant at the 5% level; that is, rainfall plays a significant role in the number of dengue cases in the city of Dhaka. As the estimate was negative, the dengue cases decrease as the rainfall increases, while adjusting for temperature and humidity.

Fourthly, we calculated the temperature anomaly using the relation (4) and plotted it in Figure 2.2 against dengue cases for the period of 2001 – 2013. As shown in Figure 2.2, when the average yearly temperature was 25.9°C (-0.1 anomaly) or 25.8 °C (-0.2°C anomaly), the number of dengue cases were higher than the number of dengue cases in the average temperature (26°C) of 29-year period (1985-2013). We also observed that at higher anomalies of 0.1°C - 0.6°C (leading temperature rise to 26.1°C - 26.6°C), the dengue cases were lower than the dengue cases in average temperature (26°C). Thus, the number of dengue cases in the city of Dhaka declined when the average yearly temperature was 26°C and higher.

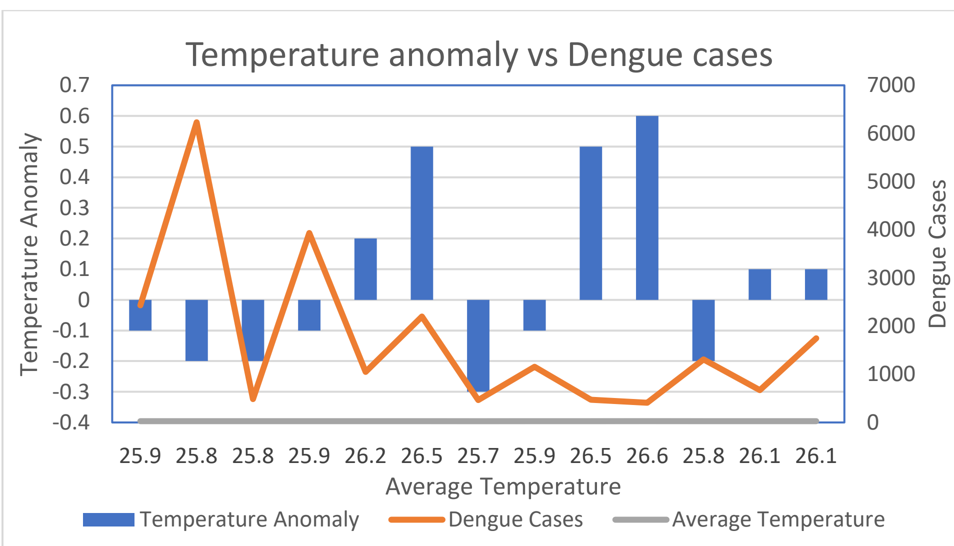

Figure 2.2: Temperature anomaly vs Dengue cases for the 13-year study period (2001-2013). (Source: Bangladesh Meteorological Department (BMD) and Directorate General of Health Services (DGHS), Bangladesh, 2001-2013.)

We calculated the rainfall anomaly using the relation (4) and plotted it against dengue cases in Figure 2.3 for the 2001 – 2013 period. The dengue cases tended to be higher for the annual average rainfall amount at 133mm (-38.18 anomaly) and 160mm (-10.76 anomaly) as compared with the number of dengue cases for the average rainfall of 170 mm during the 29-year period of 1985-2013. We also observed that at higher anomalies, such as 69.74 or 49.07, derived from higher yearly average rainfall of 240mm or 220mm, the dengue cases tended to be lower than the number of dengue cases for the average rainfall. Based on the data collected, we infer that with an increase in the amount of rainfall (more than annual average of 200mm), the number of dengue cases tend to decline.

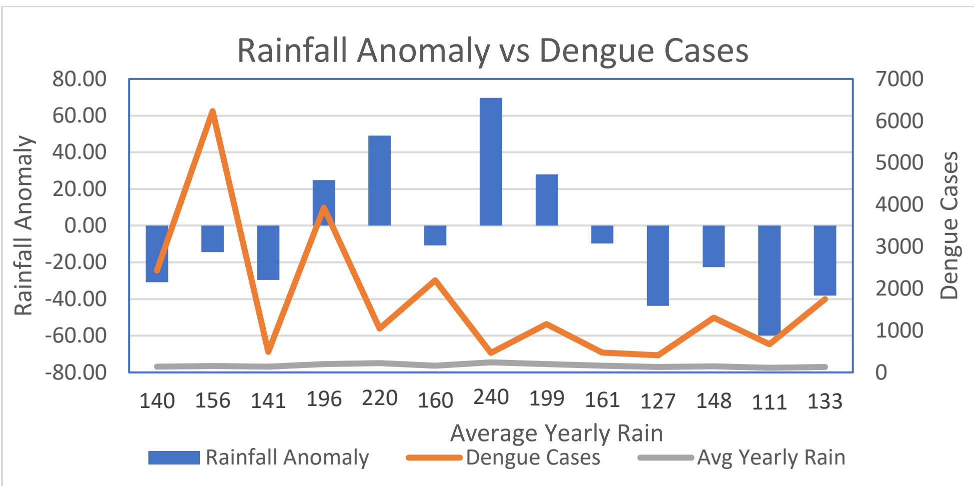

Figure 2.3: Rainfall anomaly vs Dengue cases for the 13-year study period (2001-2013).
(Source: Bangladesh Meteorological Department (BMD) and Directorate General of Health Services (DGHS), Bangladesh, 2001-2013.)

2.4 Discussion

Departing from conventional two-dimensional approaches, in this study we undertook a step-by-step approach to determine the relationships between climatic factors (i.e. temperature, humidity and rainfall) and *Stegomyia* indices, and subsequently between *Stegomyia* indices and dengue cases in the city of Dhaka, Bangladesh. Our study sought to develop a more complete understanding of the effects of climate on dengue cases by viewing the climate-vector-disease triad as a sequential, step-by-step process.

In designing our study, we drew from Githeko's (2012) study in Bangladesh. Githeko (2012) observed that most previously studies on dengue only considered climatic or biological effects in isolation and emphasized that since climatic factors directly influence the breeding and prevalence of dengue vector mosquitos (e.g. *Ae. aegypti*), it was vital to study the effect of climate on the biological domain in order to fully understand the dynamics of dengue outbreaks. Following this recommendation, we attempted to determine the relationships within the climate-vector-dengue triad, with the aim of meeting the four objectives stated below.

Our first objective was to determine the relationships between climatic factors and dengue vector abundance. The results of our study provide evidence that overall dengue vector abundance is significantly influenced by climatic factors, though the significance of this relationship varies for each index and pair of factors. We found that mean rainfall (MR) and lag mean rainfall (LMR) at one month were positively and significantly related to Container Index (CI) i.e. an overwhelming majority (i.e. 79%) of the variability in CI could be explained by MR and LMR. Similarly, mean relative humidity (MH) and mean rainfall (MR) were found to be significantly related to the Breteau Index (BI), although MH was negatively associated with BI.

The regression model reveals that climatic factors account for about 72% of the variability in BI, which aligns with conclusions drawn by several other studies conducted in tropical regions (Nakhapakorn & Tripathi, 2005; Tseng et al., 2009; Barrera, Amador & MacKay, 2011; Pham et al., 2011; Naish et al., 2014; Cheng et al., 2016). However, while previous studies made the link between rainfall, water levels in indoor and outdoor containers, and the consequent increase in vector breeding and density and dengue prevalence, our findings and that of several other studies revealed that the dynamics of dengue spread are not so straightforward, and that the effects of temperature and relative humidity were also significant and complex.

For example, Barrera, Amador and MacKay's (2011) study in San Juan, Puerto Rico found rainfall to be a significant predictor of mosquito abundance and dengue incidence but determined that during dry periods the abundance of water containers continued to provide mosquitos with suitable breeding grounds. Thus, both climatic and anthropogenic factors contributed to the abundance of *Ae. aegypti*.

Several comparable studies in Vietnam, Ecuador, Taiwan, Thailand, and China, which investigated the relationships between *Stegomyia* indices and *Aedes* abundance, provide useful insights into the impact of weather conditions on mosquito ecology. Pham et al.'s (2011) study in the central high province of Vietnam confirmed a positive association between HI, BI, and CI and elevated temperatures, high humidity and rainfall, and a negative association with hours of sunlight (Pham et al., 2011). Stewart-Ibarra et al. (2013), in an empirical investigation of *Ae. aegypti* in Ecuador, confirmed that mosquito oviposition (egg-laying) was significantly driven by rainfall and minimum temperature. Tseng et al. (2009) in their study of Taiwan found that temperature, lagged rainfall, and lagged density levels had positive and significant effects on the density of the mosquito population. They further observed that the mosquito population density levels increased with the rise of temperature increase by 1°C and enhanced rainfall level by 1 mm; humidity was not major factor in dengue cases except in the eastern regions of the country.

Both Nakhapakorn and Tripathi (2005) and Naish et al. (2014) found that in Thailand, humidity is a crucial variable in the spread of dengue as high humidity – along with high temperatures and the presence of stagnant water - create ideal breeding conditions for *Ae. aegypti*.

Cheng et al. (2016) examined the climate-vector abundance relationship in terms of the risk of dengue outbreak in Guangzhou, China, and found that that high precipitation during the monsoon increases vector abundance, but early and more frequent intervention and less vertical transmission can reduce the risk of dengue outbreak in successive time periods. They suggested that because the risk of dengue outbreak is profoundly influenced by human and institutional interventions (i.e. control measures), climatic factors, and vertical transmission, it is imperative to be able to estimate these parameters in order to predict the risk of infection.

The second objective of our study was to determine the relationship between DF/DHF cases and vector abundance, as established by the parameters of the *Stegomyia* indices. Vector abundance, the rate of mosquito bites, and the magnitude of DENV infection can be understood through examination of the relationship between *Stegomyia* indices and reported dengue cases in hospitals and clinics. This is a common epidemiological research framework that has been widely used in tropical areas (Tseng et al., 2009; Barrera, Amador & MacKay, 2011; Stewart-Ibarra et al., 2013; Bowman, Runge-Ranzinger & McCall, 2014). Our empirical investigation in the city of Dhaka, Bangladesh has revealed that dengue cases in the City are significantly related to *Stegomyia* indices. We also found that CI is the most significant index, associated with dengue incidence, accounting for 49% of the variability in dengue cases. In the context of Dhaka, these findings underscore the pivotal role of rainfall and stagnant water, relative to temperature and humidity, in affecting vector abundance and dengue incidence, as CI reflects the percentage of water-holding containers infected with larvae and/or pupae. These results are supported by Stewart-Ibarra et al.'s (2013) study in Ecuador, which found that mosquito oviposition was significantly driven by rainfall and minimum temperature, and that areas with large numbers of water storage containers played a major role for pupal development - the single most significant predictor of dengue outbreaks.

Previous studies on vector-dengue incidence have put forward two main philosophies regarding disease prevention and management. One school of thought argues that since dengue incidence is mainly driven by higher vector breeding associated with high temperature and rainfall, the policy focus should be on vector control. Pham et al. (2011), for example, observed that in Vietnam the incidence of dengue fever is significantly and positively associated with *Stegomyia* indices. They argued that because higher vector abundance leads to higher rates of dengue infection, it is of utmost importance to control mosquitos during periods of high temperature and rainfall to reduce the risk of any outbreak. Similarly, the Barrera, Amador & MacKay's (2011) study in San Juan, Puerto Rico, asserted that although both weather and anthropogenic activities are responsible for the abundance of *Ae. aegypti,* it is oviposition which is significantly correlated with dengue incidence, and which requires immediate attention.

Another school of thought asserts that *Stegomyia* indices, especially larval indices, are not sufficient to explain the vector-disease incidence relationship. Bowman et al. (2014) reviewed the evidence systematically and concluded that the association between *Stegomyia* indices and dengue transmission was insufficient to predict an outbreak and called for the use of standardized study design and routine adult mosquito sampling in order to better understand vector ecology. In their study of the city of Kaohsiung, Taiwan, Chang et al. (2015) came to a similar conclusion and argued that there may be different outbreak thresholds for different regions, local ecologies and herd immunity levels. They also observed that dengue incidences occurred within 1-2 months' lag after the peak of adult mosquito population. As our findings revealed the relationship between vector abundance and dengue cases to account for only 49% of the variability in dengue incidence in the city of Dhaka, this study leaves room for other factors such as differences in adult mosquito numbers, infection rate of the adult mosquito, extrinsic incubation period, herd immunity, and population density, to be integrated into future epidemiological model for dengue.

The third objective of our study was to determine the relationship between climatic factors and DF/DHF cases. As the majority of studies on the climatic dimensions of dengue emergence ignored the entomological dimension, we pursued a longitudinal study of the city of Dhaka in order to more fully understand the disease propagation complex. The results of our generalized linear model reveal that, when the relationships between dengue cases and climatic factors during monsoon months over a twelve-year period are tested, mean temperature and mean rainfall are found to be significant at a 10% level and mean relative humidity and lag mean rainfall (i.e. rainfall at one-month lag) at a 5% level. The model explains 93% of the variability in dengue cases while considering climatic factors. As noted earlier, Karim et al.'s (2012) study in Dhaka confirmed that rainfall, maximum temperature and relative humidity can explain 61% of the variability in reported dengue cases at a two-month lag. The study also found that the monsoon season, with a peak in August, was highly predictive of most reported dengue cases in Dhaka.

It is evident from both Karim et al.'s and our findings that of all climatic factors, rainfall has the most influence on dengue incidence in Dhaka. Arcari et al. (2007) in Indonesia and Johansson et al. (2009b) in Puerto Rico also observed a strong positive relationship between rainfall and dengue incidence. Nonetheless, several recent investigations in Asia and Latin America concluded that the relationship between precipitation and dengue incidence may not be linear, as excess rainfall can negatively impact vector breeding (Gordon, 1988; Poveda et al. 1999; Thammapalo et al., 2005; Halide & Ridd, 2008; Jury, 2008; Wu et al., 2009). Similar effects were predicted in Dhaka, where continuous heavy rainfall has the potential to flood *Aedes* breeding sites and wash larvae out into fast-flowing rivers, killing them. A significant negative observed association between rainfall and dengue cases, which is reflected in the confidence interval for the co-efficient of rainfall, confirms - albeit indirectly - the negative effects of rainfall on vector abundance and dengue cases. The confidence interval for the co-efficients of temperature and relative humidity were positively and significantly associated with dengue cases in Dhaka.

Both short (0-5 weeks) and long lag times between climatic factors and increasing dengue incidence have previously been confirmed by studies in Bangladesh (Hashizume et al., 2012; Karim et al., 2012) and in Sri Lanka (Ehelepola et al., 2015). In Dhaka, Hashizume at al. (2012) explain, dengue incidence rarely rises immediately following heavy rainfall. The lag time between rainfall and emerging dengue cases, however, can vary due to several factors. The typical short (0-5 week) lag results directly from the life cycle of *Aedes* mosquitos. Heavy rainfall may leave stagnant pools of water on the ground or in objects such as discarded tires, which are ideal habitats for mosquito breeding.

Deviations from this standard lag time, however, can emerge from variation in geographic location, elevation, humidity, temperature, infection rate of mosquitoes and other environmental factors. For instance, while in Bangladesh we mostly observed a short lag time (< 5 weeks), in Sri Lanka, Ehelepola et al. (2015) observed an average 5-7-week lag, positively correlated with rainfall, temperature, humidity and hours of sunshine (but negatively correlated with wind). In Singapore, Hii et al. (2009) observed a 5-16-week lag for temperature and a 5-20 week lag for precipitation. Based on an investigation of dengue incidence in Hanoi, Vietnam, Do et al. (2014) distinguished between lag times caused by temperature and rainfall (8-10 weeks lag) and by relative humidity (18 weeks).

The final objective of our study was to determine the pattern of seasonality and climate anomaly and their effects on DF/DHF cases. To this end, we undertook a longitudinal study covering a 13-year period (2001-2013) and assessing temperature, rainfall and humidity data. Considering significant relationships of dengue incidence with climatic factors, longitudinal study in terms of seasonality in dengue cases and their variation inter-annually has only recently received wider attention (Tseng et al., 2009; Hii et al., 2012; Bannister-Tyrrell et al. 2013). In our study dengue cases exhibited a yearly cyclical pattern, with higher incidence beginning in the monsoon season (June-October) and reaching a peak in August and reaching a minimum in the pre-monsoon period of January-April in alternate years.

The findings of our longitudinal study revealed that in Dhaka, temperature has a profound effect on vector breeding and DENV spread. The plot of calculated temperature anomalies vs. dengue cases for 2001-2013 exhibits that when the average yearly temperature was 25.9°C (-0.1°C anomaly) or 25.8 °C (-0.2°C anomaly), dengue cases were higher than the average. Beebe et al.'s (2009) study in Australia offers an explanation for such effects: higher temperatures in summer months force residents to store water in open containers in their homes, providing ideal breeding sites for *Aedes* mosquitos. Further, in Dhaka, when annual average temperatures reached 26.1°C-26.6°C, dengue incidence was lower than the dengue incidence of the average temperature of a 29-year period at 26°C. Overall, our study revealed that dengue incidence rises with annual average temperature up to 26°C, after which it begins to drop off.

There are some limitations to this study. First, we were constrained by missing data as continuous time series data on dengue cases for the study period were not available in the government depository on dengue surveillance. Second, the entomological surveys that collected data on *Aedes* larvae from households in Dhaka did not cover the same areas throughout the study period. The researchers of the present study therefore relied on adjusted data for specific areas which were covered repeatedly by all survey periods over a 5-year period. Third, the entomological data did not cover adult *Aedes* mosquitoes, so, we could not study estimate the extrinsic incubation period and the infection rate. Fourth, due to the unavailability of time-series data on other variables, we were unable to incorporate other contributing factors such as household water-use, vector control measures, and land-use changes into our models. Fifth, due to resource, time, and data constraints, we could not closely investigate the relationship between climatic factors and dengue vector breeding. Further empirical research on longitudinal trends in seasonality and its effects upon dengue vector breeding and DENV transmission will assist improved understanding of dengue disease transformation.

2.5 Conclusion

Global warming and consequent climate change in recent decades are now widely accepted among scientists, the policy community and society at large (Oreskes, 2004; DiMento and Doughman, 2014; Linden et al., 2015). The implications of these environmental changes, particularly on the spread of emerging infectious diseases (EIDs) such as dengue, are potentially profound and far-reaching. Recognizing that only nominal attempts have thus far been made to empirically examine the dynamic causal associations within the climate-vector-disease relationships, the present study applied an innovative step-by-step approach to determine the causal relationships between climatic factors (temperature, humidity and rainfall), dengue vector abundance, and dengue cases/incidence in the city of Dhaka, Bangladesh. Our results are similar to those of other studies, confirming that there is significant correlation between climatic factors and vector abundance (Nakhapakorn & Tripathi, 2005; Tseng et al., 2009; Barrera, Amador &

MacKay, 2011; Pham et al., 2011; Cheng et al., 2016; Naish et al., 2014), and between vector abundance and dengue incidence (Tseng et al., 2009; Githeko, 2012; Stewart-Ibarra et al., 2013; Bowman et al., 2014).

As no vaccines are universally available or specific treatments are available, anti-dengue efforts must focus on prevention – particularly via controlling vector populations. From a public health perspective, the implementation of early warning systems for dengue outbreaks through by developing effective forecasting methods is paramount. The integration of climate and entomological data into the climate-vector-disease relationships to produce such a predictive model has not yet been fully realized (Hashizume et al., 2012). No previous study in Bangladesh studied the dynamics of climate-vector-disease relationships, rather focused on a linear relationship between the climatic factors and/or seasonality and dengue cases. This study included all the aspects of the above-mentioned triad and found the relationship amongst climatic factors, vector and dengue in a step by step process revealing their significance in dengue vector abundance and dengue disease occurrence. This research also studied seasonality trend for dengue occurrence along with the climate anomaly revealing optimal temperature and rainfall amounts for dengue outbreak. Thus, the present study offers a strong foundation for future work on dengue forecasting and prevention, which may prove vital as the climate continues to change and the range and seasonal dynamics of dengue and other diseases change with it. It is critical, however, to emphasize that to succeed, all such efforts require the collection of accurate time-series data on climatic factors and dengue cases by the appropriate national authority in every country of the world, including Bangladesh.

List of Abbreviations

ACF: Autocorrelation Plots; BI: Breteau Index; BMD: Bangladesh Meteorological Department; CAS: Dengue Cases; CI: Container Index; DCC: Dhaka City Corporation; DENV: Dengue Virus; DF: Dengue Fever; DGPHS: Directorate General of Public Health and Services; DHF: Dengue Hemorrhagic Fever; EID: Emerging Infectious Diseases; GAM: Generalized Additive Model; HI: House Index; IPCC: Intergovernmental Panel on Climate Change; LMR: Lag Mean Rainfall; MH: Mean Relative Humidity; MR: Mean Rainfall; MT: Mean Temperature; PACF: Partial Autocorrelation Plots.

Declarations

Ethics approval and consent to participate

This research was approved by the Bangladesh Medical Research Council (Bangladesh) and the Joint Faculty Research Ethics Board of the University of Manitoba (Canada). Administrative permission was granted by the Government of Bangladesh to access and use the meteorological data from the Bangladesh Meteorological Department, and entomological and dengue case data from the Directorate of Public Health and Services.

Consent for publication

N/A

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Concept and design: SI, CEH. Data collection and pre-processing: SI, CEH, SH. Data analysis and interpretation: SI, SH, CEH, JH. Drafting of the manuscript: SI, CEH, SH, JH. All authors read and approved the final manuscript.

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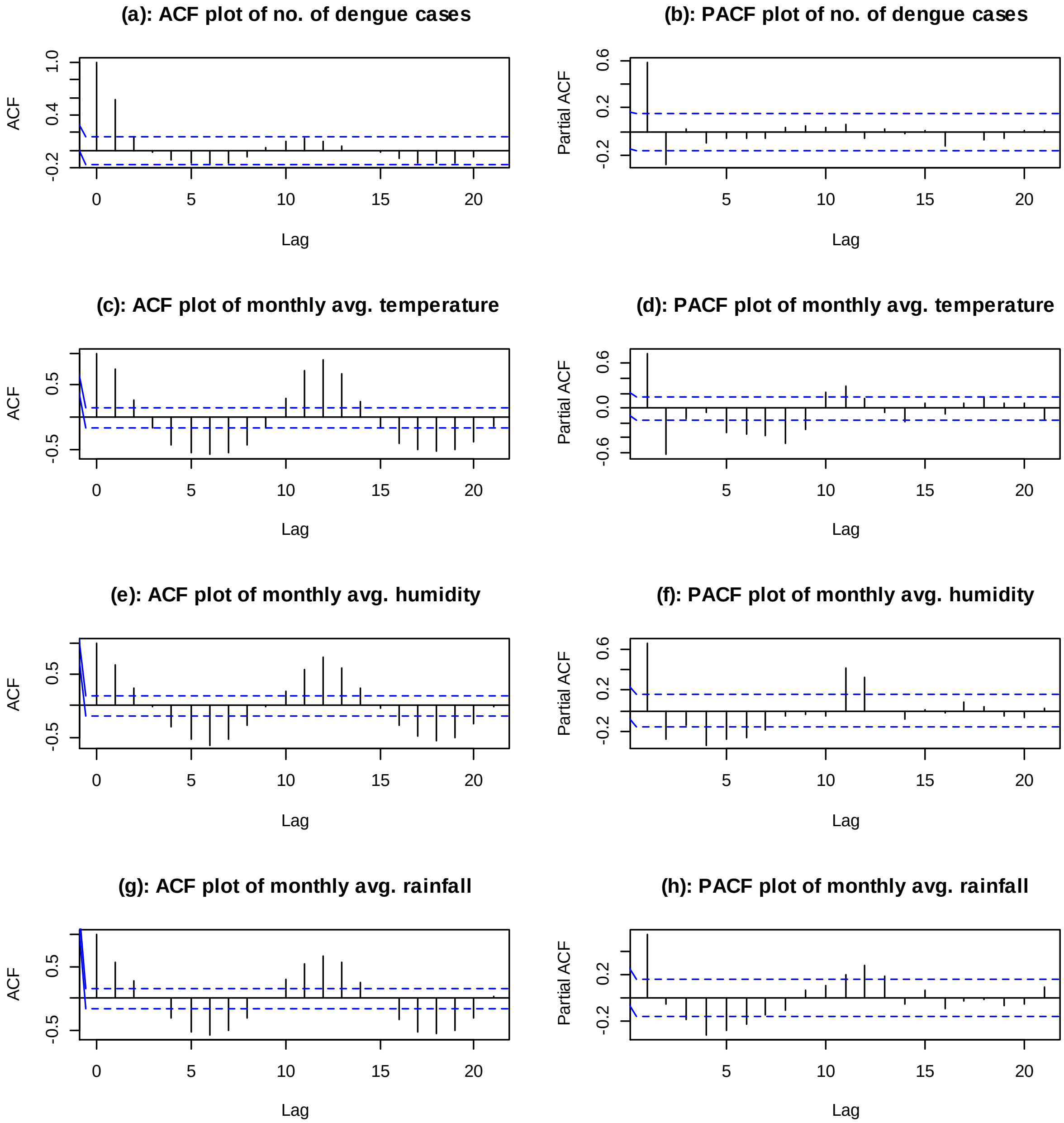
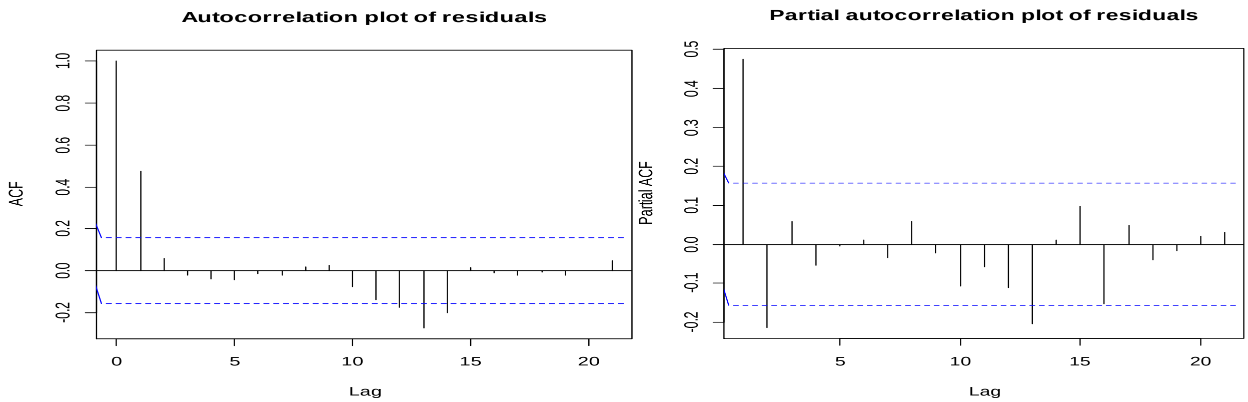


Supplementary Figure 2.1: Autocorrelation and partial autocorrelation plots for the number of dengue cases vs. climate factors for the 13-year study period (2001-2013): (a and b) monthly number of dengue cases: (c and d) monthly average temperature; (e and f) monthly average humidity; and (g and h) monthly average rainfall.



Supplementary Figure 2.2: Autocorrelation and partial autocorrelation plot of residuals for the 13-year study period (2001-2013).

Chapter 3 – Role of container type, behavioural, and ecological factors in *Aedes* pupal production in Dhaka, Bangladesh: An application of zero-inflated negative binomial model[2]

Abstract

The container-inhabiting *Aedes* mosquitoes are the major vectors transmitting dengue and several other arboviral diseases such as chikungunya and zika across the tropical world. Surveillance for immature *Aedes*, particularly pupae, is an effective tool for measuring dengue outbreak risk. While in Bangladesh, the greatest burden of dengue fever and dengue hemorrhagic fever cases has periodically been occurring since the first major outbreak in 2000, very limited research has yet been pursued to understand the dynamics of *Aedes* pupal production in this country. In this backdrop, this study was carried out to i) identify containers at household premises contributing to dengue vector productivity; ii) measure the extent of pupae productivity of household containers; and, iii) determine the effects of household ecological factors upon productivity of pupae in the city of Dhaka, Bangladesh. During the monsoon months of 2013, a total of 1,037 containers (674 wet and 363 dry) in 727 household premises in 12 wards of the city of Dhaka were inspected to measure container productivity and collect household ecological, and human behavioural data. The results reveal that the majority of immature mosquitoes (73.52% larvae and 84.91% pupae) developed in containers located outdoor that are used mostly for household chores. Plastic containers (57.55% of all immature mosquito-positive containers) used for household chores produce most of the immature mosquitos. The results of the zero-inflated negative binomial

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(ZINB) model reveal that pupae production significantly varies by container type (p-value = 0.0136) for the count regression group. However, when considering container size along with container type, container size is found significant for pupae production (p-value = 0.0041), showing that container size is confounded with the container type and the pupae production. Containers greater than 50 litres (L) are likely to produce 4.9 times more pupae than containers with <1L. Two household ecological factors are found to be significant (shade: p-value = 0.005 in the count regression group and type of water: p-value = 0.001 in the excess zero group) for pupae production. We found that containers with partial shade produce 4.6 times more pupae than without any shade, whereas in the excess zero group the expected number of observed zero pupae count is 86.5% lower in containers filled with rain water than those with tap water, tube-well water, ring well water and water from other sources. The plastic-made containers (i.e., refrigerator trays, drums, buckets) and flower tubs/trays are the most abundant immature mosquito-positive containers. These findings would help the concerned authorities to formulate programs for changing human behaviour targeting the most productive containers for *Aedes* habitat management and vector control in the city of Dhaka, Bangladesh.

Key words: Dengue, Pupae, Containers, Productivity, Behavioural Factors, Ecological Factors

3.1 Introduction

Dengue Fever (DF) is considered one of the most widespread vector-borne diseases affecting 128 countries (Brady et al., 2012), mostly in the tropical regions of the world. Every year 50 to 100 million dengue virus (DENV) infections occur worldwide, primarily affecting the children (CDC, 2016). Among the infected people, approximately 500,000 cases develop into dengue hemorrhagic fever (DHF) and 22,000 die annually (CDC, 2016). A recent estimate of population size at risk of DENV infection places it at an upper bound of 3.97 billion people (Brady et al., 2012).

Bangladesh is located in the tropical region of South Asia and has been subjected to DENV spread since 1964 (Russell et al., 1966). The region's relatively high temperature and relative humidity, especially during the summer months, provide ideal conditions for *Aedes aegypti* and *Aedes albopictus* mosquito development. The first identified epidemic of DF and DHF in Bangladesh occurred during the monsoon season of 2000 (Yunus, 2000; Hossain et al., 2003). This dengue epidemic in the cities of Dhaka, Chittagong and Khulna caused 5,551 reported cases with 93 fatalities (Yunus et al., 2001; Banu et al., 2012; Sharmin et al., 2015a; Paul et al., 2018). The magnitude of dengue incidence has fluctuated over the last two decades (Banu et al., 2012; Sharmin et al., 2015b; Dhar-Chowdhury et al., 2017). Nonetheless, the predominance of dengue incidence in the capital city of Dhaka, relative to other cities and towns of the country, has been consistent (Banu et al., 2012; Sharmin et al., 2015b).

The transmission of DENVs is complex though it is well-established in the literature that they are transmitted to humans through the bite of container-inhabiting mosquitoes *Ae. aegypti* and *Ae. albopictus* (Banu et al., 2012; Dhar-Chowdhury et al., 2016). Conventional methods to determine the risk of dengue outbreaks have focused on examining the breeding grounds for the dengue vectors, especially the larval production sites based on larval indices (Li et al. 2014; Ferdousi et al., 2015; Morales-Pérez et al., 2017). In recent years, however, surveillance for the pupal stage has been used to measure dengue outbreak risk (Stewart-Ibarra et al., 2013; Jiménez-Alejo et al., 2017; Ngugi et al., 2017;) as the abundance of *Aedes* pupae serves as an appropriate proxy for the number of female mosquitoes (Focks et al., 2000; Focks and Alexander, 2006; Barrera, Amador & Clark, 2006a; Wijayanti et al., 2016).

Recent studies also emphasized the significance of measuring container productivity while quantifying pupal counts (Barrera, Amador & Clark, 2006b; Arunachalam et al., 2010; Barrera, Amador & MacKay, 2011; Dhar-Chowdhury et al., 2016). While the containers storing water within households have been found to be the most productive sites (Barrera, Amador & MacKay, 2011; Dhar-Chowdhury et al., 2016), trees, discarded tires, and plastic containers such as drums or buckets, were the "most productive containers" for pupae production outside household structures (Barrera, Amador & Clark, 2006a; Banerjee, Aditya & Saha, 2013; Dhar-Chowdhury et al., 2016; Mboera et al., 2016; Ngugi et al., 2017). In addition, the pupal productivity is also affected by the ecology of the container sites – whether containers are sunlit or located in shaded areas (Vezzani & Albicóocco, 2009). The "most productive containers" were identified by determining the relative contribution of a particular type of container to the overall production of *Aedes* larvae and/or pupae; they are also known as "key" containers (WHO, 2011).

Different types of containers can serve as development sites for immature mosquitoes, but certain containers may produce greater numbers or be adequately abundant to be efficient sources of immature mosquitoes (Paul et al., 2018). These most productive containers usually drive the local abundance of mosquitoes and are potential targets of source reduction for vector suppression and dengue prevention. From both epidemiological and health policy perspectives, it is therefore crucial to acquire a clear and comprehensive understanding of the location and distribution of productive containers, the extent of their pupae productivity, and how they may be affected by household ecological factors. Notably, data and literature on *Aedes* abundance and its associated dynamics in Bangladesh are scanty (Ferdousi et al., 2015; Dhar-Chowdhury et al., 2016).

The results of the first survey (2011) were published in Dhar-Chowdhury et al. (2016), and a summary article containing 2011, 2012 and 2013 survey data were published in Paul et al. (2018). The analyses in this paper are based specifically on an original and independent data set for the 2013 monsoon period. In this article, we analysed in-depth the 2013 entomological survey data, aspiring to determine more practical productivity measures based on *Ae. aegypti* pupae to help formulate effective dengue outbreak warning. To this end, the objectives of this study are to: 1) identify which type of household container(s) support larvae and pupae development; 2) measure the extent of pupae productivity in the household container(s); and 3) determine the effects of human behavioural and household ecological factors upon productivity of pupae in the city of Dhaka, Bangladesh.

3.2 Materials and Methods

3.2.1 Study Area

Dhaka, the capital city of Bangladesh, is chosen for the study, considering that it is the most significant urban centre in the country in terms of population density, urban development and health issues. Most importantly, Dhaka had been the focal point of dengue epidemics since 2000. The city of Dhaka has an area of 126.34 sq. km. (census 2011) (BBS, 2016), and with a population of 18.2 million, is ranked 11th megacity in the world (UN, 2016). The Dhaka City Corporation (DCC) had 90 administrative “wards” (a local administrative unit of the city corporation. Thus, typically a city corporation consists of a number of wards in Bangladesh) during the study period.

3.2.2 Study Design

The present study is based on entomological data collected by the International Development Research Centre (IDRC, Ottawa, Canada)-sponsored Dengue Project in Bangladesh during the monsoon months (August and early September) of 2013. The household (HH) premises were considered as the Primary Sampling Units, and the HH entomological survey was conducted in 12 randomly selected wards of the city of Dhaka. A random sample of 100 HHs was targeted from each ward using a spatial randomization procedure by drawing grid cells on a map of each ward and selecting HHs with a random number table, aggregating to a total 1,200 HHs for the survey. Following reception of consents from the household heads, a total of 727 household premises were inspected by 36 trained entomologists and 24 student research assistants. The response rate of the 2013 entomological survey was 60.58% (n = 727 HHs of 1,200 HHs targeted). In order to avoid or minimize bias, the same entomologists and field research assistants surveyed all 12 wards. Recognizing that the incidence of dengue peaks in the monsoon months (June – October) in Dhaka, the entomological (to detect larvae and pupae) and associated socioeconomic surveys (to collect demographic, socioeconomic and household ecological data) were carried out in August and September months of 2013.

3.2.3 Entomological Collections

All containers inside 727 HHs as well as within a 50-meter radius of the HH premises were inspected for immature mosquitoes by trained entomologists. Containers storing water for more than 3 days, as identified by the household head/respondent, were regarded "wet containers" (Jeffery et al., 2012). Water within any outdoor containers, without any nearby water source, during the monsoon season was regarded as "rainwater". All wet containers (N=674) were inspected for *Aedes* larvae and pupae. Among the wet containers those found infested with *Aedes* larvae and/or pupae were considered "positive containers". The contents of wet containers were inspected on site by emptying them onto white enamel pans. For larger containers, larvae or pupae were collected following a dipping sampling procedure and the total number of each immature stage per container was estimated by the field entomologists. Large containers were visually inspected and sampled by five sequential dips to determine the presence or abundance of immature mosquitoes. In cases where containers were infested with fewer than 10 pupae or larvae, all were transferred to a 10-mL Falcon tube. Only a subset of larvae or pupae was collected when large numbers were present. Total number of larvae and pupae present in large containers was estimated by multiplying the number of immatures found by sequential dipping with the estimated volume of water in the infested containers.

Tubes containing larvae or pupae were then transported to the laboratory at North South University (Dhaka, Bangladesh) where larvae were killed by submerging them in formaldehyde. Species determination for larvae was carried out using dissecting microscopes and the taxonomic keys of Consoli and de-Oliveira (1994). The collected pupae were reared to the adult stage in the laboratory, before species determination. Species determination was only performed on a subset of the immature mosquitoes collected during the survey, with a random sub-sampling procedure. The subset of data is representative of the species composition across all households.

3.2.4 Classification of Containers used as Larval and Pupal Development Sites

The containers inspected were all located in the urban built up environment of the city of Dhaka. All wet containers were classified into six distinct categories based on their use in daily life: household chores, ornamental containers, household amenities, discarded materials, construction materials, and household structures (Table 3.1). We chose to categorize based on container usage by household members as such taxonomical divisions focus on functional aspects of the containers in highly urban built-environment. Contextually, they are also easier to relate to human activities and to actions for interventions. A strong basis for such function-based categorization of containers was provided by the work of Barrera et al. (2006a; 2006b; 2011) and has been used widely. We modified their categorization to adapt to the contexts of Bangladesh.

Table 3.1: Classification of containers inspected in households.

Type	Use	Description
1	Household chores	plastic mugs, plastic bottles, earthen jars (*motka*), clay pitchers, pots (clay, ceramic, aluminium), metal pans, buckets (metal, plastic), drums (metal or plastic, sealable), water tanks
2	Ornamental	cement pots, clay and glass money plant tubs, flower tubs and trays (plastic, clay), and musical instruments (wooden/gourd shell)
3	Amenities	plant axils, tree holes, animal bowls (clay, plastic), flag stand holes (metal), holes for water meters (earthen), refrigerator trays (plastic) and refrigerator related containers
4	Discarded materials	plastic bags, metal cans, bottles (glass, plastic), shells (coconut, gourd), disposable plastic containers, broken toilet parts (ceramic, plastic), and vehicle parts (battery shells, tires, other)
5	Construction	bamboo stumps, cement mixers (metal), and large plastic sheets and tarps
6	Structure	flooded floors (cement)

Note: All containers were also categorized in 3 container size groups based on water capacity volume: WCV1 = 0 - <1 L, WCV2 = 1 - <50 L and WCV 3 = ≥50+ L.

3.2.5 Data and Statistical Analyses

Descriptive statistics were used to summarize the number of *Aedes* larvae and pupae collected from the containers inspected at different locations in the household premises. A zero-inflated negative binomial (ZINB) regression model (Allison, 2012) was fitted to determine the characteristics of the association between the container type, container size and pupal productivity (i.e., pupae count) considering that application of the Poisson/negative binomial regression model would not account for over dispersion and zero-inflation in the dataset. The ZINB model assumes that our dataset contains two groups: a) count regression group, which deals with Poisson or negative binomial (NB) regression model and where our response (pupae count in wet containers) may or may not have count value of 0; b) excess zero group, which includes only the count of 0. Containers where the count is greater than 0 has been placed in the count regression group. However, container with observed count of 0 could either be in the "count regression" group or in the "excess zero" group, as determined by the model described below.

The two parts of the zero-inflated model are: a) the count regression model; and b) a binary regression model. The count regression model fits the count data; and the binary regression model is usually a logit model which fits the binary data deciding which of the two groups processes zero count of pupae. For each observation with probability p, the only possible response of the "excess zero group" is 0 count of pupae, and with probability of 1-p, the response of the count regression group is governed by a negative binomial with mean count of pupae λ. If the response Y follows a ZINB distribution, then

$$P(Y=y)=\begin{cases} p+(1-p)\left(\frac{k}{\lambda+k}\right)^{k}, & \text{if } y=0 \\ (1-p)\frac{\Gamma(Y+k)}{\Gamma(k)\Gamma(Y+1)}\left(\frac{k}{\lambda+k}\right)^{k}\left(1-\frac{k}{\lambda+k}\right)^{Y}, & \text{if } y>0 \end{cases}$$

where $0 \leq p \leq 1$, k is the overdisperson parameter and Γ is the gamma function. The parameters p and λ can be modeled as functions of covariates (container types, container size, and ecological factors). We have used the following models to analyze the data:

$$\text{Log } \lambda = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 \text{------------------------------} \quad (1a)$$

$$\text{Logit } (p) = \gamma_0 + \gamma_1 z_1 + \gamma_2 z_2 + \gamma_3 z_3 + \gamma_4 z_4 + \gamma_5 z_5 \text{ ------------------------------} \quad (1b)$$

where x_i and z_i are container type i+1 versus container type one where i = 1, 2, 3, 4, 5, and with β_i and γ_i are the corresponding regression and zero-inflated coefficients, respectively. In these models, β_0 and γ_0 are the intercepts and logit (p) = log (p/1-p).

The goodness of fit for regression models (1a and 1b) is determined by the log-likelihood, AIC (Akaike information criterion) and BIC (Bayesian information criterion). All analyses have been performed using SAS/STAT® software, version 9.4 (SAS Institute Inc., Cary, NC). Significance was set at p-value <0.05.

We have modelled the pupae productivity with the container types and the container size together using the following ZINB regression model.

$$\text{Log } \lambda = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 WCV21 + \beta_7 WCV31 \text{ ....} \quad (2a)$$

$$\text{Logit } (p) = \gamma_0 + \gamma_1 z_1 + \gamma_2 z_2 + \gamma_3 z_3 + \gamma_4 x_4 + \gamma_5 x_5 + \gamma_6 WCV21 + \gamma_7 WCV31 \ldots\ldots\ldots\ldots\ldots \quad (2b)$$

where WCV21 is the water capacity volume of container (1 to <50 L) versus water capacity volume of container WCV1 (0 to <1 litre (L)) and WCV31 is the water capacity volume of container (≥50 L) versus water capacity volume of container WCV1 (0 to <1 L).

After checking the ZINB model of pupae productivity by container types and container size, we have applied a ZINB model to examine the effects of ecological factors on pupae productivity at the household level. The human behavioural and ecological factors considered are: type/source of water used in the household (TOW: 1 if the source water was from rain drops and 0 if source of water was from tap, tube-well, and ring well), location of the containers used in household premises (INDOOR: if the location was indoor, then INDOOR = 1 and for outdoor, INDOOR = 0), stored/collected water was covered or not (CS-RAIN: if collected water was from rain drops, then CS-RAIN = 1 and if collected water was from other sources, then CS-RAIN = 0), containers located at shaded areas or not (SHADE: 0 for none, 1 for partial, and 2 for full), and vegetation affected the containers (VEG: 0 for none, 1 for vegetation exists nearby and 2 under vegetation cover).

We fitted the following ZINB models:

$$\text{Log } \lambda = \beta_0 + \beta_1 TOW + \beta_2 INDOOR + \beta_3 CS\text{-}RAIN + \beta_4 SHADE + \beta_5 VEG \text{-----------------} \quad (3a)$$

$$\text{Logit } (p) = \gamma_0 + \gamma_1 TOW + \gamma_2 INDOOR + \gamma_3 CS\text{-}RAIN + \gamma_4 SHADE + \gamma_5 VEG \text{---------------} \quad (3b)$$

where β_i and γ_i are the corresponding regression and zero-inflated coefficients, respectively. In these models, β_0 and γ_0 are the intercepts and logit (p) = log ($p/1-p$).

3.3 Results

3.3.1 Identification of Types of Containers Producing Aedes Larvae and Pupae

In our entomological inspection of 727 household premises, a total of 1,037 containers are identified of which 674 are wet containers holding a total of 10,823 immature *Aedes* mosquitoes

(9,703 larvae and 1,120 pupae). Species determination of 3,896 (36%) immature mosquitoes is carried out, of which 3,506 (90%) immatures are identified as *Ae. aegypti*, 312 (8%) are *Ae. albopictus*, and 78 (2%) are of other mosquito species including *Culex quinquefasciatus* and *Armigeres subalbatus.*

In the first step of our study, we have identified the patterns in the types of containers producing larvae and pupae during the monsoon season of 2013 in the city of Dhaka. The majority of immature mosquitoes (both larvae and pupae) are found in containers used for household chores (Type 1, n = 6,980, 64.49% of total immature mosquitoes), followed by ornamental containers (Type 2, n = 1,395, 12.89% of total immature mosquitoes), and various types of household amenities (Type 3, n = 999, 9.23% of immature mosquitoes). All other container types (Type 4-6) have harboured a total of 1,449 (13.39% of total immature mosquitoes) immature *Aedes* mosquitoes (Table 3.2). The overwhelming majority of immature mosquitoes are found in outdoor wet containers (n = 8,085, 74.70% of immature mosquitoes). The only type of container that is more productive indoor is Type 6 (structural materials). Containers dedicated to household chores (Type 1) are the most productive followed by ornamental containers (Type 2) regardless of their location (Table 3.2).

Table 3.2: Count and percentage distribution of larvae and pupae by container type and location within the household premises, Dhaka, Bangladesh, 2013.

	Container Type	Indoor Count	%	Outdoor Count	%	Overall count	%
Larvae							
	1	1876	28.91	4613	71.09	6489	66.88
	2	197	19.70	803	80.30	1000	10.31
	3	22	2.48	866	97.52	888	9.15
	4	222	27.78	577	72.22	799	8.23
	5	0	0.00	160	100.00	160	1.65
	6	252	68.66	115	31.34	367	3.78
	Total	2569	26.48	7134	73.52	9703*	100.00
Pupae							
	1	90	18.33	401	81.67	491	43.84
	2	51	12.91	344	87.09	395	35.27
	3	1	0.90	110	99.10	111	9.91
	4	19	21.84	68	78.16	87	7.77
	5	0	0.00	23	100.00	23	2.05
	6	8	61.54	5	38.46	13	1.16
	Total	169	15.09	951	84.91	1120*	100.00

Note: * refers to total count of Indoor + Outdoor

When the total number of the pupae from the survey is taken into account, 886 pupae, out of a total of 1,120, are found in container Types 1 and 2 (79.11% of total pupae count), followed by 111 (9.91% of total pupae count) in container Type 3, and the remaining 123 (10.98% of total pupae count) are in container Types 4, 5 and 6 (Table 3.2). This reveals that household chores-related and ornamental containers are most pupae producing wet containers, and most of these containers are located outside the house structure, containing 401 (81.67%) pupae and 344 (87.09%) pupae in household chores related containers and ornamental containers respectively (Table 3.2). This implies that there are uncovered containers (e.g. water tanks, pots, bottles, mugs, buckets, drums) outdoors which have had not been emptied frequently (remained undisturbed for 3 days or more) and thus allowed sufficient time for the growth of larvae into pupae. In terms of rank order by types of containers, no change has been noticed between larvae and pupae distribution.

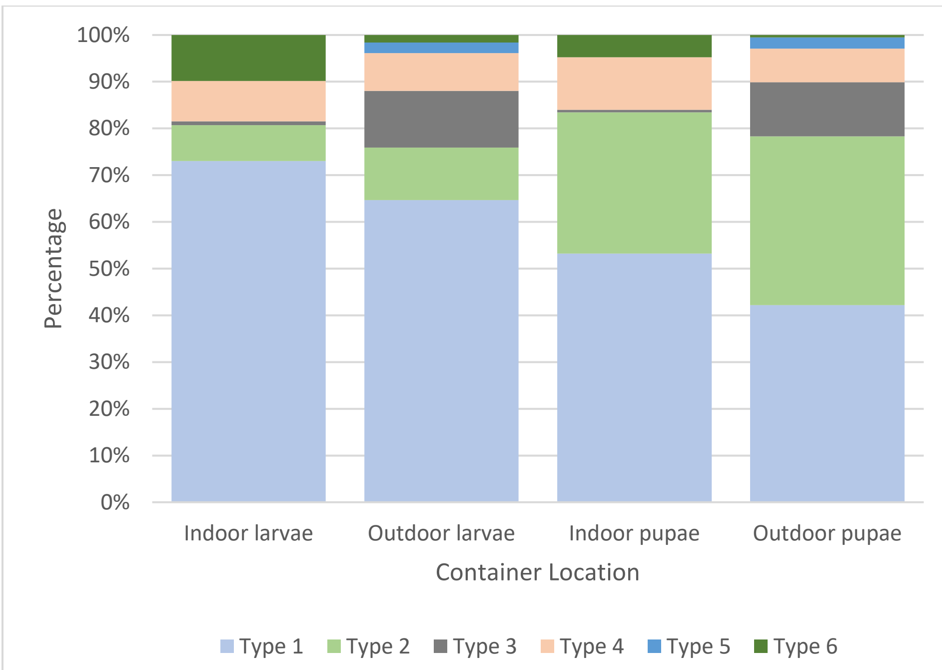

Figure 3.1: Distribution of larvae and pupae generated in each type of container comparing indoor and outdoor. Types 1-6, in different colours, are the six types of containers identified in the study. Source: IDRC's Entomological Survey, 2013.

While Type 1 containers support the development of most larvae and pupae (Figure 3.1), Type 2 containers harbour a greater proportion of pupae: only 10.31% of overall larvae counts are in Type 2 containers compared to 35.27% of pupae (Table 3.2). Among the indoor wet containers, majority of the larvae (73.02%) and pupae (53.25%) have been developed in Type 1 containers.

However, Type 2 indoor containers are more supportive to pupae production (30.18%) relative to larvae production (7.67%). Similar pattern has also been cited among outdoor containers, as Type 2 outdoor containers had 36.17% of pupae and only 11.26% of larvae. This trend indicates that mortality is lower in Type 2 (i.e. ornamental containers) and more mosquitoes reach pupation from the larval stage in those containers. Such development in ornamental containers is possible because ornamental containers are likely to get emptied less frequently than household chore containers.

The details of the distribution of immature mosquito-positive containers, presented in Supplementary Table 3.1, showing the numbers of total containers and positive containers which can provide vital clues about importance of specific containers in pupal productivity. A comprehensive account of all containers reveals that refrigerator tray (plastic), plastic drum, flower tub and tray, and plastic buckets (14.73%, 12.95%, 12.50% and 9.82% of all the immature mosquito-positive containers respectively) are most abundant immature-mosquito positive containers; these account for 50% of total immature-mosquito positive containers. Various types of plastic-made containers, representing all sizes, account for 45.54% of all immature mosquito-positive containers (Supplementary Table 3.1). In terms of most abundant pupae-positive containers, refrigerator tray (plastic), flower tubs and trays, tires, plastic drums, and plastic buckets (16.67%, 12.82%, 8.97%, 7.69% and 5.13% of all the pupae-positive containers respectively) account for 51.28% of total pupae-positive containers (Supplementary Table 3.2).

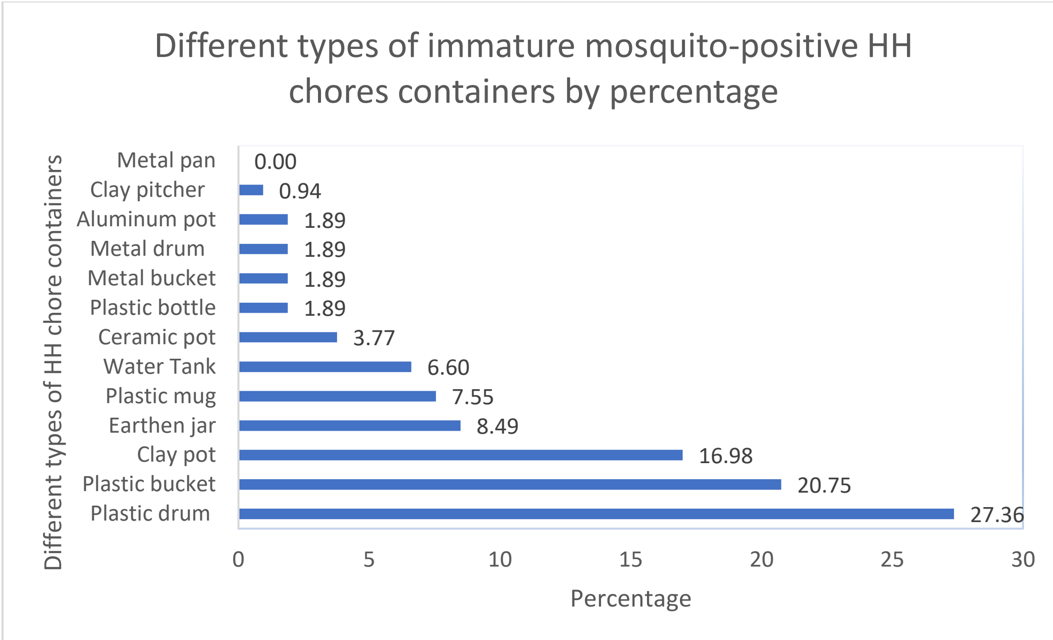

Figure 3.2: Proportion of different types of immature mosquito-positive household chore containers (Type 1) infested with immature mosquitoes.
(Source: IDRC's Entomological Survey, 2013.)

Among the Type 1 containers (used for household chores), plastic containers are most abundant immature mosquito-positive containers (57.55% of all Type 1 containers); of which plastic drums (27.36%) are found to be the "most productive containers" for immature mosquito (larvae and pupae) production, followed by plastic bucket (20.75%), clay pot (16.98%), earthen jar (8.49%), plastic mug (7.55%), water tank (6.60%), ceramic pot (3.77%) and plastic bottle (1.89%) of different sizes (Figure 3.2).

All containers are also categorized in 3 container size groups based on water capacity volume: WCV1 = <1 L, WCV2 = 1 to <50 L and WCV 3 = ≥50 L (see supplementary Table 3.3 for distribution). According to the size distribution of containers, when all types of containers are taken into account, the most immature-mosquito positive containers (117, 34.31% percentage of immature-mosquito positive containers) and most pupae-positive containers (40, 11.73% of pupae-positive containers) are medium sized containers with volumes 1 to <50 L (see supplementary Table 3.3). However, the proportions of the infestation are not too different from the other two categories.

3.3.2 Pupae Productivity vs Container Types: A regression analysis using ZINB model

The relationships between pupae production and container types are examined. Our response variable 'pupae count' in the containers is assessed, and we have found that 592 (87.83% of the total response count 674) are zero count in the response. The means (mean = 1.09, variance = 19.08) confirmed that the response variable 'pupae count' has been zero-inflated and over dispersed. In addition, over dispersion and zero-inflation tests are performed. For over dispersion, the null hypothesis is 'no over dispersion', and based on Chi-square test the null hypothesis is rejected ($p < 0.001$). For zero-inflation test, the null hypothesis is 'no zero inflation'. Based on the Vuong's statistic value (Vuong, 1989), the ZINB regression model is preferred ($p = 0.0001$) over the negative binomial model (Long, 1997). Models for "pupae by container types" using four regression methods namely, Poisson, negative binomial (NB), zero-inflated Poisson (ZIP) and ZINB have been fitted (Xu, Zhu, and Han, 2017). The goodness of fit results from the fitted regression models have revealed that the ZINB model has had the largest log likelihood and the smallest AIC and BIC values (Table 3.3).

Table 3.3: Goodness of fit for four types of regression models.

Models	log-likelihood	AIC	BIC
Poisson	-3450.71	6913.43	6940.47
NB	-506.79	1027.58	1072.14
ZIP	-1333.71	2691.42	2745.51
ZINB	-492.24	1010.48	1069.07

The ZINB regression model is then applied to find out the relationship of pupae productivity with different types of containers, where container Type 1 is considered as the reference category. Overall, the results have exhibited that pupae production varies between container types (p-value = 0.0136) and not all container types contribute to significant pupae productivity (Table 3.4).

Table 3.4: The ZINB regression model results for determining the relationship between container types and pupae productivity.

Container	Count regression group				Excess zero group			
types	Estimate	p-value	OR*	95% CI for OR	Estimate	p-value	OR*	95% CI for OR
Type 2 vs Type 1	0.541	0.295	1.718	0.624, 4.725	-1.096	0.005	0.334	0.156, 0.714
Type 3 vs Type 1	-1.126	0.021	0.324	0.125, 0.843	-1.042	0.009	0.353	0.162, 0.767
Type 4 vs Type 1	-1.269	0.013	0.281	0.103, 0.761	-1.476	0.001	0.229	0.092, 0.564
Type 5 vs Type 1	-0.998	0.288	0.369	0.059, 2.321	-2.686	0.051	0.068	0.004, 1.013
Type 6 vs Type 1	-1.764	0.061	0.171	0.027, 1.084	-2.049	0.068	0.129	0.014, 1.166

Note: *OR = Odds ratio. Significance level was set at p-value <0.05. Container Type 1 is the reference container.

These results reveal that when container types are compared to the reference category container Type 1 in the "count regression" group, only container Types 3-4 are significantly different, implying that the expected pupae count varies significantly for containers Types 3-4 while compared to Type 1. For the "excess zero group", when container types are compared to the reference category container Type 1, all categories are significant except for Type 6; meaning that the effect of container Types 2-5 has been distributed across the two groups of the model.

In order to measure the extent of significance of the above-mentioned container types, pupae counts have been predicted for both the “count regression” group and the “excess zero group”. For the “count regression” group, the expected number of pupae count in container Type 3 and Type 4 is decreased by 67.6% and 71.9%, respectively, when compared to that of container Type 1 while holding other container types constant. These results (Table 3.4) indicate that the container Type 1 has the highest pupae productivity amongst all six types of containers. For the excess zero group, the odds of being in the excess zero group for observed zero pupae count in the container Type 2, Type 3 and Type 4 is decreased by 66.6%, 64.7%, and 77.1% respectively, when compared to the zero pupae count in container Type 1 and holding other container types constant. The overall results indicate that the effect of container types has been distributed across both the groups (count regression and excess zero groups) of the model. The expected pupae count in container Types 3 and 4 is lower than the expected number of pupae count in container Type 1 in the regression group where the pupae count is greater than zero. Also, the probability of observed zero pupae count in container Types 3 and 4 is lower than the observed zero pupae count in container Type 1 in the excess zero group. It is thus apparent that container Type 1 is producing the greatest number of pupae as well as contains more observed zero counts than the other types (Figure 3.1).

3.3.3 Pupae Productivity vs Container Types and Container Size: A regression analysis using ZINB model

We pursued a combined analysis of pupae productivity with the container types based on usage and container size together a) to identify the significant relationship with the pupae productivity, and b) to determine whether the container size is confounded with the pupae productivity and the container type. Bivariate analysis has shown that both the container type and the container size are significantly related with the pupae productivity (p-value = 0.0136 and p-value = <0.0001, respectively). We then have modelled the pupae productivity with both the container type and the container size together using ZINB model, where the container Type 1 and WCV 1 are considered as the reference categories. Overall, the combined results show that pupae production significantly varies by container size (p-value = 0.0041) (see Table 3.5). The container types based on usage are not found significant and the container size is confounded with the pupae production and container type.

These results reveal that when container types based on usage and container size, in the "count regression" group, only container WCV31 is significantly different when compared to reference category WCV1, implying that the expected pupae count increases significantly for container size (50 and more L) while compared to WCV 1 (0 to <1 L). Container types (Type1 – Type 6) based on usage are not significant here, proving that container size plays a confounding role in pupae production and container types. For the "excess zero group", when container types based on usage are compared to the reference category container Type 1, all categories appear to be significant; meaning that the effects of container types in excess zero distribution differ significantly from each other. Container size, however, is not significant in excess zero group.

Table 3.5: The ZINB regression model results for determining the relationship between container types, container size and pupae productivity.

Container types	Count regression group				Excess zero group			
	Estimate	p-value	OR*	95% CI for OR	Estimate	p-value	OR*	95% CI for OR
WCV2 vs WCV1	0.163	0.678	1.177	0.545, 2.542	-0.409	0.214	0.664	0.349, 1.266
WCV3 vs WCV1	1.586	0.002	4.885	1.809, 13.184	-0.670	0.148	0.512	0.207, 1.267
Type 2 vs Type 1	0.471	0.306	1.602	0.651, 3.947	-1.398	0.0008	0.247	0.109 0.560
Type 3 vs Type 1	-0.339	0.467	0.712	0.286, 1.775	-1.112	0.005	0.329	0.151, 0.719
Type 4 vs Type 1	-0.553	0.232	0.575	0.232, 1.426	-1.576	0.0004	0.207	0.087, 0.494
Type 5 vs Type 1	-0.223	0.789	0.800	0.157, 4.084	-2.710	0.009	0.067	0.009, 0.504
Type 6 vs Type 1	-0.989	0.242	0.372	0.071, 1.950	-1.979	0.032	0.138	0.023, 0.845

Note: *OR = Odds ratio. Significance level was set at p-value <0.05. Container Type 1 and container's water capacity volume (WCV1) are reference types.

In order to measure the extent of significance of the container size and container types based on usage (Type 1 – Type 6), pupae counts have been predicted for both the "count regression" group and the "excess zero group". For the "count regression" group, the expected number of pupae count in container size ≥50 L increases by 4.9 times, when compared to that of container size <1 L while holding other container size constant. The results (Table 3.5) indicate that the container size ≥50 L has the highest pupae productivity amongst all sizes of containers. For the excess zero group, the odds of being in the excess zero group for observed zero pupae count in the container Type 2, Type 3, Type 4, Type 5 and Type 6 is decreased by 75.3%, 67.1%, 79.3%, 93.3% and 86.2%, respectively, when compared to the zero pupae count in container Type 1 while holding other container types constant. The overall results indicate that the effect of container types has been distributed across both the groups (count regression and excess zero groups) of the model and varies significantly in the excess zero distribution.

3.3.4 Association between Pupae Productivity and Household Ecological Factors: ZINB regression model

The ZINB model was fitted to determine the relationship between the household ecological factors and the pupae productivity. For the "count regression" group, overall the SHADE is significantly contributing to the pupae productivity (p-value = 0.005). In particular, the shade = 1 *vs* shade = 0 is significant (p-value = 0.001); but, shade = 2 *vs* shade = 0 is not significant. The expected number of pupae count in the count regression group for SHADE (shade = 1) is increased 4.6 times [OR = exp(1.5266) = 4.6, 95% CI: (1.8, 11.76)] when compared to the pupae count for shade = 0 after adjusting all other ecological factors. This implies that the containers (under the count regression group) placed in partial shade is 4.6 times more likely to produce pupae than containers without shade. No other ecological factors under the count regression group had an effect on pupae production in the containers.

The results of the multiple ZINB regression model from the "excess zero group" reveal that the type of water source (TOW) is significant (p-value = 0.001) when all the variables are taken into account. This means that the effect of type of water source has been distributed in the two portions of the model in a way that the odds of observed zero pupae count for TOW = 1 compared to TOW = 0 is 0.135 [OR = exp(-2.0025) = 0.135, 95% CI (0.566, 0.958)]; i.e. the expected number of observed zero pupae count in TOW = 1 (rain water) is 0.135 times lower than the expected number of zero pupae count in TOW = 0 (tap, tube-well, ring well or other water). This means that, for containers in the excess zero group, the expected count of observed zero pupae count is 86.5% lower in rain water than those in tap water, tube-well water, ring well water and others while adjusting the other variables.

3.4 Discussion

The "key" containers that are identified by determining the relative contribution that a particular container type makes to the overall production of *Aedes* pupae are often called the "most productive containers" (WHO, 2011). This concept is used widely in contemporary entomological research (Barrera, Amador & Clark, 2006a; 2006b). Our study reveals that, in terms of identifying the containers affecting dengue vector productivity at the household level, larvae and pupae distribution patterns by containers types are similar. The identified "most positive containers" for both larvae and pupae are medium size containers (1 - <50 L) used for household chores (Type 1) and kept outdoor. However, the "most productive containers" for pupae are large size containers (≥50 L) which are kept outdoor. These containers are mostly used for water storage purposes. A few studies in Bangladesh have revealed that although most abundant and productive containers are found within and nearby household premises, their location has generally been outdoors (Ferdousi et al., 2015; Dhar-Chowdhury et al., 2016; Paul et al., 2018). Our study also conforms to this finding as the most productive containers are within household premises with close proximity to the host, even if they are outside the house, which may also translate into elevated bite rates, which vary for different species of mosquitoes, as mentioned in other studies (Ngowo et al., 2017; Ryan et al., 2017).

In an urban area (Maracay City) of Venezuela, a higher proportion of mosquito breeding sites included small plastic/metal containers (21%) and buckets or containers of 10-20 L (20%), and most breeding sites were found outdoors (86.7%) (Elsinga et al., 2018). The Dhar-Chowdhury et al. (2016) study of the city of Dhaka, Bangladesh also identified various types of plastic containers as the most productive development sites for *Aedes* pupae. Our study confirms these findings by identifying that drums, buckets, mugs, bottles and refrigerator trays having similar materials (made of plastics) are the most favourable development sites for immature (both larvae and pupae) *Aedes* mosquito. We also found that in immature mosquito-positive container distribution and pupae-positive container distribution, refrigerator tray (plastic), flower tub and tray, plastic drums and plastic buckets are most abundant positive containers. These results are similar to the findings of Dhar-Chowdhury et al. (2016), but in their study refrigerator trays produced fewer immature mosquitoes. The reasons for the higher number of refrigerator trays and flower tubs and trays are likely to be related to human behavior and practice. Now-a-days, the refrigerators are quite affordable to various socioeconomic groups due to local production and the available provision for payment in installments. Moreover, possessing a refrigerator at home along with flower tubs/trays for aesthetic purposes is regarded as valuable social status symbols. These containers serve as favorable sites for *Aedes* mosquito development, especially for pupae because the refrigerator trays and flower tubs/trays usually have clean water and they are not emptied frequently.

The present study revealed that, in the city of Dhaka, the majority of containers that produced most of the pupae were used for water storage. Our results are similar to the findings of

Fulmali, Walimbe and Mahadev (2008) where water supply and non-potable water storage containers were designated as high risk in terms of *Ae. aegypti* larval development sites. Amongst all other possible breeding containers, plastic drums and other containers made of plastics were more infested with the larvae than others. According to our findings and some other urban studies, it seems that increased usage of these plastic containers is associated with urbanization and alterations of natural vector habitats, especially with concentration in the household premises (Fulmali, Walimbe and Mahadev, 2008; Anders et al, 2015; Alcalá et al., 2015).

Some studies registered that relatively larger water containers (such as indoor and outdoor tanks) were most productive in terms of pupal development. For example, in Columbia, Alcalá et al. (2015) observed that water storage tanks were more favourable household pupal breeding sites. An entomological survey following the 2000 dengue outbreak in Dhaka by Ferdousi et al. (2015) also identified indoor tanks as the ‘highest productive containers’ for *Ae. aegypti*. In three coastal areas of Mexico, Morales-Pérez et al. (2017) also identified the concrete tanks and barrels as the most productive containers in terms of immature *Aedes* production. In their study, containers with medium to large volumes of water (from 5-2000 L) were used for storing water, but in our investigation in Dhaka, we found that only 6.60% tanks with large volume of water (both covered and uncovered) for household usage were positive with immature *Aedes* mosquito; whereas, most abundant immature-mosquito and pupae positive containers were in the category of medium (1 to <50 L) size used for water storage purposes. In Dhaka city, piped water is not reliably available (Ferdousi et al., 2015; Sharmin et al., 2015a; Dhar-Chowdhury et al., 2016) because of poor water supply system or power outages creating problems to the supply (Dhar-Chowdhury et al., 2016), and this compels people to store water at household premises for household chores and other purposes. These containers holding the stored water for future usage eventually create favorable development sites for *Aedes* mosquito.

Discarded materials such as disposed tires and buckets lying outdoor was observed as most productive *Ae. aegypti* pupal production sites in Cairns, Queensland, Australia (Williams et al., 2013). While in our study discarded materials (Type 4 containers) are found not to be the most productive, these materials did support approximately 8% of larvae and pupae observed in household premises. Notably, in addition to the rain water in the discarded containers, availability of nutrients has been cited as an important factor of *Aedes* production in outdoor environment (Banerjee et al., 2015; Dhar-Chowdhury et al., 2016). A combination of favourable factors such as uncovered stored water or rain water along with a source of nutrients in the presence of nearby trees/plants/vegetation makes very favourable perennial sites for immature *Aedes* development (Strickman & Kittayapong, 2003). Because of availability of nutrients for the development of larval mosquitoes, the sewage drainage systems in Kolkata, West Bengal, India were found to be a more functional habitat for *Aedes*, yielding larger adult mosquitoes than other development sites (Banerjee et al., 2015). As it was outside the scope of the present study, future research in Dhaka on *Aedes* pupae productivity should look into these nutritional aspects.

A number of recent studies have argued that the traditional larval indices are not effective tools to measure the risk of dengue outbreak and called for analysing productivity of pupae instead (Barrera, Amador & Clark, 2006b; Wijayanti et al., 2016). Arduino (2014) asserted that as, in Brazil, the correlations between the traditional indices (Container index, Breteau index and Household index) and pupal productivity indices were not statistically significant and called for more studies for the fit of the pupal productivity indices to predict dengue risk. In our application of the ZINB model, we have found that the pupal productivity is significantly related to “container type”. Since our container classification is based on container use, this implies that pupae production significantly varies with container use where human choice and behaviour play vital roles. In this regard, Padmanabha et al. (2010) in a study in Colombia, found that temperature and human behavior of water usage influenced *Ae. aegypti* larval and pupal production most. Our investigation confirmed that human behavioural elements or activities significantly affect container use, vector breeding, and pupae production which are similar to findings of other studies (Barrera, Amador & MacKay, 2011; Arduino, 2014; Dhar-Chowdhury et al., 2016). As many of the Type 1 containers typically are not completely dried out or are not emptied (e.g. big or medium bottles, buckets or drums) due to lack of necessary attention and thus serve as favorable development sites; and also, it is more likely that the water of Type 2 containers (e.g. flower tubs and vases, plant pots) was less disturbed and thus resulting in favorable development site for pupae. However, when we accounted for the size of the container along with the container types based on usage, we have found that container size is confounded with pupae production and container type; and the container size is found to be the pre-dominant factor for most productivity of the pupae. The ≥50 L containers are 4.88 times more productive when compared to < 1 L sized containers. Our results are similar to the findings of other studies which mentioned that *Aedes* productivity increases positively with the container size (Harrington et al., 2008; Richardson et al., 2013; Schafrick et al., 2013).

Household environment or micro-level ecological factors that affect the productivity of pupae have received wider attention in the existing literature (Barrera, Amador & Clark, 2006a; Padmanabha et al., 2010). The Barrera, Amador and Clark (2006a) study in Puerto Rico inferred that the environmental factors were associated with the larval and pupal productivity of *Ae. aegypti*, as trees, water volume of the containers, and lower water temperatures had highly influenced pupal productivity. In our study, the ZINB model results revealed that partial shade from sunlight/light (for “count regression” group) and the type of water source (for “excess zero” group) were more likely to facilitate or limit pupal production than other factors, respectively. In the “count regression” group, the containers with partial shades produced 4.6 times more pupae than the containers without any shade, indicating that temperature likely played a role in pupal development. This finding is re-affirmed by other studies mentioning that container usage, volume and temperature have demonstrated to influence pupal productivity (Barrera, Amador & Clark, 2006a; Padmanabha et al., 2010).

In the context of household ecological factors, water infrastructure and type of water source have been cited by numerous studies as important factor of the productivity of the immature mosquitoes (Arunachalam et al., 2010; Stewart-Ibarra et al., 2013; Ferdousi et al., 2015; Dhar-Chowdhury et al., 2016). Ferdousi et al.’s study (2015) in Dhaka associated a positive relationship of the type of household, presence of water storage system and shaded outdoors with *Aedes* larvae. In terms of dengue transmission, Dhar-Chowdhury et al. (2016) associated the household dengue risk factors with the use of different types of containers for storing water by the households. In this regard, we have found that the containers located outside with stored tap water or water in the discarded household chore containers which remain uncovered for substantial period of time are positive breeding grounds for immature *Aedes*. Most of them are located outside household structures.

Findings of Stewart-Ibarra et al. (2013) study of a cohort in Ecuador similarly revealed that the pupal productivity of *Ae. aegypti* was influenced by climatic factors and by some household environmental factors such as water storage, access to piped water and condition of households. A study by Arunachalam et al. (2010) demonstrated that type of water source for the containers can function as facilitating or limiting factor, chiefly depending on biophysical environment – mentioning that uncovered outdoor water containers near vegetation and not being used for minimum seven days were most productive containers for pupae. Some analysts emphasized geographical or regional factors in determining predominance of indoor or outdoor containers in larval and pupal productivity (Moreno-Madriñan et al., 2014; Ngugi et al., 2017). Studies in Bangladesh (Dhar-Chowdhury et al., 2016; Paul et al., 2018) observed no major intra-urban differences in Dhaka, and future studies in Bangladesh should be pursued to examine more rigorously inter-urban and inter-regional differences in *Aedes* pupal production that may explain why dengue is more prevalent in Dhaka (Banu et al., 2012).

The scope of this study is limited by several factors. First, data for this represent a cross-sectional investigation, and therefore the trends of pupal production and container use are not reported here but elsewhere (Paul et al., 2018). The variations due to seasonality (wet and dry) could not therefore be analysed. However, details of the immature *Aedes* productivity are offered. Second, the study considered the containers within the household premises and thus left out other possible breeding sites in public places in the urban macro-environment. Third, this research focused only on immature mosquito production and did not account for the adult mosquitoes which would provide more accurate prediction of risk and thus help formulating a more precise outbreak prediction model. Finally, generalizing the contributions of containers in the production of *Aedes* in the Dhaka urban built area should be made with caution as the context and settings of rural and suburban areas would be different.

3.5 Conclusion

The present study inspected household premises in the city of Dhaka, Bangladesh and revealed the magnitude and dynamics of immature *Aedes* development, with a focus on the role of containers use in pupal production. The investigation identified that large-sized (≥50 L) containers, mostly made of plastic such as drums, buckets, and bottles primarily used for household chores were the most productive containers responsible for harbouring *Ae. aegypti* pupae. These types of containers are commonly possessed by city dwellers and yield sizeable populations of adult female *Aedes* mosquitoes (Paul et al., 2018). The use of Zero-inflated Negative Binomial (ZINB) regression made our study a unique one as this model can resolve the problem of both over dispersion and excessive zeroes in the same time.

Behaviour change is necessary among the city dwellers to appropriately use, dispose and recycle containers. In addition, responsible authorities are required to target the most productive containers for *Aedes* habitat management to undertake efficient measures for vector control (Barrera, Amador & Clark, 2006a; Padmanabha et al., 2010; Ngugi et al., 2017; Medeiros et al., 2018). The most common plastic containers should be target for interventions. In the present-day context of the urban centres in Bangladesh, refrigerator trays, plastic drums and buckets, flower tubs/trays, holding 1-50L of water for more than 7 days, are found to be the most positive containers. As these containers are the most common and positive containers presently, they should be the targets for intervention at the household level. Mass and community-focussed awareness building and health education emphasizing the role of *Aedes* in dengue transmission, the need to use lidded containers, the need to clean/empty water from refrigerator trays and flower tubs/trays, and the need to clean household premises, are likely to enhance uptake of these required changes in human behaviour.

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Supplementary Table 3.1: Distribution of positive containers with *Aedes* larvae and pupae in households inspected in Dhaka city, Bangladesh, 2013 monsoon.

Container Name	Total containers inspected	Positive containers with immature mosquito (count)	Containers with immature mosquito (%)
Refrigerator tray (plastic)	93	33	35.48
Plastic drum (sealable)	147	29	19.73
Flower tub & tray	57	28	49.12
Plastic bucket	101	22	21.78
Clay pot	47	18	38.30
Tires	16	15	93.75
Earthen jar (Motka)	15	9	60.00
Plastic mug	23	8	34.78
Flooded floor	13	8	61.54
Water Tank	16	7	43.75
Money plants tub	14	7	50.00
Discarded & broken toilet parts	9	6	66.67
Plastic sheet to cover large object	7	6	85.71
Ceramic pot	4	4	100.00
Cement pot	5	3	60.00
Tin/metal can	4	3	75.00
Plastic bottle	23	2	8.70
Refrigerator related containers	9	2	22.22
Metal bucket	5	2	40.00
Flag stand hole	2	2	100.00
Metal drum	2	2	100.00
Vehicle parts	2	2	100.00
Aluminum pot	2	2	100.00
Disposable Plastic Containers	27	1	3.70
Plastic bags	7	1	14.29
Clay pitcher	3	1	33.33
Plant axil	2	1	50.00
Coconut shell (dry or green)	7	0	0.00
Animal bowl	5	0	0.00
Glass bottle	3	0	0.00
Metal pan	1	0	0.00
Tree hole	1	0	0.00
Bamboo stump	1	0	0.00
Hole for water meter	1	0	0.00

Supplementary Table 3.2: Distribution of pupae-positive containers with *Aedes* mosquito in households inspected in Dhaka city, Bangladesh, 2013 monsoon.

Container Name	Total containers inspected	Pupae-positive containers (count)	Pupae-positive containers (%)
Refrigerator tray (plastic)	93	13	13.98
Flower tub & tray	57	10	17.54
Tires	16	7	43.75
Plastic drum (sealable)	147	6	4.08
Clay pot	47	5	10.64
Plastic bucket	101	4	3.96
Discarded & broken toilet parts	9	3	33.33
Plastic sheet to cover large object	7	3	42.86
Flooded floor	13	3	23.08
Water Tank	16	2	12.50
Cement pot	5	2	40.00
Money plants tub	14	2	14.29
Ceramic pot	4	2	50.00
Plastic mug	23	2	8.70
Earthen jar (Motka)	15	2	13.33
Clay pitcher	3	1	33.33
Tin/metal can	4	1	25.00
Metal bucket	5	1	20.00
Plastic bags	7	1	14.29
Flag stand hole	2	1	50.00
Metal drum	2	1	50.00
Plant axil	2	1	50.00
Vehicle parts	2	1	50.00
Disposable Plastic Containers	27	1	3.70
Refrigerator related containers	9	1	11.11
Aluminum pot	2	1	50.00
Plastic bottle	23	1	4.35
Metal pan	1	0	0.00
Animal bowl	5	0	0.00
Coconut shell (dry or green)	7	0	0.00
Tree hole	1	0	0.00
Bamboo stump	1	0	0.00
Hole for water meter	1	0	0.00
Glass bottle	3	0	0.00

Supplementary Table 3.3: Distribution of positive containers (by size) with *Aedes* larvae and pupae in households inspected in Dhaka city, Bangladesh, 2013 monsoon.

Categories of containers by size	Total containers	Immature mosquito-positive containers (count)	Immature mosquito-positive containers (%)	Only pupae-positive containers (count)	Only pupae-positive containers (%)
0-1 L	207	69	33.33	25	12.08
1-50 L	341	117	34.31	40	11.73
50+ L	123	38	30.89	13	10.57
Total	671	224	33.38	78	11.62

* Note: there were 3 missing data for size of containers.

Chapter 4 – Association among ecological and behavioural attributes, dengue vector, and disease control: a cross-sectional study of the city of Dhaka, Bangladesh[3]

Abstract

Background

This study examines vector density, the prevailing knowledge, awareness, attitudes and practice (KAAP) of community members regarding dengue disease and their willingness to pay (WTP) for vector control in Dhaka, Bangladesh.

Methods

A population-based, cross-sectional study design was followed: i) an entomological survey was carried-out in 727 randomly selected households in 12 wards, representing 4 urban ecological zones; and ii) a survey of 330 household heads was conducted to study their KAAP. Chi-square test and multinomial logistic regression (MLR) were applied to investigate factors associated with WTP and other variables.

Results

The *Stegomyia* indices significantly vary among the urban zones, revealing that the paved and built areas with concentrated public/commercial services have the highest mosquito density. Most respondents (93.9%) knew about dengue and its severity (90.3%); however, many of them were unaware (79.3%) about the types of mosquito causing dengue. MLR modeling reveals that average spending/month for mosquito control, household income, and knowledge about the

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[3] This chapter has been accepted as: Islam, S., Haque, C.E., Hossain, S., & Walker, D. (2019). Association among ecological and behavioural attributes, dengue vector, and disease control: a cross-sectional study of the city of Dhaka, Bangladesh. *International Health*.

effects of land-use and seasonality on dengue were significantly associated with the WTP for controlling the dengue vector.

Conclusions

Concerted efforts should be made to increase awareness about dengue transmission and develop community-based sustainable dengue vector control programs involving both public and private sectors.

Keywords: Dengue, Vector density, Knowledge and awareness, Attitude and practice, Vector control, Willingness to pay

4.1 Introduction

Dengue is one of the major vector-borne diseases of the present-day world (WHO, 2018). The spread of the dengue vector (*Aedes aegypti* and *A. albopictus*) has caused the dengue fever (DF) and severe dengue to become endemic in more than 128 countries (Brady et al., 2012). Estimates suggest 96 million new apparent infections take place every year, with 294 million inapparent infections (Bhatt et al., 2013). To tackle such an invasive disease, a vaccine for dengue, Dengvaxia® (CYD-TDV), was developed by Sanofi Pasteur and licensed in 2015. The vaccine obtained approval in 20 countries. However, results of Phase 3 trials have been mixed, with contradictions for sub-populations. In particular, recent serostatus results revealed that sub-populations with no prior dengue virus (DENV) infection had higher risk of severe dengue with the vaccination (WHO, 2019). Despite some progress in recent years on vaccine development, none are universally available for public health use for all at-risk individuals because of safety concerns. Hence, prevention and control of dengue virus (DENV) transmission still requires to rely primarily on effective vector control (Brady et al., 2012; Saied et al., 2015).

The spread of the vector and DENV are accelerated by numerous factors at various scales (household, neighbourhood, urban zone, city, region etc.) including urbanization, climate change, changes in land-use, population growth, erratic water supply due to increased population, problems in the water supply system, droughts, and increased trade and mobility. The altered neighbourhood environment has become a preferred habitat and breeding site for the major vector (*Aedes* mosquitoes) (WHO, 2009). Recognizing that a vector control strategy is the major intervention point for controlling dengue, and that the urban ecological zones may be associated with vector abundance and density, research on detecting and explaining these complex relationships has a vital role in them (Figure 4.1). Among diverse approaches, following Pickett and Cadenasso (2006), in our study, urban ecological zones have been regarded as distinct areas of a city characterized by unique land- and waterscapes and habitat that maintain a distinct ecological character in respect to biological and cultural diversity. Therefore, they are labelled as Integrated Urban Ecological Zones (IUEZs). As numerous studies have revealed that better knowledge and awareness about the vector and the disease among the city dwellers are associated with reduction of vector breeding (Paz-Soldán et al., 2015; Elsinga et al., 2018), it is crucial to investigate the state of KAAP and their associated attributes. With a general failure of public agencies in vector control in many developing countries, the focus has recently shifted to the potential of private citizens' efforts and their willingness to pay (WTP) for vector control (Harapana et al., 2017).

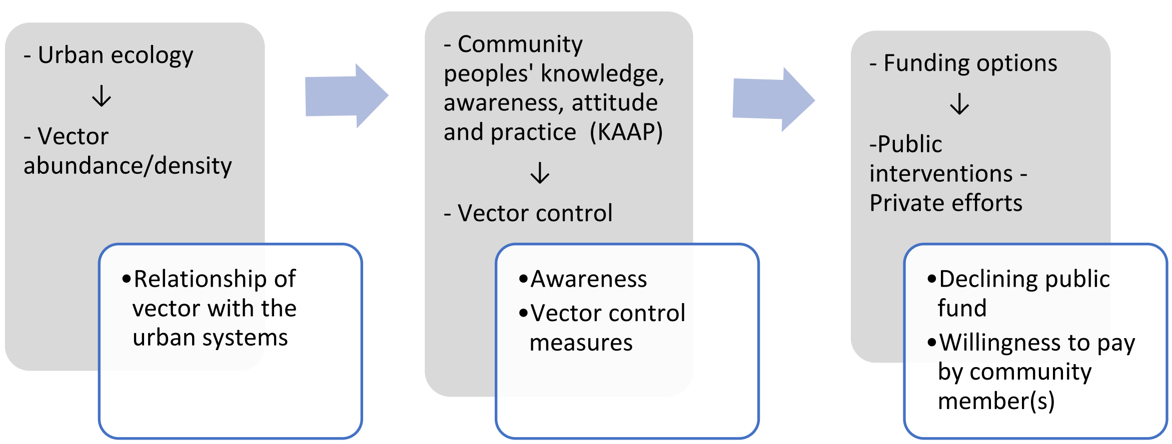

Figure 4.1: Schematic representation of relationships among dengue vector, urban ecology, community peoples' knowledge, awareness, attitude, and practice (KAAP) and vector control activity options.

To our knowledge, no systematic study has yet been conducted in Bangladesh that encompasses the aspects of vector density by urban ecological zone, inhabitants' KAAP regarding dengue and its control, and their WTP for vector control. An International Development Research

Centre (IDRC), Canada project on dengue in Bangladesh, initiated in 2010-11 to investigate the problem from a socioeconomic perspective, published its results previously (Dhar-Chowdhuhry et al., 2014). The present study was carried out during 2013-14 under the same project, but with a different and expanded scope and the following objectives: i) to examine whether there are any significant differences among the IUEZs (see Supplementary Table 4.1) in terms of *Stegomyia* indices (House Index, Breteau Index, Container Index, Pupae-per-Person Index); ii) to examine the current status of KAAP regarding dengue, its transmission, IUEZ differentials, and their explanatory factors; iii) to map the status of vector control measures undertaken by city dwellers, IUEZ differentials, and to identify the explanatory factors; and iv) to determine the status of WTP for vector control, IUEZ differentials, and to identify the underlying influencing factors that explain dwellers' WTP for vector control.

4.2 Materials and Methods

4.2.1 Selection of the Study Area for Entomological Survey

The Dhaka City Corporation (DCC) area was chosen as the study area considering its socioeconomic, political and demographic importance as the capital of Bangladesh and its high vulnerability to dengue epidemics (Banu et al., 2012). The city core covers 126.3 km^2 and is divided into 90 wards – a ward refers to an administrative sub-unit representing at least one local community. With more than 12 million people (Dhar-Chowdhuhry et al., 2014), Dhaka is one of the most densely populated cities in the world. Dengue outbreaks take place most years, with varying annual fatalities and hospitalization: since the 2000 outbreak, more than 49,000 have suffered from DF and severe dengue, with 316 fatalities (Roy & Alam, 2018).

4.2.2 Delineation of Integrated Urban Ecological Zones (IUEZs)

A Rapid Eye image for the city of Dhaka ($23^{0}40^{/}09^{//}$N to $23^{0}54^{/}05^{//}$N and $90^{0}19^{/}45^{//}$E to $90^{0}30^{/}35^{//}$E) for 2013 was procured for identification of current land cover. Supervised classification with 6 training samples and 4 test samples for each of the categories of land cover was performed. Land use data procured from the Dhaka City authority were overlaid with the classified land cover map. The land use classes were then connected with the Rapid Eye classified imager through a *Spatial Join* operation in Arcmap 10.1. The average percentage of each land cover/use type for each of the 90 wards was determined by overlaying the ward boundaries on the land cover map. The city was then classified into 4 Integrated Urban Ecological Zones (IUEZ): i) Residential, Vegetation and Bare Soil (RVBS), ii) Residential and Water-bodies (RAWB), iii) Paved/built Area, Services and Commercial Activities (PASC), and iv) Commercial, Residential and Industrial Area (CRIA) using the function *agnes* from the R-package *cluster* (Struyf, Hubert & Rousseeuw, 1997) (see Supplementary Table 4.1).

4.2.3 Entomological Data Collection

Using a probability proportional sampling procedure by IUEZ, a total of 12 wards (13.3%; 12/90) were randomly chosen, resulting in 4 wards (20,25,35,40) in RVBS, 2 wards (26,58) in RAWB, 5 wards (13,38,69,76,78) in PASC and 1 ward (60) in CRIA (Figure 4.2). A random sample of 100 households was targeted from each selected ward, resulting in a possible 1200 sampling units. With a response rate of 60.6% (727/1200), a total of 727 households were inspected by trained entomologists to collect mosquito larvae and pupae. The entomological survey was carried out by the IDRC-sponsored project personnel during August and September (monsoon) of 2013.

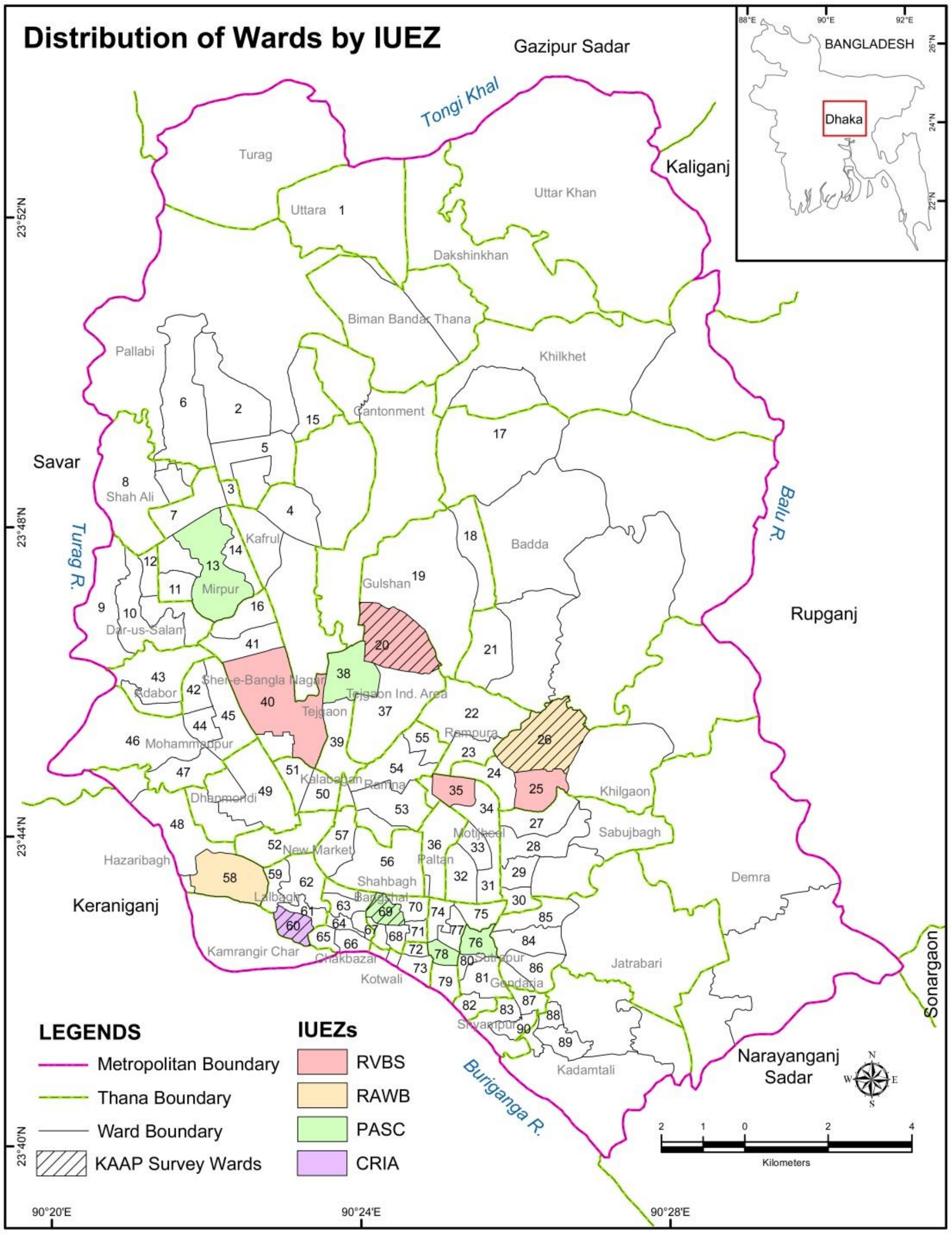

Figure 4.2: Location of sampled wards (n=12) by Integrated Urban Ecological Zone (IUEZ) for the 2013 entomological survey (in colour), and sampled communities (four wards) for the 2014 KAAP survey (patterned) in the Dhaka City Corporation (DCC) area.

4.2.4 Sampling of Households for KAAP Survey

For the purpose of administering the KAAP survey in the selected twelve wards, one ward from each IUEZ was randomly chosen, resulting in the following: ward 20 in RVBS, ward 26 in RAWB, ward 69 in PASC, and ward 60 in CRIA zone. Using a probability proportional sampling procedure, a total of 360 households were targeted in the four selected wards, of which 330 responded (91.7%). The first author interviewed the corresponding household heads during June-July of 2014.

4.2.5 Data Analysis

Descriptive and computational statistical data analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC), and the results are presented in sequence: an analysis of *Stegomyia* indices in the IUEZs, the status and explanatory factors of knowledge and awareness among city dwellers, and the status and explanatory factors of vector control measures being undertaken by them. Association of the *Stegomyia* indices was evaluated through the Chi-square test for equality of proportions amongst the three IUEZs (RVBS, RAWB, and PASC); considering the unmet minimum number in the CRIA zone, data for this zone were merged with RVBS. The descriptive analysis involved 18 variables related to participant responses regarding KAAP and WTP (Table 4.1).

Table 4.1: Variables with descriptions

Description of the variables	**Abbreviated name of the variable**
Age of respondent	Age
Gender of respondent	Gender
Education level of respondent	Education
Household income (in Bangladeshi Taka - BDT)	Income
Knowledge of dengue/heard of dengue before	KnDf
Knowledge of severity of dengue fever (DF)	MagnitudeDf
Knowledge of association of land-use with dengue	LucozD
Knowledge of association weather with dengue	WcozD
Knowledge of association of seasonality with dengue	SeasonMos
Knowledge of types of mosquito bites causing dengue	GenMosBite
Knowledge of dengue prevention	DepiPrev
Effectiveness of government control measures (e.g. fogging and spraying)	GovCon
Attitude and practice of control measures using bed net	ConBedN
Attitude and practice of control measures using coil/spray	ConCS
Attitude and practice of control measures using electric gadgets (e.g. electric bat, electric liquid solution dispenser)	ConElecGaz
Attitude and practice of control measures using fan	ConFan
Average spending per month (in BDT) for mosquito control by household	AvgCPM
Willingness to pay for vector mosquito control	WTP

Chi-square tests were performed to identify factors associated with knowledge and awareness, and IUEZ differentials; to determine if there are differences in control measures among the IUEZs; to identify factors influencing vector control measures; and to determine if there are differences in WTP for vector control among the IUEZs. The multinomial logistic regression (MLR) method was applied to identify the factors influencing WTP. To single out important variables related to WTP, univariate analysis of 18 explanatory variables was performed. Based on a cut-off p-value <0.1, 11 explanatory variables were included in the MLR model and a stepwise selection method was applied to identify the key explanatory factors of WTP.

4.3 Results

4.3.1 Stegomyia Indices in the IUEZs

With an overall response rate of 60.6% to the entomological survey, and a coverage of a total of 727 inspected households that met the minimum required response rate of ≥50% (Davern et al., 2010), the likelihood of a nonresponse bias is minimum. A total of 674 wet containers were identified, of which 224 were 'positive' in terms containing *Aedes* larvae and/or pupae (Table 4.2), including a total of 1120 *Aedes* pupae [identification methods are detailed elsewhere (Dhar-Chowdhuhry et al., 2016)].

Table 4.2: Distribution of response rate, number of positive containers, and number of pupae collected by IUEZ, Dhaka (12 wards), 2013.

IUEZ	No. of house holds target ed	No. of inspecte d househo lds	Respo nse rate (%)	No. of positive househo lds	No. of wet contain ers	Avg. no. of wet contain er per househ old	No. of positive contain ers	Avg. no. of immatu re mosqui to positive contain ers per househ old	No. of collect ed pupae (count)	No. of people slept last night at the househ olds
RVBS*	500	314	63	45	272	0.87	84	0.27	524	915
RAWB	200	128	64	14	128	1.00	33	0.26	74	355
PASC	500	285	57	50	274	0.96	107	0.38	522	806
All Zones	1200	727	61	109	674	0.93	224	0.31	1120	2076

*RVBS merged with CRIA in consideration of unmet minimum size in CRIA for statistical tests.

The 2013 monsoon season survey results reveal 15% (109/727) of the inspected households were positive for *Aedes* larvae and/or pupae. Distribution and prevalence of vector mosquitoes can be described by the traditional *Stegomyia* indices. Overall, 30.8 positive containers were observed per 100 households inspected, with a range between 0.26 in RAWB and 0.38 in PASC zones (Table 4.3). The mean Pupae per Person Index (PPI) was 0.54 ─ 0.57 in RVBS, 0.21 in RAWB, and 0.65 in PASC, revealing the highest PPI in the PASC zone, the area pre-dominated by paved/built areas, residential buildings, and public and commercial service infrastructure.

As shown in Table 4.3, the *Stegomyia* indices, except for House Index, vary significantly among the IUEZs (Container Index = 33.2; 95% CI: 29.7–36.8%, p-value = 0.018; Breteau Index = 30.8; CI: 95% 27.5–34.2%, p-value = 0.007; and PPI = 0.54, p-value = 0.0001). These results indicate that, in Dhaka city, IUEZs have profound impacts upon mosquito abundance and density, and that urban ecology and functional characteristics have significant impacts on vector abundance and spatial distribution. Differences were detected in mosquito abundance and density as a function of urban ecology (IUEZ).

Table 4.3: *Stegomyia* Indices by Urban Ecological Zone, Dhaka (12 wards), 2013.

IUEZ	**House Index**	**95% Confidence Interval (CI)**	**Container Index**	**95% Confidence Interval (CI)**	**Breteau Index**	**95% Confidence Interval (CI)**	**Pupae Per Person (PPI)**
RVBS*	14.3	10.2-17.8	30.8	25.5-36.5	26.8	23.0-33.0	0.57
RAWB	10.9	5.6-16.4	25.8	18.4-33.6	25.8	18.4-33.6	0.21
PASC	17.5	13.5-22.4	39.1	33.2-44.8	37.5	32.4-43.6	0.65
All Zones	14.9	12.3-17.5	33.2	29.7-36.8	30.8	27.5-34.2	0.54

*RVBS merged with CRIA in consideration of unmet minimum size in CRIA for statistical tests.

Note: House Index = No. of positive households/no. of households visited (%), Container Index = No. of positive containers/No. of wet containers (%), Breteau Index = No. of positive containers/No. of households visited (per 100 households), PPI = No. of pupae collected/no. of people slept last night.

4.3.2 Respondents' Demographic and Socioeconomic Characteristics

The sociodemographic breakdown of KAAP survey respondents (i.e., household heads) is depicted in Table 4.4. Among the 330 respondents, 56.7% (187/330) were women and most were adults (the 31-50-year age-group accounted for 43.7% (135/309). Almost a quarter (24.5%; 78/318) of the respondents had never attended school and 39.3% (125/318) had an educational background beyond grade 12. The majority of the sampled households had incomes below BDT 25,000 (approximately US $300) per month.

Table 4.4: Characteristics of respondents of KAAP survey (n=330), Dhaka (4 wards), 2013-14.

Demographic and socioeconomic characteristics	**Category**	**Frequency (n=330)**	**Percent**
Age	15-30	112	36.3
	31-50	135	43.7
	50+	62	20.1
	Median	35	
Gender	Male	143	43.3
	Female	187	56.7
Education	No schooling/ primary education	78	24.5
	Secondary	115	36.2
	Higher secondary/Diploma	52	16.4
	Graduate and postgraduate	73	23.0
Income/month (in BDT)	≤25000	175	54.7
	25001-50000	80	25.0
	≥50001	65	20.3

4.3.3 Status of Knowledge and Awareness of Dengue and its Associated Factors

Results of bivariate analyses of respondents' knowledge and awareness of dengue and its associated factors are presented in Table 4.5. Of 330 respondents, 309 (93.9%; 95% CI: 92.2–96.6%) had some knowledge about dengue from various sources. However, while 261 of 329 respondents (79.3%; CI: 74.9–83.7%) were unaware of whether male or female mosquito bites can cause dengue infection, 297 respondents (90.3%; CI: 86.7–93.5%) agreed that DF and severe dengue can have 'serious' health implications. The majority of respondents were aware of the association between dengue incidence and land use (52.6%; 172/327; 95% CI: 47.2–58.0%) or weather (57.0%; 187/328; 95% CI: 51.6–62.3%), as well as with rainy early summer and monsoon seasonality (68.6%; 225/328; 95% CI: 63.6–73.6%). An overwhelming majority of respondents agreed that dengue diseases can be prevented by various measures (79.3%; 261/329; 95% CI: 74.9–83.7%). Knowledge and awareness variables (GenMosbite, DEpiPrev, LUcozD, WcozD) were found, through Chi-square tests, to be significantly associated with the level of education (p-values <0.0001, 0.0003, 0.0002. 0.026 respectively, at 5% level) (Figure 4.3).

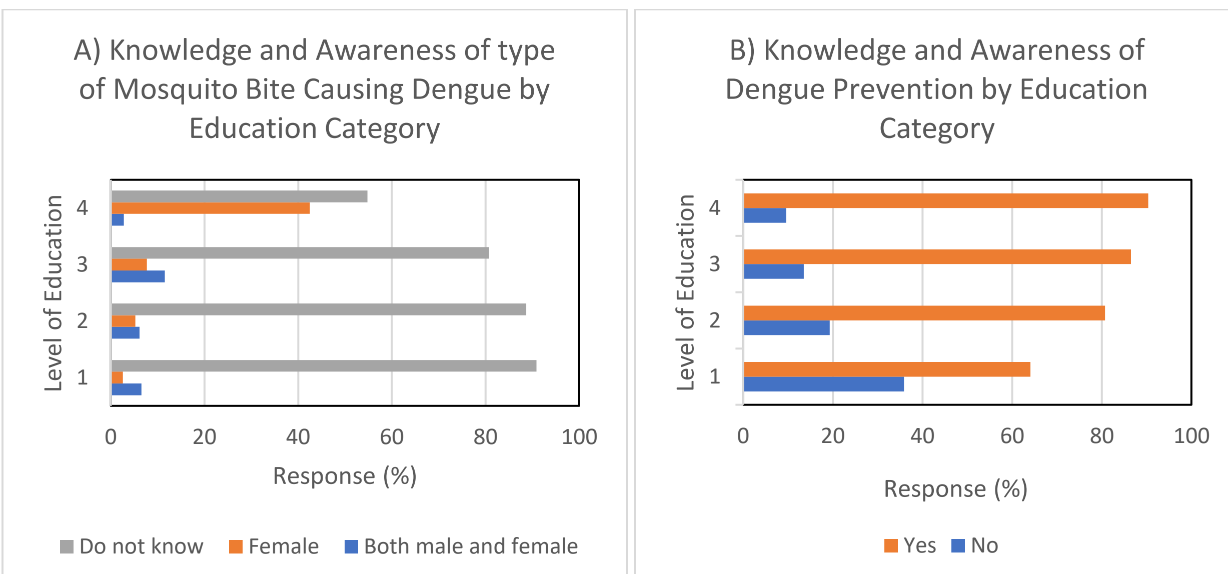

Figure 4.3: Distribution (%) of knowledge and awareness among respondents (n = 329) by education category (1 = No schooling/primary education, 2 = Secondary, 3 = Higher secondary/Diploma, 4 = Graduate & postgraduate): a) type of mosquito bites causing dengue; b) dengue prevention options.
Source: KAAP Survey, 2014.

Table 4.5: Distribution and bivariate test results of responses concerning knowledge of dengue by KAAP survey participants (n=330), and by IUEZ, Dhaka (4 wards), 2014.

Variable/Category		Respondents'		IUEZs								p-value
		All Zones		RVBS		RAWB		PASC		CRIA		
		n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	
Prior knowledge of dengue/heard of dengue												
	Yes	309	(93.9)	97	(92.4)	85	(96.6)	64	(94.1)	63	(92.7)	0.630
	No	20	(6.1)	8	(7.6)	3	(3.4)	4	(5.9)	5	(7.3)	
Knowledge of magnitude of dengue fever												
	Serious	297	(90.3)	96	(91.4)	86	(97.8)	60	(88.2)	55	(80.9)	0.019*
	Mild	14	(4.3)	5	(4.8)	1	(1.1)	4	(5.9)	4	(5.89)	
	Don't know	18	(5.4)	4	(3.8)	1	(1.1)	4	(5.9)	9	(13.2)	
Knowledge of association of land-use with dengue												
	Yes	172	(52.6)	63	(60.6)	42	(47.7)	37	(55.2)	30	(44.1)	0.131
	Don't know	155	(47.4)	41	(39.4)	46	(52.3)	30	(44.8)	38	(55.9)	
Knowledge of association of weather with dengue												
	Yes	187	(57.0)	61	(58.1)	44	(50.0)	38	(56.7)	44	(64.7)	0.326
	Don't know	141	(43.0)	44	(41.9)	44	(50.0)	29	(43.3)	24	(35.3)	
Knowledge of association of seasonality with dengue												
	Early Summer[1]	75	(22.9)	20	(18.9)	20	(22.7)	22	(32.3)	13	↓↓(19.7)	0.049*
	Monsoon[2]	150	(45.)	42	(39.6)	42	(47.7)	34	(50.0)	32	(48.5)	
	Winter[3]	103	(31.4)	44	(41.5)	26	(29.6)	12	(17.7)	21	(31.8)	
Knowledge of types of mosquito bites causing dengue												
	Both male & female mosquito	22	(6.7)	4	(3.8)	2	(2.3)	5	(7.4)	11	(16.4)	0.0006*
	Female	46	(14.0)	24	(22.6)	11	(12.5)	6	(8.8)	5	(7.5)	
	mosquito	261	(79.3)	78	(73.6)	75	(85.2)	57	(83.8)	51	(76.1)	
	Don't know											
Knowledge of dengue prevention												
	Yes	261	(79.3)	90	(85.7)	69	(78.4)	51	(75.0)	51	(75.0)	0.240
	No	68	(20.7)	15	(14.3)	19	(21.4)	17	(25.0)	17	(25.0)	
Total		330	(100)	106	(100)	88	(100)	68	(100)	68	(100)	

Note: [1] Early summer = April – May, [2] Monsoon = June – September, [3] Winter = December – January.
* Significant at p <0.05 level.

In terms of IUEZ communities, significant differences among the respondents regarding their knowledge of the severity of dengue infection (p-value=0.019), its association with seasonality (p-value=0.049), and the types of mosquito bites that may cause dengue infection (p-value=0.0006) existed (Table 4.5). The extent of knowledge of DF and its severity was noticeably higher among the respondents from the RAWB (ward 26) than other IUEZs.

4.3.4 Attitudes toward Vector Control Measures and Willingness to Pay (WTP)

Of the 329 respondents, 261 (79.3%; 95% CI: 74.9–83.7%) demonstrated an affirmative attitude towards prevention and/or control of dengue infection. Bivariate analyses of such attitudes towards the prevention or control of dengue via vector control show (Table 4.6) that the majority of respondents are inclined towards using coils and/or mosquito repellant spray (72.1%; 238/330; 95% CI: 67.3–76.9%), and bed nets (57.6%; 190/330; 95% CI: 52.3–62.9%). In addition, two-thirds of the respondents (66.7%; 220/330; 95% CI: 61.6 – 71.8%) reported that government and/or institutional measures were not effective in limiting the propagation of the dengue vector or the spread of dengue infection.

Given the general failure of public services in vector control measures (Mahmood, 2006), an overwhelming majority of respondents (89.4%; 295/330; 95% CI: 86.1–92.7%) spent privately for vector control measures. Of them, 48.8% (144/330) spent a modest amount, BDT 101-400/month, for this purpose. All respondents, including the 35 respondents who had not spent any money for vector control, expressed their WTP for control measures (Table 4.6). Notably, while only 63 out of 295 respondents (21.4%; 95% CI: 16.7–26.1%) had been spending more than BDT

400 at the time of the survey, 117 of all respondents (35.5%) reported they would pay more than BDT 400 in the future.

Table 4.6: Distribution and bivariate analyses of responses concerning vector control measures, spending/month by household, and WTP for vector control (n=330), and by IUEZ, Dhaka (4 wards), 2014.

Variable/Category		**Respondents'**		**IUEZs**								**p-value**
		All Zones		**RVBS**		**RAWB**		**PASC**		**CRIA**		
		n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	
Attitude and practice of control measures using bed net												
(ConBedN)	Yes	190	(57.6)	65	(61.3)	58	(65.9)	29	(42.7)	38	(55.9)	0.025*
	No	140	(42.4)	41	(38.7)	30	(34.1)	39	(57.3)	30	(44.1)	
Attitude and practice of control measures using coil/spray												
(ConCS)	Yes	238	(72.1)	86	(81.1)	57	(64.8)	47	(69.1)	48	(70.6)	0.071
	No	92	(27.9)	20	(18.9)	31	(35.2)	21	(30.9)	20	(29.4)	
Attitude and practice of control measures using electric gadgets												
(ConElecGaz)	Yes	57	(17.3)	16	(15.1)	12	(13.6)	22	(32.4)	7	(10.3)	0.003*
	No	273	(82.7)	90	(84.9)	76	(86.4)	46	(67.6)	61	(89.7)	
Attitude and practice of control measures using fan												
(ConFan)	Yes	162	(49.1)	51	(48.1)	44	(50.0)	38	(55.9)	29	(42.6)	0.484
	No	168	(50.9)	55	(51.9)	44	(50.0)	30	(44.1)	39	(57.4)	
Awareness of government control measures												
(GovCon)	Yes	110	(33.3)	38	(35.8)	20	(22.7)	27	(39.7)	25	(36.8)	0.095
	No	220	(66.8)	68	(64.2)	68	(77.3)	41	(60.3)	43	(63.2)	
Average spending for mosquito control/moth by households												
(AvgCPM)	0-100	88	(29.8)	19	(20.2)	20	(25.3)	25	(42.4)	24	(38.1)	0.002*
	101-400	144	(48.8)	53	(56.4)	45	(57.0)	27	(45.8)	19	(30.1)	
	>400	63	(21.4)	22	(23.4)	14	(17.7)	7	(11.8)	20	(31.8)	
Willingness to pay for mosquito vector control												
(WTP)	0-100	117	(35.5)	34	(32.1)	30	(34.1)	25	(36.8)	28	(41.2)	0.393
	101-400	96	(29.0)	28	(26.4)	23	(26.1)	24	(35.3)	21	(30.9)	
	>400	117	(35.5)	44	(41.5)	35	(39.8)	19	(27.9)	19	(27.9)	
Total		330	(100)	106	(100)	88	(100)	68	(100)	68	(100)	

* Significant at $p < 0.05$ level.

Chi-square test results revealed that there were significant differences among the IUEZs in the use of bed nets (p-value = 0.025), electronic gadgets (p-value = 0.003) and average monthly spending for vector control (p-value = 0.002). Among the IUEZs, no significant difference in terms of WTP for vector control was registered.

4.3.5 Explanatory Factors Associated with the Attitude towards WTP

A multinomial logistic regression (MLR) model with stepwise method, based on 11 variables, was carried out to identify factors related to WTP for vector control purposes. This resulted in 5 significant variables (AvgCPM, Income, LUcozD, SeasonMos, ConAeElecGaz) associated with WTP (p-values: <0.0001, 0.006, 0.018, 0.001 and 0.009, respectively; Table 4.7). The findings indicate that if monthly household income increases, WTP for vector control would correspondingly increase. For example, the OR=2.56 (CI: 1.00–6.52) implies that WTP 101-400 BDT vs ≤100 BDT per month would increase by 2.56 times if household monthly income increases from <25000 to ≥25000 BDT, after adjusting for other factors. The MLR results also revealed that enhancement of knowledge of the effects of land use on dengue, effects of seasonality on dengue incidence, and adoption of electronic gadgets would all increase WTP for vector control measures (Table 4.7).

Table 4.7: Results of Multinomial Logistic Regression (MLR) Model identifying factors influencing Willingness to Pay (WTP) to control dengue vector mosquitoes (n=330), Dhaka (4 wards), 2014.

Explanatory Variables	**Explanation of the variables**	**p-value**	**OR**	**(95% CI)**
Average cost per month (AvgCPM)		<0.0001*		
AvgCPM 2 vs 1 WTP 2	When, AvgCPM 101-400 vs ≤100, then WTP 101-400 vs ≤100[1]		8.12	(3.74- 17.62)
AvgCPM 2 vs 1 WTP 3	When, AvgCPM 101-400 vs ≤100, then WTP >400 vs ≤100[1]		9.80	(4.15- 23.15)
AvgCPM 3 vs 1 WTP 2	When, AvgCPM >400 vs ≤100, then WTP 101-400 vs ≤100[1]		10.26	(2.96- 35.57)
AvgCPM 3 vs 1 WTP 3	When, AvgCPM >400 vs ≤100, then WTP >400 vs ≤100[1]		61.23	(17.55- 213.62)
Income		0.006*		
Income 2 vs 1 WTP 2	When Income 25k-50k vs 0-25k, then WTP 101-400 vs ≤100		2.56	(1.00-6.52)
Income 2 vs 1 WTP 3	When Income 25k-50k vs 0-25k, then WTP >400 vs ≤100		5.22	(2.03-13.39)
Income 3 vs 1 WTP 2	When Income 50k+ vs 0-25k, then WTP 101-400 vs ≤100		0.99	(0.36-2.75)
Income 3 vs 1 WTP 3	When Income 50k+ vs 0-25k, then WTP >400 vs ≤100		2.73	(1.04-7.16)
Knowledge of Land-use causing dengue (LUcozD)		0.018*		
Yes vs Don’t know WTP 2	When LUcozD Yes vs Don’t know, then WTP 101-400 vs ≤100[1]		0.46	(0.22-0.98)
Yes vs Don’t know WTP 3	When LUcozD Yes vs Don’t know, then WTP >400 vs ≤100		1.16	(0.52-2.58)
Knowledge of season causing dengue (SeasonMos)		0.001*		
Summer vs Monsoon WTP 2	When SeasonMos Summer vs Monsoon, then WTP 101-400 vs ≤100[1]		3.03	(1.20-7.64)
Summer vs Monsoon WTP 3	When SeasonMos Summer vs Monsoon, then WTP >400 vs ≤100		6.98	(2.65-18.36)
Winter vs Monsoon WTP 2	When SeasonMos Winter vs Monsoon, then WTP 101-400 vs ≤100[1]		1.89	(0.82-4.37)
Winter vs Monsoon WTP 3	When SeasonMos Winter vs Monsoon, then WTP >400 vs ≤100		3.96	(1.66-9.42)
Using electronic gadget for mosquito control (ConAeElecGaz)		0.009*		
Yes vs No WTP 2	When ConELecGaz Yes vs No, then WTP 101-400 vs ≤100[1]		2.13	(0.78-5.82)
Yes vs No WTP 3	When ConELecGaz Yes vs No, then WTP >400 vs ≤100		4.42	(1.67-11.68)

Note: [1] Reference category is 1 for WTP, * Significant at p <0.05 level.

4.4 Discussion

The results of the present study show that urban ecological and functional characteristics have profound impacts on *Aedes* abundance and spatial distribution in Dhaka, Bangladesh. From analyses of the traditional *Stegomyia* indices and PPI, it is evident that *Aedes* abundance (reflected in modest to high indices values) is significantly influenced by city dwellers' KAAP, particularly in respect to managing water containers within their premises as sources of infestation (Dhar-Chowdhury et al., 2014; Ferdousi et al., 2015). As about one-third of the residents do not have access to piped potable water (Mahmood, 2006; Dhar-Chowdhury et al., 2016), they tend to store water and inadvertently create sites for vector mosquitoes to develop. This problem is augmented by frequent power failures and interruptions in water delivery (Dhar-Chowdhury et al., 2014; Dhar-Chowdhury et al., 2016). In several Latin and Central American cities, Barrera, Amador and MacKay (2011), and Stewart-Ibarra et al. (2013) observed a similar influence of environmental and human behavioural factors on *Aedes* productivity and abundance. Although several studies observed tires as a major breeding site of *Aedes* (Higa et al, 2010; Getachew et al., 2015), due to limited coverage of our entomological survey primarily to household premises, we did not find tires as a major breeding site in Dhaka. In urban areas of Thailand, Barbazan et al. (2008) calculated a PPI of 0.8, and in Cambodia, Seng et al. (2009) observed PPIs between 1.0 and 4.4. In Dhaka, a relatively low PPI ─ 0.58 by Dhar-Chowdhury et al. (2016) and 0.54 by the present study (Table 4.3) ─ compared to other Southeast Asian countries is likely the result of Dhaka's extremely high population density.

Our study identified that education level is significantly associated with the KAAP of city dwellers regarding dengue, and that variations among the IUEZs in land use/cover patterns and the educational status of the respondents has noticeably influenced differences in their *Stegomyia* indices. These were reflected in the significant differences in Container Index, Breteau Index and PPI among the IUEZs. For instance, the PASC zone, characterized by the predominance of paved and built-up areas including residential, service and commercial buildings and other infrastructure had the highest mosquito density in terms of House Index, Breteau Index and Container Index. Our overall findings of varying mosquito density by IUEZ are similar to a recent study in Rio de Janeiro, Brazil that observed variable dengue vector distribution among and within neighbourhoods (Xavier et al., 2017). Our findings imply a strong positive correlation of vector productivity and abundance with urban infrastructure, the surrounding environment and supportive habitat within the households. Several studies in this context have asserted that environmental factors induced by urbanization and associated changes in land use/surface area, water-bodies, vegetation coverage and surface type, are significant factors enhancing *Aedes* habitats, which in turn may result in high risk of disease transmission (Sarfraz et al., 2012; Delmelle et al., 2016).

In the present study, we found that the majority of the respondents (93.9%) have heard about dengue via different sources, including collaborative health education programs, and were aware of the serious adverse effects of DF and severe dengue (90.3%). An overwhelming majority (79.3%) of the respondents agreed that dengue infection and spread can be prevented, and a majority knew that land-use change, weather and seasonal differences contribute to dengue incidence. In this regard, collaborative education campaigns in Nicaragua (Mayers, 2013) and the Philippines (Yboa & Labrague, 2013) have proven effective in enhancing knowledge and awareness of the disease and its transmission. Conforming with our findings, numerous studies have confirmed that people with better knowledge of the vector and the disease were associated with lower breeding rates (Paz-Soldán et al., 2015; Elsinga et al., 2018). According to these studies, knowledge and education led to change human practices and behavior, which eventually reduce vector breeding and dengue infection rates.

Similar to our findings, a Peruvian study observed that knowledge about dengue was positively associated with higher levels of education, and improved prevention practice was associated with higher socioeconomic status (Paz-Soldán et al., 2015). A nation-wide study in Malaysia also revealed that income, occupation, and knowledge about the dengue vector, dengue disease and its risks were closely associated with rigorous dengue prevention practices (Wong et al., 2015). However, other studies have cautioned that knowledge about dengue does not always transfer to practice among community members (Paz-Soldán et al., 2015; Elsinga et al., 2018).

According to the findings of our study, most of the community members (79.3%) are unaware of the types of mosquito bites that may cause dengue infection, and a high degree of confusion in conceptualizing dengue transmission is evident. Dhar-Chowdhury et al.'s (2014) findings revealed that substantial gaps exist between local knowledge and experts' views regarding dengue risk and severity, causes and symptoms of dengue, dengue vector ecology, and dengue transmission risk and control. Despite these gaps, the results of our study revealed some improvements in local community members' basic knowledge about dengue and its vector, serious adverse effects of DF and severe dengue, the association of weather and seasonality with dengue incidence, and disease prevention. This change is likely attributable to recent awareness-building campaigns through the media and collaborative health education programs by the governments and NGOs.

According to the WHO (2014), several specific measures can be taken to prevent and control dengue, including eliminating mosquito breeding grounds, effective solid waste disposal, covering, emptying and cleaning water storage containers every week, applying insecticide, and using window screens, coils and vaporizers. In recent years, some newer measures such as, mosquito control through genetic manipulation, sterile insect technique and attractive toxic sugar baits have also produced promising outcomes (WHO, 2016). A recent multi-country study in Asia found spraying with insecticide was the major vector control measure taken by governments (Arunachalam et al., 2012). However, as Mahmood (2006) found, in our study in Dhaka, two-thirds of the respondents agreed that government control measures were not effective. As well, continued use of pyrethroid based aerosol products should be guided by the insecticide resistance status of the key vectors in sentinel sites. While inquiring about control measures, we found that the most commonly used measures were coils and spraying repellents and insecticides, because of their convenience and affordability to all income groups. These practices indicate an inclination towards private spending in part as a response to the failure or limitations of public programs.

Despite recognition that dengue is a rapidly growing and important disease, there are only a few studies carried out thus far related to the economic aspects (e.g., WTP for vector control and/or vaccine) of the disease (Dickinson et al., 2016; Harapana et al., 2017). Since government authorities, including the Dhaka City Corporation and the national government, are not very active nor effective in controlling the dengue vector and transmission in Bangladesh (Mahmood, 2006; Ferdousi et al., 2015; Dhar-Chowdhury et al., 2016), exploring citizens' WTP privately is crucial. These are all the more important in consideration of the declining trend in public funding for the health sector at large.

Our study, the first of its kind in Bangladesh examining WTP, revealed that the average household spending per month for mosquito control was modest (BDT 101-400, approx. 1.2-5 US$), and the majority of respondents were willing to spend more in the future. A similar study in Florida and Arizona, USA reported that about two-thirds of the study population expressed that they would be willing to pay US $25 more annually, on top of governmental dengue control measures (Dickinson et al., 2016). Conforming to our findings in Dhaka, the US study also observed that education, income and perceived knowledge about the disease are important factors influencing people's WTP. Among the limited studies on WTP thus far, most have revealed that socioeconomic status is highly correlated with WTP, especially in the case of a vaccine, if any were available (Dickinson et al., 2016; Harapana et al., 2017).

Overall, the present study revealed that the majority of local people have some knowledge of dengue, they attempt to control the vector privately considering the local context and are willing to pay for mosquito control to reduce and prevent dengue. However, the use of control measures taken at the individual level is unlikely to be very effective. For example, usage of personal protective insect spray, mosquito coils, bed nets or electric gadgets commonly used by the respondents would only be effective within their household premises. The public spaces where exposure often occurs, such as roads, sewerage and storm drains, public and commercial buildings, vegetated areas, meadows, canals and streams are not covered by such measures.

It is therefore critically important for the public authorities to take up effective dengue vector control measures like spraying/fogging the neighbourhoods regularly or applying appropriate insecticide in vector breeding sites and provide subsidized window/door screens. Further education and training of community members on how to control vectors (e.g. using lidded containers, proper waste disposal) and avoid mosquito bites (e.g. wearing clothes properly covering the body, use spray/coil) is recommended to eliminate the remaining inequities in knowledge attributable to differences in socioeconomic status and education levels. Public health officials and local NGOs can act as a bridge between the government and the community people in controlling and preventing dengue. An integrated and collaborative mosquito control by the government, NGOs and the community people can thus effectively reduce dengue spread and incidence.

The present study was limited in scope by several factors. First, the urban ecological classification part of the study covered only 12 and the KAAP survey only 4 out of 90 wards, and therefore any generalization should be made with caution. Second, the entomological data used in this study refer to a cross-sectional survey period (the monsoon season of 2013), and therefore an analysis of any trends could not be performed. Third, a detailed questionnaire on institutional (both governmental and NGO) control measures was not included. Further research on these issues, along with individual and private sector contributions, concerning effective vector and dengue prevention and control is necessary.

4.5 Conclusion

In this study, we concluded that overall dengue vector abundance in the city of Dhaka is modest to high, primarily affected by household level water storage, and vector spatial distribution is significantly associated with the land use/cover characteristics of the IUEZs. The water containers possessed and used by households produce large populations of *Aedes*, especially during the monsoon, enhancing the risk of pathogen transmission (Paul et al., 2018). Such water container management has likely been influenced by the lack of awareness among a majority of city dwellers about the virus-vector-host relationships and dengue transmission. Effective public and community education campaigns are needed to promote and encourage the implementation of water and waste management strategies by city dwellers as means of dengue vector control. In addition, the private sector, from the perspective of corporate social responsibility, also needs to pay serious attention to dengue prevention and control. This can in part be achieved by implementing and complying with international regulations and standards (e.g., International Health Regulation 2005 to control vectors and reservoirs at point of entry by airport authorities).

Reaffirming findings of other recent studies (Mahmood, 2006; Dhar-Chowdhury et al., 2014; Ferdousi et al., 2015; Dhar-Chowdhury et al., 2016; Paul et al., 2018), our research revealed that government and other institutional interventions to control vector mosquitoes have been sporadic and generally ineffective. Although most households currently spend some of their own funds for vector control within their premises, control in public space is by and large non-existent or ineffectual. In our study, which to our knowledge is the first in Bangladesh on WTP for vector control, we found that all respondents were willing to pay more for effective vector control as they recognized the associated high health risk. However, government programs must continue to support communities through sustainable vector control measures, such as subsidizing the price of window and door screens, mosquito traps and to provide logistic supports for the systematic reduction of mosquito breeding sites. The materialization of such private citizen and private sector roles in city-wide vector and dengue control, however, would require good governance, transparency and accountability from the public institutions dealing with health risks.

Authors' contributions

SI and CEH conceived and designed the study; SI and CEH finalized the study tools and collected data; SI conducted the KAAP survey interviews; SI, CEH and SH contributed to the literature review; SI and SH contributed to data analysis; SI, CEH, SH and DW contributed to data interpretations. SI, CEH, SH and DW contributed to the preparation of the manuscript. All authors read different versions of the manuscript and approved the final version. CEH is guarantor of the paper.

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Ethical considerations and approval

This research was approved by the Bangladesh Medical Research Council, Dhaka, Bangladesh; the University of Manitoba Joint Faculty Research Ethics Board, Winnipeg, Manitoba, Canada. All participants provided informed consent before participation in the study.

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Supplementary Table 4.1: Characteristics of Integrated Urban Ecological Zones (IUEZ), Dhaka, Bangladesh, 2013-14*.

IUEZ	Characteristics
Residential, Vegetation and Bare Soil (RVBS)	Typified by high degree cover of greenspace such as, parks or grassy areas or well-vegetated by trees and other green cover, as well as undeveloped areas with bare soil (Wards 20, 25, 35, 40)
Residential and Water-Bodies (RAWB)	Typified by areas with predominance of residential areas and water-bodies such as lakes, ditches, river, canals (Wards 26 and 58)
Paved Area, Services and Commercial Activities (PASC)	These are the areas with predominance of paved areas (e.g. roads, buildings and other forms of built-up areas) along with public services and commercial activities (Wards 13, 38, 69, 76 and 78)
Commercial, Residential and Industrial Area (CRIA):	Characterized by numerous commercial activities, residential buildings and small and medium industries (Ward 60).

*All of the 90 wards of Dhaka city were grouped into 4 Integrated Urban Ecological Zones (IUEZ) using the Principal Component Analysis (PCA). The application of the IUEZ concept was based on High Ecological Resolution Classification for Urban Landscapes and Environmental Systems (HERCULES) by Cadenasso, Pickett and Schwarz (2007) [Cadenasso, M.L., Pickett, S.T.A., Schwarz, K. (2007). Spatial heterogeneity in urban ecosystems: reconceptualising land cover and a framework for classification. *Frontiers in Ecology and the Environment*, *5*(2), 80-88]. From these 4 IUEZs, 12 wards were chosen by following a stratified random sampling procedure for studying the overall *Stegomyia* indices as well as in each IUEZ.

Chapter 5 – Discussion and Conclusion

5.1 Introduction

The effects of climatic, urban ecological/functional, and human behavioural factors on vector (*Aedes*) density, dengue disease transmission, and disease control measures in Dhaka, Bangladesh were explored in this thesis. This final chapter summarizes the findings of this research as they relate to the four specific research objectives laid out in the planning phase. The following section includes a discussion of the overarching themes identified that broadly connect the thesis findings, followed by a discussion of these findings in the global context. The chapter concludes by highlighting the contributions of the thesis to the existing literature on dengue, its limitations, and recommendations for future research.

5.2 Overview of Findings

The complexity of vector-borne disease transmission calls for an integrated approach considering ecological, biological, and human aspects (Spiegel et al., 2005). Prior studies have identified several risk factors associated with dengue including institutional, political, biophysical, and household factors (Stewart-Ibarra et al., 2014). In a systematic review study, Viennet et al. (2016) revealed that the following specific risk factors are common to dengue outbreaks all over the world: changing climate, urbanization, increasing population, increased population movement, distribution of vectors and water management. These issues and variables, coupled with insufficient vector management and poor awareness and engagement on the part of community members, combine to accelerate the worldwide spread of dengue. Keeping these facts in mind, this study sought to more thoroughly understand the complex interactions within the climate-vector-disease relationships as well as identifying the human/societal aspects affecting the implementation and success of dengue control initiatives. The findings of the study with respect to the original research objectives are summarized in Table 5.1:

Table 5.1: Research findings by objectives.

Research objectives	Major findings
1. To determine the degree to which climatic variability and seasonality affect dengue vector abundance and dengue disease occurrence.	Strong evidence was found for an increase in *Aedes* abundance during seasonal increases in temperature, relative humidity, and rainfall associated with the monsoon, as well as for a subsequent increase in dengue occurrence. Results revealed that mean rainfall (MR) and lag mean rainfall (LMR) were significantly related to Container Index (CI), and that Breteau Index (BI) was significantly and positively related to mean relative humidity (MH) and MR. A highly significant relationship between dengue cases (CAS) and *Stegomyia* indices [House Index (HI), BI] was also observed. In examining longitudinal (2001-2013) data to determine the association between dengue incidence and climatic factors, significant evidence of time lag between MR and CAS was found. A negative association was found between mean rainfall and dengue cases, and dengue cases increased up until an annual average temperature of 26°C.
2. To identify the factors governing *Aedes* mosquito productivity at the household level.	The results revealed that the majority of immature mosquitoes developed in containers located outdoors that are used mostly for household chores. Plastic containers used for household chores produce most of the immature mosquitos. The results of the zero-inflated negative binomial (ZINB) model revealed that pupae production significantly varies by container type. However, when considering container size along with container type, container size is found to be significantly correlated with pupal productivity, with containers greater than 50 litres(L) producing 4.9 times more pupae than containers of less than 1L. Two household ecological factors (shade and type of source of water) are found to be significant for pupae production. Containers with partial shade produce 4.6 times more pupae than those without any shade. The plastic-containers (e.g. refrigerator trays, drums, buckets) and flower tubs/trays were found to be the most abundant immature mosquito-positive containers.

3. To determine the degree to which integrated urban ecological/functionality factors (e.g., urban landscape and neighbourhood environment) affect vector abundance.	The *Stegomyia* indices significantly vary among the urban zones, revealing that the paved and built areas with concentrated public/commercial services have the highest mosquito density.
4. To identify the KAAP of the local community members regarding dengue vector and the disease, influencing factors and their WTP for vector control measures.	Most respondents were aware of DF and DHF and their severity, but many were ignorant of the types of mosquitoes which carried the causative DENV. The Chi-square test showed that education status significantly increases knowledge and awareness of dengue, and that income is significantly related to usage of electronic gadgets (e.g. electric bat) and fan for mosquito control. Multinomial logistic regression (MLR) modelling revealed that average monthly spending on mosquito control, household income, knowledge about the effects of land-use and seasonality on dengue, and the usage of electronic gadgets were significantly associated with the WTP for vector control measures.

Based on the above findings (Table 5.1), the study identified four interdisciplinary themes: the effects of climatic variables on dengue vector (*Aedes*) and disease, the effects of container type, size and household ecological conditions on *Aedes* productivity, the influence of urban ecological/functionality factors on *Aedes* density, and the effects of knowledge, awareness, attitude, and practices (KAAP) of local community members on dengue control measures in Dhaka, Bangladesh.

5.3 Overarching Themes

Despite the extensive research already done on the individual driving factors of dengue transmission and incidence, a holistic understanding of the interactions within the climate-vector-disease relationships remains an incredibly challenging goal. However, such an understanding is essential for developing disease management measures as dengue continues to spread and place millions of people worldwide at risk of infection.

5.3.1 Climatic Factors and Dengue

The disease epidemiology for emerging infectious diseases (EIDs) like dengue remains a poorly-researched area (Teixeira et al., 2005; Moore, 2008; Brisbois & Ali, 2010; Laughlin et al., 2012) and is still commonly understood as being purely pathogen-driven or vector-driven. While some epidemiologists have incorporated climatic factors into their analyses, climate is largely regarded as a separate, unrelated field (Githeko et al., 2000; Semenza & Menne, 2009; Murray, Quam & Wilder-Smith, 2013; Lorenz et al., 2017).

Most studies on dengue have been conducted in tropical areas where disease transmission occurs at an optimal temperature range of 20-35°C (Kuno, 1995; Wu et al., 2010; Yu et al., 2011). Previous studies in various countries reported a positive association between temperature, mosquito abundance/density and dengue transmission (Nagao et al., 2003; Thammapalo et al., 2005; Jury, 2008; Hii et al., 2009; Tseng et al., 2009; Wu et al., 2009; Wu et al., 2010; Yu et al., 2011; Colón-González et al., 2013; Banu et al., 2014; Naish et al., 2014) Studies have shown that dengue outbreaks in most countries coincide with the wet season and increased precipitation (Nagao et al., 2003; Nakhapakorn & Tripathi, 2005; Arcari, Tapper & Pfueller, 2007; Hsieh & Chen, 2009; Su, 2008; Yu et al., 2011; Colón-González et al., 2013; Naish et al., 2014). However, there are regions where dengue epidemics were recorded during periods of low rainfall, with no positive correlation found between rainfall and dengue transmission (Norman, Theodre & Joseph, 1991; Biswas et al., 1993). In an Indonesian study, relative humidity was found to be the most important predictive factor for dengue outbreaks with a 3-4-month lag time (Halide & Ridd, 2008). This study also observed that people store water in open containers during dry periods, resulting in high dengue incidence as the containers became breeding grounds for vector mosquitoes. On the other hand, in Thailand dengue cases were largely reported in high-humidity environments (Nakhapakorn & Tripathi, 2005).

The results of the present study indicate that dengue vector abundance is significantly influenced by climatic factors, though the significance of this relationship varies for each index and pair of factors. The regression model reveals that climatic factors account for about 72% of the variability in Breteau Index (BI), which aligns with conclusions drawn by several other studies conducted in tropical regions (Nakhapakorn & Tripathi, 2005; Tseng et al., 2009; Barrera, Amador & MacKay, 2011; Pham et al., 2011; Naish et al., 2014; Cheng et al., 2016).

The study revealed that dengue cases in Dhaka are significantly related to *Stegomyia* indices. However, as the relationship between vector abundance and dengue cases is found to account for only 49% of the variability in dengue incidence in Dhaka, there remains much research left to do on the roles of other factors such as adult mosquito numbers, herd immunity, and population density. The results of the generalized linear model explain 93% of the variability in dengue cases while considering climatic factors. It is evident from the findings that of all climatic factors, rainfall has the most influence on dengue incidence in Dhaka (also see Karim et al., 2012).

A significant negative association between rainfall and dengue cases was observed, which may be attributed to continuous heavy rainfall washing larvae from their breeding sites into fast-flowing rivers and killing them. The study also showed that dengue cases exhibit a yearly cyclical pattern, with higher incidence beginning in the monsoon season (June-October), reaching a peak in August (also see Sharmin et al., 2015), and reaching a minimum in the pre-monsoon period of

January-April in alternate years. The findings of our longitudinal study revealed that in Dhaka, temperature has a profound effect on vector breeding and DENV spread. Overall, our study revealed that dengue incidence rises with annual average temperature up to 26°C, after which it begins to decrease.

5.3.2 Dengue Vector Productivity

The transmission of dengue virus (DENV) is complex and the productivity of the vector is one of the most important driving factors for in dengue outbreaks. It is well-established that the bite of container-inhabiting mosquitoes (*Ae. aegypti* and *Ae. Albopictus)* transmit DENV to humans (Banu et al., 2012; Dhar-Chowdhury et al., 2016). Previous studies emphasized on the significance of measuring container productivity while quantifying pupal counts (Barrera, Amador & Clark, 2006a; Arunachalam et al., 2010; Barrera, Amador & MacKay, 2011; Stewart-Ibarra et al., 2013; Dhar-Chowdhury et al., 2016) and the "most productive containers" are usually found outside household structures (Barrera, Amador & Clark, 2006b; Mboera et al., 2016; Ngugi et al., 2017). Literature also states that the pupal productivity is affected by the ecology of the container sites (Vezzani & Albicóocco, 2009). As data and literature on *Aedes* abundance and its associated dynamics in Bangladesh are limited (Ferdousi et al., 2015; Dhar-Chowdhury et al., 2016), my thesis research attempted to determine the *Aedes* mosquito productivity of household containers based on their size and usage.

The study revealed that for both larvae and pupae, the "most positive containers" are of medium size – between 1 and 50 litres (L) and kept outside for use in household chores. However, the "most productive containers" for pupae were larger (over 50 L) and used mainly for water storage because of poor water supply system (Ferdousi et al., 2015; Dhar-Chowdhury et al., 2016;

Paul et al., 2018). My research findings have also revealed that, refrigerator trays (plastic), flower tubs and trays, plastic drums, and plastic buckets were the most abundant positive containers, corroborating the findings of Elsinga et al. (2018) and Dhar-Chowdhury et al. (2016). It was also found that human behavioural elements or activities significantly affect container use, vector breeding, and pupae production which are similar to findings of other studies (Padmanabha et al. 2010; Barrera, Amador & MacKay, 2011; Arduino, 2014; Dhar-Chowdhury et al., 2016). Many of these containers are used for household chores (e.g. bottles, buckets or drums) and not regularly emptied, creating favourable breeding sites for mosquitoes.

My study also revealed that the most productive containers in Dhaka were those used for water storage and were made of plastic. It is evident from the findings of this study, as well as others (Fulmali, Walimbe & Mahadev, 2008; Alcalá et al., 2015; Anders et al., 2015), that increased usage of these plastic containers is associated with urbanization and the alteration of natural vector habitats. Poor access to piped water compels many people to store water for household chores in open containers, creating ideal mosquito breeding sites (Ferdousi et al., 2015; Sharmin et al., 2015; Dhar-Chowdhury et al., 2016).

Some studies have found that larger water containers (5-2000L) were most productive in terms of pupal development (Alcalá et al., 2015; Ferdousi et al., 2015; Morales-Pérez et al., 2017). Results of this study revealed that container size is confounded with pupae production and container type; being the pre-dominant factor for most productivity of the pupae, where ≥50 L containers are 4.88 times more productive when compared to < 1 L sized containers. These results are similar to the findings of other studies which mentioned that *Aedes* productivity increases positively with the container size (Harrington et al., 2008; Richardson et al., 2013; Schafrick et al., 2013).

My research also identified that partial shade from sunlight/light and the type of water source were more likely to facilitate or limit pupal production than other factors - a finding corroborated by prior studies (Barrera, Amador & Clark, 2006b; Padmanabha et al., 2010). It was also found that containers located outside with stored tap water that remain uncovered for long periods of time are the most productive breeding grounds for immature *Aedes*.

5.3.3 Urban Ecology/Functionality and Dengue

A number of prior studies have examined the effect of vector density, spatio-temporal distribution of urbanization, changes in land-use, and population growth on the spread of the vector and DENV. Some revealed that the Breteau Index (BI) is a better predictor of dengue incidence (Chiaravalloti-Neto et al., 2015; Sanchéz et al., 2006; Sanchéz et al., 2010); while others asserted that the 'pupae-per-person' index (PPI) is superior (Focks & Alexander, 2006; Seng et al., 2009). A number of spatio-temporal studies noted that vector abundance and disease transmission can vary spatially (Arboleda, Jaramillo-O & Peterson, 2012; Sarfraz et al., 2012; Delmelle et al., 2016; Reyes-Castro et al., 2017; Xavier et al., 2017) due to changes in environmental factors (Delmelle et al., 2016; Xavier et al., 2017) land-use, land cover and urbanization (Sarfraz et al., 2012; Li et al., 2014), population density, and socioeconomic factors (Delmelle et al., 2016; Reyes-Castro et al., 2017). Better understanding of these spatial relationships could be vital to developing better intervention strategies for controlling the spread of DENV.

In Bangladesh, the main factors affecting dengue transmission are high population density, poor waste management facilities (Mahmood & Mahmood, 2011), rapid unplanned urbanization (Mahmood & Mahmood, 2011; Sharmin et al., 2015), environmental changes, and changing human mobility (Sharmin et al., 2015). Recognizing that urban ecological zones may be associated with vector abundance and density, this study attempted to examine these complex relationships by analysing vector density within Integrated Urban Ecological Zones (IUEZs) following the urban zoning classification approach (Pickett & Cadenasso, 2006; Cadenasso, Pickett, & Schwarz, 2007).

Results of my study showed a comparatively lower PPI (0.54) than other studies conducted in Southeast Asian countries (Barbazan et al., 2008; Seng et al., 2009), which is likely due to the extremely high population density of Dhaka. The PASC zone, characterized by the predominance of paved and built-up areas including residential, service, and commercial buildings and other infrastructure, had the highest mosquito density in terms of House Index, Breteau Index, Container Index and PPI. Previous studies have also confirmed that urbanization (Mahmood & Mahmood, 2011; Li et al., 2014; Sharmin et al., 2015; Delmelle et al., 2016) is a key factor for increased mosquito (*Aedes*) density. Overall findings of the thesis of varying mosquito density by IUEZ are similar to a Brazilian study that observed variable dengue vector distribution among and within neighbourhoods (Xavier et al., 2017) implying a strong positive correlation of vector productivity and abundance with urban infrastructure, surrounding environment and supportive habitat within the households. Several studies in this context have stated that changes in land use/surface area, water-bodies, vegetation coverage, and surface type associated with urbanization all contribute to enhancing *Aedes* breeding habitats (Sarfraz et al., 2012; Li et al., 2014; Delmelle et al., 2016).

5.3.4 Knowledge, Awareness, Attitude and Practice and Dengue

Numerous studies have revealed that better knowledge and awareness of the vector and dengue disease among city dwellers is associated with a reduction in vector breeding (Arunachalam et al., 2010; Arunachalam et al., 2012; Castro et al., 2013; Mayxay et al., 2013; Paz-

Soldán et al., 2015; Lugova & Wallis, 2017; Elsinga et al., 2018). As no systematic study has yet been conducted in Bangladesh regarding inhabitants' KAAP regrading dengue and WTP regarding vector control, my study adds enormous value to the existing literature. This study revealed that *Aedes* abundance is significantly influenced by city dwellers' KAAP, particularly in respect to managing water containers within their premises as sources of infestation (Dhar-Chowdhury et al., 2014; Ferdousi et al., 2015). As about one-third of the residents of Dhaka do not have access to piped potable water (Mahmood, 2006; Dhar-Chowdhury et al., 2016), they tend to store water and inadvertently create mosquito development sites.

The present study identified that education level is significantly associated with the KAAP of city dwellers regarding dengue, which is similar to Paz-Soldán et al.'s (2015) study. It was also revealed in the current study that an overwhelming majority of the respondents agreed that dengue infection and spread can be prevented, and the majority knew that land-use change, weather and seasonal differences contribute to dengue incidence.

Conforming with the findings of this research, some studies have asserted that people with better knowledge of the vector and the disease were associated with lower breeding rates (Paz-Soldán et al., 2015; Elsinga et al., 2018). According to these studies, knowledge and education led to change human practices and behaviour, which eventually reduce vector breeding and dengue infection rates. According to the findings of this study, most of the community members are unaware of the types of mosquito bites that may cause DENV infection, and there is a high degree of confusion about the transmission.

Despite these gaps, the results of my study revealed some degrees of basic knowledge of the community members about dengue and its vector, DF and DHF severity and disease prevention. This general knowledge is likely attributable to recent awareness-building campaigns run by government education programs and NGOs.

Various vector control measures mentioned in the literature (Arunachalam et al., 2010; WHO, 2014; Achee et al., 2015; WHO, 2018) had been linked to local people's knowledge, practices and government interventions (Tseng et al., 2009; Arunachalam et al., 2010; Achee et al., 2015). On control measures, a number of studies focused on willingness-to-pay (WTP) for vector control and vaccination. In a previous study in the USA, WTP was found directly associated with income and education (Dickinson et al., 2016). A research in Taiwan identified that knowledge of changing climate increasing the dengue transmission influenced the community people to pay more to control dengue vector (Tseng et al., 2009). With public services in developing countries largely falling short on disease-control initiatives, focus has increasingly shifted to private citizens' individual efforts to mitigate the spread of dengue (Harapana et al., 2017).

Two-thirds of the respondents in my study agreed that government control measures were not effective; which contradicts a previous multi-country study in Asia which found that spraying with insecticide was the major vector control measure taken by the studied governments (Arunachalam et al., 2012). My study further found that the most commonly used mosquito control measures in Dhaka were mosquito coils and spraying individual-sized repellents and insecticides because of their convenience and affordability to all income groups. Despite a recognition of the growing threat of dengue, relatively few studies have been conducted on the economic aspects (e.g. WTP for vector control and/or vaccination) of the disease (Dickinson et al., 2016; Harapana et al., 2017). Since government authorities are not very active nor effective in controlling the dengue vector and transmission in Bangladesh (Mahmood, 2006; Ferdousie et al., 2015; Dhar-

Chowdhury et al., 2016), determining citizens' WTP privately is crucial to developing effective disease-control methods. This study revealed that the majority of respondents were willing to spend more in the future on dengue disease control in Dhaka, and that education, income and perceived knowledge of the disease are important factors influencing people's WTP.

5.3.5 My Reflections and the Research Journey

The long winding path of the PhD journey had been very challenging, and I must acknowledge that it increased my knowledge manifold and enlightened me in various aspects. With a bachelor's degree of science majoring in Environmental Management with an Economics minor, and a master's degree of science in Regional and Rural Development Planning, I commenced the journey of the doctoral degree to combine at least one or two of my previous fields of expertise. Therefore, I started with gaining knowledge through various types of credited course-works including climate sciences, epidemiology, biostatistics, climate change adaptation and even extended to just attending lectures of entomology and human ecology. Combining pertinent knowledge with my prior exposure to environmental management, quantitative and qualitative statistics, I found the opportunity to try out a new dimension – the scope of an "interdisciplinary" study through the IDRC's Ecohealth Program sponsored research project on "Climatic Variability, Social-Ecological Changes, and Dengue Disease in Bangladesh". The research started with the proposal development which included a conceptual framework including the study of the climatic factors, urban ecological factors, vector productivity, and human/social dimensions with different sets of feedback loops. For this study, I chose the capital city of Dhaka in Bangladesh as this is one of the fastest growing cities of the world and has a recent history of dengue.

After completing the comprehensive examination and obtaining ethics approval, the field work in Dhaka, Bangladesh provided me with hands-on experience of KAAP survey, interviews and secondary data collection. During the fieldwork, I faced major challenges regarding surveillance data on vector and dengue cases for a trend analysis study. Moreover, there was no access to the private sector's (private hospitals and clinics) data. Therefore, I had to settle for a cross-sectional study for vector productivity and the human/social part of the study. The major outcomes of my study were as follows:

1) No prior researches in Bangladesh studied the climate-vector-disease relationships holistically, with most research assuming a linear causal relationship between climatic factors and dengue incidence. My study regarded all three factors as an interconnected system and investigated the complex relationships between them with regards to dengue transmission. It also analyzed a trend showing association between seasonality and dengue cases and a climate anomaly trend for 13 years, revealing the optimal temperature and rainfall conditions associated with dengue outbreaks.
2) My thesis research findings revealed that container size along with containers types, location, and household ecology are very important factors in *Aedes* mosquito productivity. These findings make this study a unique one in the context of Bangladesh while revealing the significant factors of vector productivity and pointing out that human behavioral and attitude are very important in creating vector habitat.
3) The study showed that *Aedes* mosquito (immature) density is significantly related to integrated urban ecological zones, revealing that the paved and built areas with concentrated public/commercial services have the highest mosquito density. This is a very unique contribution to Bangladesh studies.

4) The KAAP survey revealed the current state of knowledge, awareness, attitude and practices among community members regarding dengue transmission, risk, and control. The study also determined the factors influencing people's willingness to pay (WTP) dengue control measures - the first study of its kind in Bangladesh to do so.
5) Based on the complex systems theory and the works of Lebel (2003) and Caprara et al. (2009), I followed the epistemological plurality approach incorporating four thematic areas, and eventually developed a framework for integrated dengue management systems. Through this study I realized that without an integrated and simultaneous process, an infectious disease like dengue cannot be controlled or prevented.

Figure 5.1 is a comprehensive framework for dengue management which shows all probable contributing factors of vector abundance and dengue disease occurrence. This integrated dengue management system model for the city of Dhaka includes four major elements: climatic factors, vector ecology, urban ecology, and human/social elements. All these elements together capture the epistemological plurality of the study.

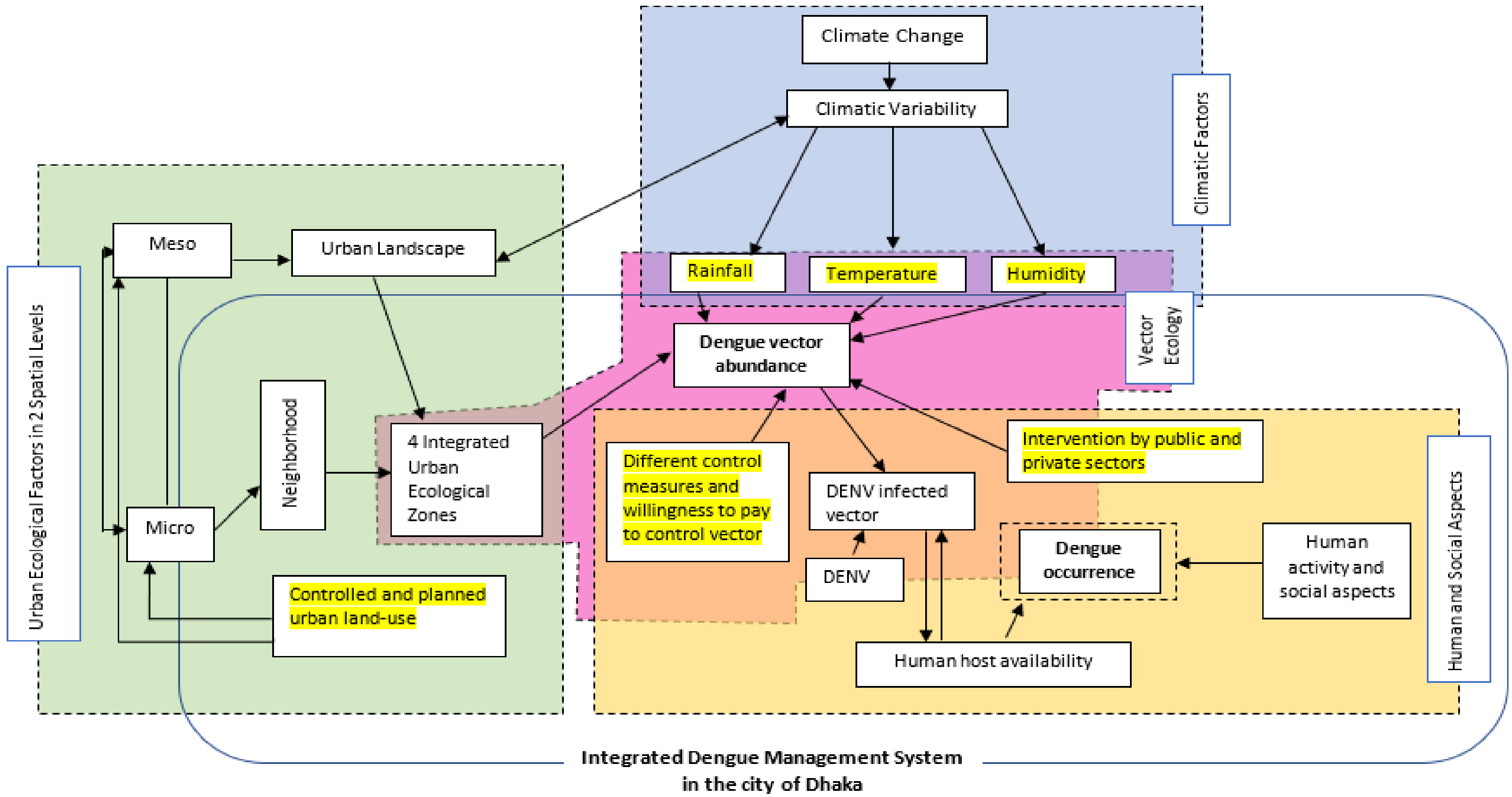

Figure 5.1: Integrated Dengue Management System: coupling between socio-ecological aspects (conceptualized after Lebel, 2003 and Caprara et al., 2009). This diagram is a simplified version of an elaborated figure shown in Appendix 5.A.

The present study focused on climate variability, vector productivity, urban ecology/functionality, and human interaction and practices while revealing four major intervention areas (highlighted in yellow in Figure 5.1) for vector control and disease mitigation. These intervention points are as follows:

- The results of the study confirmed that climatic factors (temperature, rainfall and humidity) are very important factors along with the seasonality in Bangladesh and that the monsoon/post-monsoon time are very crucial times for dengue transmission. We cannot control the climate, but human interaction with this physical attribute of the nature can be altered by targeting vector control methods during peak mosquito-breeding periods.

- The micro-level of the spatial distribution incorporating household and neighbourhood studies through IUEZs analysis under this thesis explains how important urban zoning are for *Aedes* mosquito control by showing significant variation of vector density by IUEZ. This implies that intervention through controlled and planned urban land-use is crucial in terms of vector control. The government of Bangladesh through Dhaka City Corporation can play a vital role in planning and controlling the land-use in Dhaka.

- Findings regarding vector productivity at the household level revealed that household container usage should be controlled through targeting different types and size of container producing *Aedes* mosquito. Such interventions should be implemented both by community members and the government.

- Our findings indicate that improved KAAP and proper and effective control measures coupled with the willingness to pay for mosquito control can bring about significant decrease in vector and prevent dengue incidence in Dhaka.

5.3.6 Future Research Opportunities

Given its limited scope, this research could not cover all aspects of vector abundance and dengue disease incidence and leaves room for further research in a number of areas. Based on the findings of this study, the following areas are recommended for further research:

- Study of mosquito bite rates, the infection rate of adult *Aedes* mosquitoes, and genetic characteristics of the human host population. Nominal investigation has already carried out in these areas in Bangladesh. Recognizing the importance of estimating the 'vectorial capacity' of the *Aedes* mosquitoes, research in these thematic areas is urgently needed.
- Investigation of abundance/density of adult *Aedes* mosquitos, the extrinsic incubation period, and 'vectorial capacity' is urgently required as these are vital factors for accurately predicting the risk of dengue outbreaks.
- Determination of the relationships between herd immunity, population density and dengue incidence. This would provide an estimate of the population at risk for future dengue outbreaks.
- Identification of the factors affecting the dengue serotypes and their interactions. Current knowledge is mostly limited to clinical data, and there is very limited knowledge and information on population-based serotypes of DENV.
- Longitudinal entomological and dengue incidence data collection for understanding the trend in disease dynamics are required. Current entomological data sets, provided by the Directorate General of Health Services (DGHS) of the Government of Bangladesh, do not cover entomological data of all the months of various years, rather they are fragmented. Also, the data-sets on dengue cases, provided by the DGHS, are hospital/clinic-based and therefore of limited scope and utility. In Bangladesh, poor and marginalized groups

affected by DF/DHF do not usually report to hospitals and are thus not accounted for in government data. Therefore, a population-based longitudinal data collection and their effective analysis are urgently needed.

5.4 Scholarly Contributions of the Thesis

Interdisciplinary study

My research contributes to both theoretical knowledge and practical applications within the public health sector. Prior studies on DF transmission have largely followed a disciplinary approach, studying the disease from a single narrow perspective - biomedical, climatological, ecological, sociological etc. By following an interdisciplinary, epistemologically pluralistic approach, my study integrates the climatological and multi-level, integrated urban ecological factors while incorporating human dimension. The findings of my study also contribute to the IDRC-funded project on DENV infection and transmission study in Bangladesh. As my research also encompasses the perception of the disease, climatic variability, integrated urban ecological factors, from a 'social-ecological system' perspective, these aspects contribute to the growing body of work on the "epistemological pluralistic" interdisciplinary research approach.

Climate trend and dengue

The implications of climate change for the future spread of dengue are potentially profound. My study applied an innovative step-by-step approach to determine the causal associations within the climate-vector-disease relationships in Dhaka, Bangladesh. The study established a significant correlation between climatic factors and vector abundance, and between vector abundance and dengue occurrence, an integrated, holistic result not matched by any prior studies in the region. Also, by studying the relationship between seasonal variation and dengue incidence accounted for 13 years, and long-term climate trends (climate anomaly) and dengue incidence over a 13-year period, the study generated a useful data set for future researchers seeking to study the effects of climate change on dengue transmission.

In-depth study on vector productivity

The study inspected household premises in the city of Dhaka, Bangladesh and revealed the magnitude and dynamics of immature *Aedes* development, with a focus on the role of containers in pupal production. Previous studies carried out in Bangladesh investigated some aspects of pupal productivity, but did not reveal the effects of container size, type, usage, and placement in one single study. In addition, this study used the ZINB technique in its analysis, resulting in more precise findings.

Ecological effects on vector

This research studied the household ecological factors affecting container pupal productivity and found that the amount of shade and source of the water were significant factors It was also found that urban zones with more built and paved areas had the highest abundance/density of *Aedes* mosquitoes. These results demonstrate that changing urban ecology is one of the major reasons for the accelerating spread of dengue, especially in Dhaka, Bangladesh.

Willingness to pay for vector control

My thesis research found that mosquito abundance and the spread of dengue are related to local inhabitants' knowledge and awareness of dengue and its vectors. This knowledge is in turn positively correlated with education and vector control measures are influenced by income. Willingness to pay (WTP) for mosquito control measures among the community members was found to be highest in the RVBS zone where the average cost per month for mosquito control, household income, knowledge of land-use and dengue season causing dengue and usage of electronic gadgets for mosquito control have significant effects on willingness to pay. To my knowledge, this study is the very first of its kind in Bangladesh.

Applied study with policy implication

The results of this study are intended to assist in formulating appropriate policies for controlling vectors and preventing the spread of dengue disease in Bangladesh and other affected areas. Overall, my research, through the integrated dengue management framework, is expected to assist the public health sector of Bangladesh and has the potential to be adopted worldwide.

5.5 Limitations of the Study

There are some limitations to this study:

Firstly, continuous time-series data on dengue vector and cases were not available from the government depository for the study period, which limited the analysis.

Second, the entomological surveys that collected data on *Aedes* larvae from households in Dhaka did not cover the same areas throughout the study period. Therefore, the study relied on adjusted data for specific areas which were covered repeatedly by all survey periods over a 5-year period.

Third, due to the unavailability of time-series data on other variables, I was unable to incorporate other contributing factors such as household water-use, vector control measures, and land-use changes into the trend analysis.

Fourth, due to resource, time, and data constraints, I could not closely investigate the relationship between climatic factors and vector breeding. The variations due to seasonality (wet and dry) could not therefore be analysed. However, data on immature *Aedes* productivity were incorporated into my findings.

Fifth, the study only investigated water containers within household premises and thus left out other possible mosquito breeding sites in the urban macro-environment. Also, the categorization of containers by size, for example, 1L-50L, is a broad group in terms of mosquito breeding. Smaller categories could be considered in future research to provide more precise results.

Sixth, this research focused only on immature mosquito production and did not account for adult mosquitoes. Therefore, the extrinsic incubation period and infection rate could not be estimated, which would provide a more accurate prediction of risk and a more precise outbreak prediction model.

Seventh, this study only covered 12 wards (of 90 wards) of Dhaka, and the entomological data was collected during only one season (monsoon) in 2013. Therefore, city-wide or seasonal trends could not be assessed. The KAAP survey was also only conducted in 4 wards, which is not a large enough sample to accurately represent the entire city or country.

Eighth, a detailed questionnaire on institutional (governmental and NGO) control measures was not included. Further research on these issues, along with individual and private sector contributions, concerning effective vector and dengue prevention and control is required.

Ninth, there is no surveillance data on vector or dengue disease incidences in Bangladesh for longitudinal analysis. Moreover, the limited data available are not centralized as there is no data sharing policy procedure in place across the different administrative authorities of Bangladesh. This was the most crucial limitation of the present study.

5.6 Conclusion and Recommendations

Applying the theory of Landscape Epidemiology for the study of mosquito-borne diseases in rapidly-changing urban ecosystems, Lambin et al. (2010) argue that the spatial variations at different levels in infection risk can be viewed through the pathogenic cycle and the biology of vectors, hosts and pathogens, ecosystem processes, and land use. These are in turn driven by many factors such as landscape scale, structure, composition, connectivity, climate, species interaction within themselves and with humans, human behaviour and mobility, knowledge and perception of disease risk, and socio-economic conditions. This thesis attempts to holistically study the climate-vector-host relationship at different levels, with the intention of filling the gaps in our understanding of dengue and its prevention/control by developing an integrated conceptual framework.

The integration of climate data, entomological data, human knowledge, attitude and practice data into the climate-vector-host-dengue nexus to produce a complete predictive model of dengue incidence and transmission has not yet been fully realized. This thesis offers a strong foundation for future work on dengue forecasting and prevention. It is critical, however, to emphasize that in order to succeed, all such efforts require the collection of accurate time-series data on climatic factors and dengue cases by the appropriate national authority in every country of the world, including Bangladesh. Some recommendations to improve dengue control and prevention process are as follows:

- City dwellers must take action to reduce the number of open water containers in use in order to deny breeding sites to DENV-carrying mosquitoes.
- Mass and community-focused awareness-building and health education campaigns emphasizing the role of *Aedes* in dengue transmission, and the need to use for closed water

containers, and clean household premises are needed in order to further reduce mosquito breeding sites.

- Responsible authorities must target the most productive containers for *Aedes* habitat management in order to undertake efficient measures for vector control.
- A centralized surveillance system for vectors and dengue disease cases is desperately in need in Bangladesh and other affected / at-risk countries.
- As Stewart-Ibarra et al. (2014) outlines in their study, the Government of Bangladesh should focus on more institutional coordination, implement more public vector control initiatives, coordinate with local communities, and improve health education and monitoring programs and monitor all the aspects related to dengue.

In conclusion, all the stakeholders of society including the government policymakers, NGOs, the private sector, and community members should be involved in the dengue control and prevention process. Dengue can be controlled only with a coordinated and integrated system of conceptualization, explanation, and application of interventions. The materialization of such private citizen and private sector roles in city-wide vector and dengue control, however, would require good governance, transparency, and accountability from the public institutions dealing with health risks.

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Appendix 1.A – Ethics Approval

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APPROVAL CERTIFICATE

November 4, 2013

TO: **Sabrina Islam** (Advisor E. Haque)
Principal Investigator

FROM: **Susan Frohlick, Chair**
Joint-Faculty Research Ethics Board (JFREB)

Re: **Protocol #J2013:120**
"The Threat of Dengue Fever in Bangladesh: Effects of Climate Variability and Ecological Factors on Dengue Vector Abundance and Dengue Disease Occurrence"

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, please mail/e-mail/fax (261-0325) a copy of this Approval (identifying the related UM Project Number) to the Research Grants Officer in ORS in order to initiate fund setup. (How to find your UM Project Number: http://umanitoba.ca/research/ors/mrt-faq.html#pr0)**

- **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

Appendix 1.B – Research Questions

To formulate an integrated control, prevention, and mitigation plan for dengue infection in Bangladesh, it is very important to know about how both the physical environment and human factors affect dengue vector abundance and dengue disease occurrence. The physical environment, climate variability, and the rapidly-changing urban ecology are of particular interest here. Keeping these in mind, this study attempted to answer the following research questions:

1. How and to what extent are climatic variability and seasonality correlated with dengue vector abundance and dengue disease occurrence in the human population?

2. How is *Aedes* mosquito productivity distributed and what are the important factors influencing mosquito productivity in Dhaka?

3. How and to what extent are urban ecological/functionality factors (e.g. the urban landscape and neighbourhood environment) and the human environment related to dengue vector abundance?

4. What knowledge, awareness, attitudes and practices (KAAP) do local community members possess regarding changes in seasonality, climate variability, and integrated urban ecology and their effects on vector breeding sites, vector abundance and dengue disease occurrence? How do urban dwellers currently control mosquito populations and what is their willingness to pay (WTP) for vector-control measures at household level?

Appendix 1.C – Detailed Conceptual Framework (Initial)

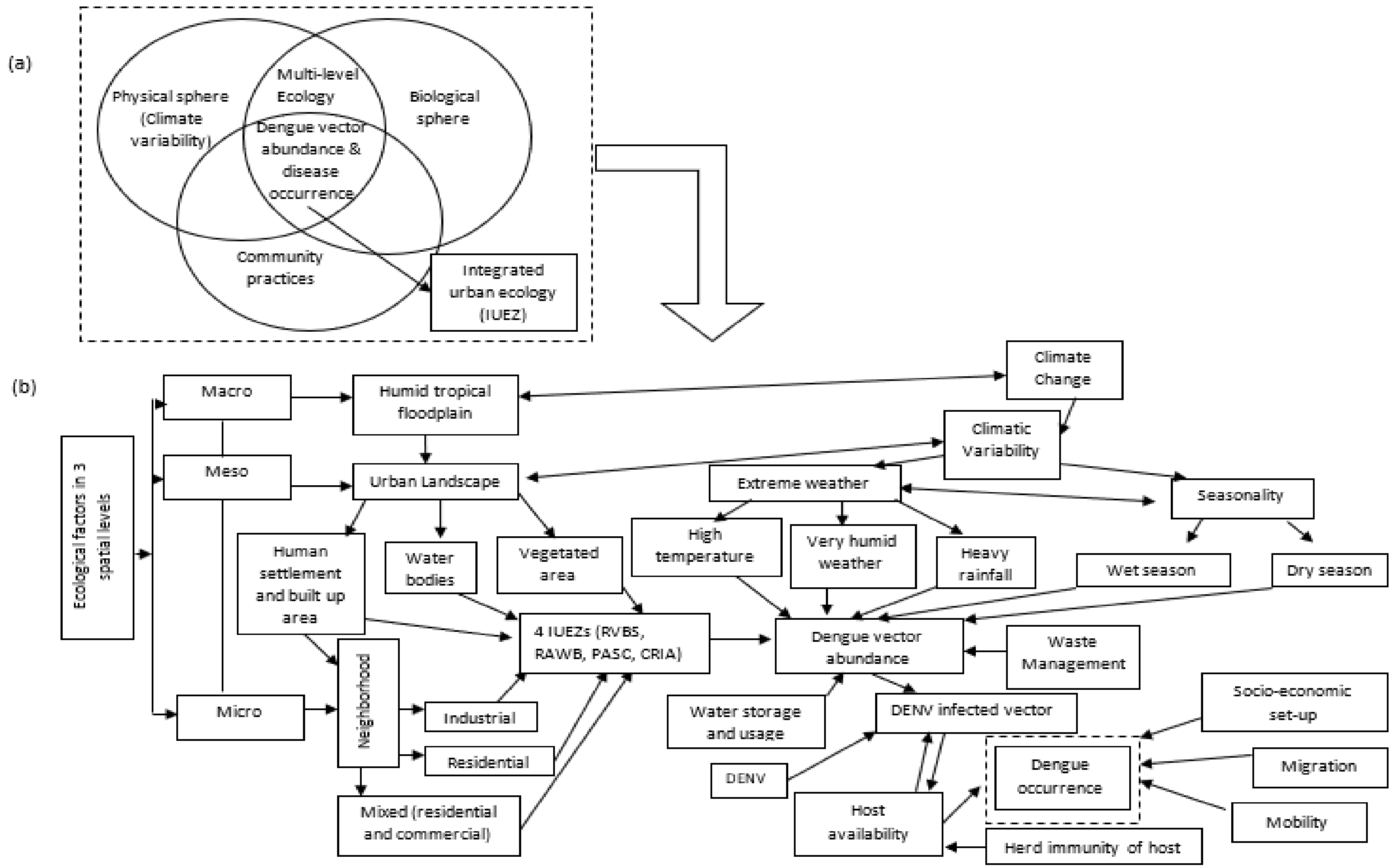

Figure 1.C: (a) Climate-ecological model for dengue vector abundance. (b) Conceptual framework showing relationships amongst climate, ecology and dengue vector abundance and dengue occurrence [both (a) and (b) are conceptualized after Lebel, 2003 & Caprara et al., 2009].

Appendix 1.D – Delineation of Urban Ecological Zones, Map creation and classification

Rapid Eye Image of 15 January 2013 for Dhaka city ($23^0 40^/ 09^{//}$ N to $23^0 54^/ 05^{//}$ N and $90^0 19^/ 45^{//}$ E to $90^0 30^/ 35^{//}$ E) was purchased for identification of present land cover status of Dhaka city. Supervised classification with 6 training samples and 4 test samples for each of the categories were selected for the land cover classification. The ancillary data were collected (between 2008 and 2015) from different governmental sources. These agencies included Water Development Board of Bangladesh, Department of Roads and Highways, Local Government Engineering Department (LGED), Dhaka City Corporation and *Rajdhani Unnayan Kortripokkho* (Dhaka City Development Corporation).

Maximum likelihood classification technique was applied for the supervised classification. Dhaka city authority already has a generalized land-use classification of the year 2015. The ancillary data was overlayed with the classified land-cover map. The land-use classes of the Dhaka city ancillary data were then connected with the Rapid Eye classified imager through *Spatial Join* operation in Arcmap 10.1. Several geoprocessing tools were employed to get a generalized land-use and land-cover map for Dhaka city. The output map was projected at Bangladesh Transverse Mercator Projection. (Projection parameters are: False Easting = 500000, False Northing = -2000000, Central Meridian = 90^0, Scale Factor = 0.9996)

The average percentage of each landcover type for each of the 90 wards was determined by overlaying the ward boundaries on the landcover map and summarizing by zone in Arcmap 10.1. A classification [based on seven indicators: bare soil and built area (building and paved area), water surface, vegetation, residential area, public services and commercial area, commercial and industrial area] into Integrated Urban Ecological Zones (IUEZ) was performed using R function

agnes from R-package ***cluster*** (Struyf, Hubert & Rousseeuw, 1997). The association matrix was based on chord distance (Legendre & Legendre, 2012) using the ***designdist*** function from the ***vegan*** R-package (Dixon, 2003) and Ward's as the clustering method (Struyf et al., 1997). A dendrogram of the "*wards*" (administration unit) was produced and four urban zones were identified. For visualization purposes a PCA of the Wards was also produced using the ***prcomp*** function in the statistical software R (R Core Team, 2019).

The IUEZs are described briefly:

1) IUEZ 1- Residential, Vegetation and Bare Soil (RVBS): Typified by high cover of greenspace such as parks or grassy areas or well-vegetated by trees and other green cover, as well as undeveloped areas with bare soil (e.g Wards 20, 25, 35, 40);
2) IUEZ 2 - Residential and Water-bodies (RAWB): Typified by areas with pre-dominance of residential areas and water-bodies such as lakes, ditches, river, canals (e.g Wards 26 and 58);
3) 3) IUEZ 3- Paved area, Services and Commercial Activities (PASC): These are the areas with pre-dominance of paved areas (e.g. roads, buildings and other forms of built-areas) along with public services and commercial activities (e.g Wards 13, 38, 69, 76 and 78);
4) 4) IUEZ 4 – Commercial, Residential and Industrial Area (CRIA): Characterized by many commercial activities, residential buildings and small and medium industries (e.g Ward 60).

All the 90 wards of Dhaka city were put in the principal component analysis (PCA) run and were grouped in the above mentioned four classes. From these, 12 wards in four IUEZs (as mentioned above) were chosen, for studying *Stegomyia* indices, based on the close proximity to the centre (average) of the classified IUEZs, their acquaintance with the urban functioning and availability of entomological data. Then, four study sites (out of these 12 wards) were selected based on close proximity to the centre for the HH survey: Ward 20 for IUEZ 1 (RVBS), Ward 26 for IUEZ 2 (RAWB), Ward 69 for IUEZ 3 (PASC) and Ward 60 for IUEZ 4 (CRIA).

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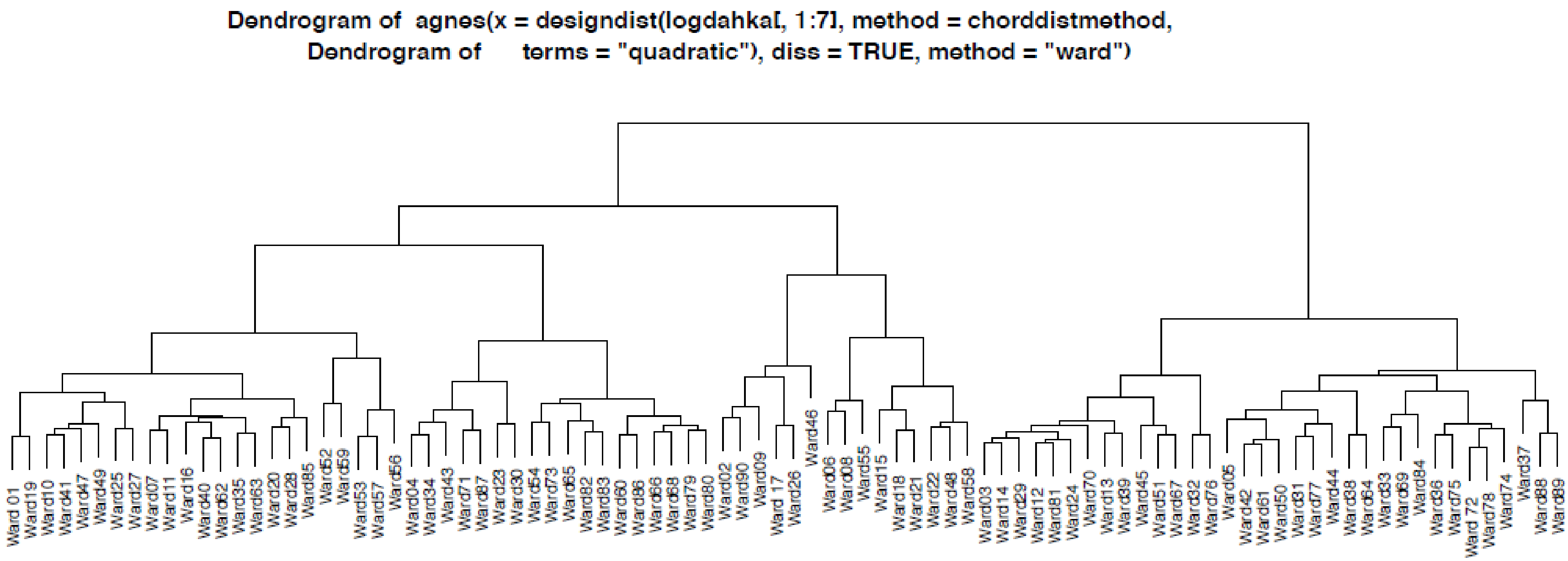
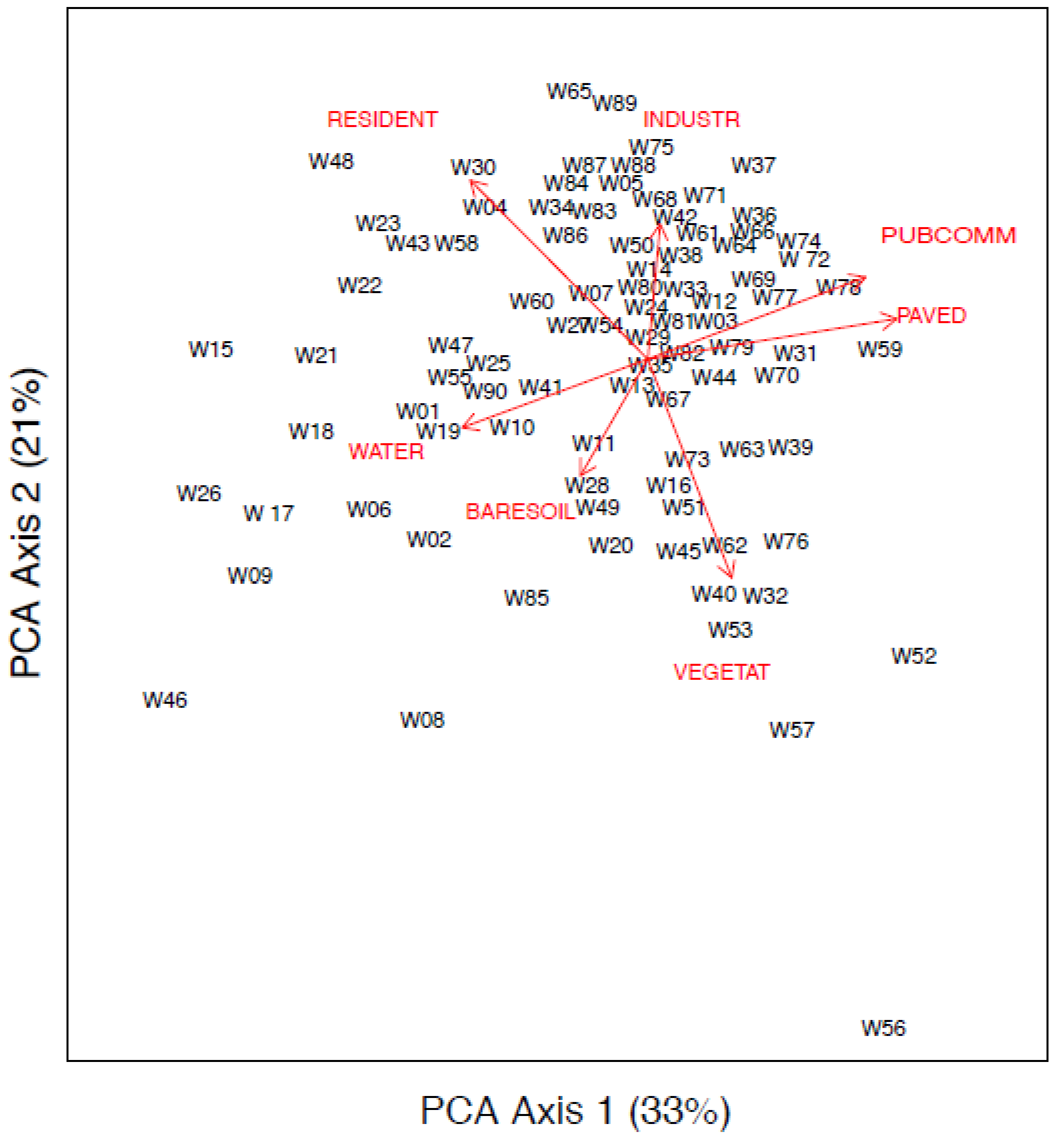
R Core Team. (2019). *R: a language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna. https://www.R-project.org.

Struyf, A., Hubert, M. & Rousseeuw, P.J. (1997). Clustering in an object-oriented environment. *Journal of Statistical Software*, *1*(4),1-30.

Appendix 1.E – Dendogram for 90 Wards in Dhaka



Appendix 1.F – PCA of the Wards in Dhaka



Appendix 4.A – KAAP Study Questionnaire

HOUSEHOLD QUESTIONNAIRE SURVEY

This questionnaire is prepared for an academic research in the field of public health dealing with dengue fever. The content and information provided herein will be kept confidential and will be used only for research purposes.

PART 1: INFORMATION OF THE SURVEY

Ward number: _____________ GIS position (Lat/Long) or, Grid cell no:_____________

Household address:____

Name of the Owner of the Household:____

Date: _____________ Start time: _____________ End Time: _____________

Field Investigator's Signature:____

PART 2: DEMOGRAPHIC INFORMATION

2.1 Name of the Respondent (Head of the Household)____

2.1.1 Sex: ☐ Male ☐ Female 2.1.2 Age (in years) _____________

2.1.3 Religion ☐ Islam ☐ Hinduism ☐ Buddhism ☐ Christianity ☐ Others____________ ☐ None

2.1.4 Educational Status

☐ Primary ☐ Secondary ☐ SSC ☐ HSC ☐ Diploma/ certificate

☐ Bachelor degree ☐ Master degree ☐ Others (specify)____________ ☐ No Education

2.1.5 Monthly household income (BDT) ☐ Below 10,000 ☐ 10,001-25,000

☐ 25,001-50,000 ☐ 50,001-75,000 ☐ 75,001-100,000 ☐ above 100,000

2.2 Name of the Respondent (If different from 2.1) ______________________

2.2.1 Sex: ☐ Male ☐ Female 2.2.2 Age (in years) ____________

2.2.3 Religion ☐ Islam ☐ Hinduism ☐ Buddhism ☐ Christianity ☐ Others ____________ ☐ None

2.2.4 Educational Status

☐ Primary ☐ Secondary ☐ SSC ☐ HSC ☐ Diploma/ certificate

☐ Bachelor degree ☐ Master degree ☐ Others (specify) ____________ ☐ No Education

2.2.5 Monthly household income (BDT) ☐ Below 10,000 ☐ 10,001-25,000

☐ 25,001-50,000 ☐ 50,001-75,000 ☐ 75,001-100,000 ☐ above 100,000

2.3 Other information

2.3.1 Number of people living in the house (family members and others) ____________

2.3.2 Number of people staying at home during day time____________

PART 3: HOUSING INFORMATION

3.1 Residence ownership ☐ Own ☐ Rented ☐ Public land (*Khas* land)

3.2 Number of years living in the current residence ____________

3.3 Number of years living in the current neighbourhood____________

3.4 Type of the residence:

☐ Slum-house ☐ Semi-permanent house ☐ Independent house ☐ Multi-story Building (till 6 floors)

☐ High-rise Apartment (more than 6 floors) ☐ One-story multi-unit complex ☐ Others ____________

3.5 Is there any elevator (in case of multi-story/high-rise apartment building)? ☐ Yes ☐ No

3.6 What are the building materials of your residence?

	Brick/ Concrete	CI Sheet	Thatch	Others (specify) ____________
Roof materials	☐	☐	☐	☐
Wall materials	☐	☐	☐	☐

3.7 Number of units (apartments) in the residence ______________

3.8 Number of floors in the residence (in case of multi-story/high-rise apartment building) ______________

3.9 Floor no. of the respondent's residence (in case of multi-story/high-rise apartment building)__________

3.10 Proximity to the nearest household (in meters)__________

3.11 Do the windows have screens? ☐ Yes ☐ No

PART 4: MOBILITY INFORMATION

4.1 Number of people going out of home during day time ______________

4.2 Information on everyday mobility and travel

HH member list	Commuting (where does anyone of the household go?)			Travel: Has anyone from the household visited some other place within country or another country (write the name of the place/country)				Migration: Has anyone migrated in from other place/country) (write the name of the place/country)			
	Place *	Distance (km.)**	Frequency of mobility (everyday = 1, occasional = 2)	< 3 months	>3 months	Name of the place/country	Distance (km.)**	< 3 months	>3 months	Name of the place/country	Distance (km.)**
1											
2											
3											
4											
5											
6											

* 1= Market, 2 = Office, 3 = School/College/University, 4 = Shopping mall, 5 = Mosque, 6 = Others (specify)

** Distances to be filled by the Field Investigators (FI) ____________

4.3 Where does anyone go for medical treatment of any kind?

☐ Hospital/Clinic **in the** neighbourhood, specify place and distance in meters______________

☐ Hospital/Clinic **outside** the neighbourhood, specify place and distance in meters____________

PART 5: VEGETATION INFORMATION

5.1 Is there any open greenery near the residence?

☐ Yes ☐ No If yes, specify the greenery (garden, park, forest etc.)__________________

5.2 Is there any stagnant water body near the residence?

☐ Yes ☐ No (if no, go to 5.3)

5.2.1 If yes, specify the water body type:

☐Pond ☐Pot hole ☐Reservoir for construction ☐ Ditch ☐Other ______________

5.2.2 If yes, specify the water body distance from the residence in meters:______________

5.3 Do you have plants inside your residence? ☐Yes ☐ No

5.4 Do you have roof-top gardens with potted plants? ☐ Yes ☐ No

5.5 Do you have front yard/ back yard having gardens with potted plants? ☐ Yes ☐ No

5.6 Do you have any balcony having gardens with potted plants? ☐ Yes ☐ No

5.7 If yes for any of 5.3, 5.4, 5.5, 5.6, what type of vegetation is there in/around your residence (multiple ans.)?

☐ Grass ☐ Shrubs/bushes ☐Vines ☐Orchards ☐ Trees ☐ Others ______________

PART 6: KNOWLEDGE ABOUT CLIMATE VARIABILITY AND SEASONALITY

6.1 When does it usually rain? Specify months ______________

6.2 Have you observed any changes in rainfall pattern recently? ☐ Yes ☐ No

6.2.1 If yes, please specify the type of change______________

6.3 When the temperature is very high? Specify months ______________

6.4 Have you observed any changes in temperature pattern recently? ☐ Yes ☐ No

6.4.1 If yes, please specify the type of change ______________

6.5 Do you know about climate change? ☐ Yes ☐ No

6.6 Do you think that the climate is changing? ☐ Yes ☐ No

6.7 If yes, please specify the reason _______________

PART 7: KNOWLEDGE ABOUT MOSQUITO AND ITS BREEDING SITES

7.1 Do you know that there are different types of mosquitoes? ☐ Yes ☐ No

7.2 How many types of mosquitoes do you see in your residence? _______________

7.3 What type of mosquito bite is responsible for dengue?

☐ Male ☐ Female ☐ Both ☐ Do not know

7.4 Where do you mostly see the mosquitoes resting/hiding at your residence (multiple ans. acceptable)?

☐ Behind the curtains ☐dark corners of the rooms ☐behind the beds and sofas

☐ In the kitchen ☐ In the bathroom ☐ Others _______________

7.5 When do mosquitoes bite more? ☐ Day ☐ Night

7.6 If more bites are during day time, does the mosquito have stripes (*shada-kalo dora kata*)? ☐ Yes ☐ No

7.7 During what season do you see more mosquitoes?

☐ Summer(Apr-May) ☐Monsoon(Jun-Sep) ☐ Autumn(Oct-Nov) ☐Winter(Dec-Jan) ☐ Spring(Feb-Mar)

7.8 Where do mosquitoes generally lay their eggs (multiple ans. acceptable)?

☐Dirty water ☐Clean water ☐Wet clothes ☐ Plants ☐ Flower vase

☐Waste bins ☐ Others (specify)________________________ ☐ Do not know

7.9 Have you ever seen eggs/larvae/pupae in your residence? ☐ Yes ☐ No

7.10 If yes, where? ☐Dirty water ☐ Clean water ☐Wet clothes ☐Plants ☐Flower vase

☐Waste bins ☐ Others (specify) ________________________

7.11 Do you know that mosquito can grow in stored water and stagnant water in wastes? ☐ Yes ☐No

7.12 Do you store water? ☐ Yes ☐ No

7.13 Why do you store water? ______________________

7.14 If you store water, how frequently do you empty the containers/reservoir?

☐Daily ☐Alternate day ☐ Weekly ☐ Fortnightly ☐ Monthly ☐ Others(specify)____________

7.15 What do you do with the solid waste (plastic or tin bottles/cans/jars/drums, broken utensils, coconut shells, tires of wheels etc.)?

Dispose the waste in following ways	Frequency			
	Daily	Alternate day	Weekly	Other (specify)
☐ Throw off in a specific location just by the residence	☐	☐	☐	☐
☐ Throw off a specific location off the residence property	☐	☐	☐	☐
☐ No fixed area of disposal	☐	☐	☐	☐

PART 8: KNOWLEDGE ABOUT DENGUE DISEASE AND ITS VECTOR

8.1 Have you ever heard about dengue fever? ☐ Yes ☐ No

8.2 What type of a disease is dengue fever? ☐ Serious ☐ Mild ☐ Do not know

8.3 Do you know about dengue fever as well as dengue hemorrhagic fever? ☐ Yes ☐ No

8.4 Do you know how dengue virus spreads from one person to another (multiple ans. acceptable)?

☐ Direct contact with other person ☐ Mosquito ☐ Water ☐ Flies ☐ Birds

☐ Dirty environment ☐ Rats, pigs and other animals ☐ Others (specify) ____________

8.5 Do you think the changed land-use type of your neighbourhood has caused dengue? ☐ Yes ☐ No ☐ Do not know

8.6 Do you think the changed weather in Dhaka has caused dengue epidemic? ☐ Yes ☐ No ☐ Do not know

8.7 Can dengue epidemic be prevented? ☐ Yes ☐ No ☐ Do not know

8.8 Have you ever received suggestions on dengue virus spread prevention and control? ☐ Yes ☐ No

PART 9: PERCEPTION AND EXPERIENCE ABOUT DENGUE AND INVESTMENT INTEREST IN DENGUE CONTROL

**Field Investigator informs the respondent about the purpose and scales before interviewing

		Strongly agree	Agree	Not decided	Disagree	Strongly Disagree
		5	4	3	2	1
9.1	Dengue fever is linked with rainy season	☐	☐	☐	☐	☐
9.2	My family takes measures to prevent dengue fever	☐	☐	☐	☐	☐
	9.2.1 If the response is 4 or more, what type of precaution is taken? ________________					
9.3	It is necessary to clean water containers in and around the house once a week	☐	☐	☐	☐	☐
9.4	It is difficult to eliminate mosquito breeding places	☐	☐	☐	☐	☐
9.5	It is essential for neighbours to collaborate in dengue prevention	☐	☐	☐	☐	☐
9.6	Government takes necessary steps to prevent dengue	☐	☐	☐	☐	☐
9.7	Government should give incentives to the HHs participating in dengue fever prevention activities	☐	☐	☐	☐	☐
9.8	Health workers are solely responsible for removing mosquito breeding sites	☐	☐	☐	☐	☐
9.9	We receive sufficient support from public health workers regarding dengue prevention	☐	☐	☐	☐	☐

9.9.1 If the response is 4 or more, what kind of support did you receive? ________________

9.10 Have you ever been to the hospital with dengue concerns? ☐ Yes ☐ No

9.10.1 If yes, what was your experience? ____________________________

9.11 Did anybody of your household have dengue in last 3 months? ☐ Yes ☐ No

9.11.1 If yes, when? ____________________________

9.12 Did anybody of your household have dengue during the monsoon of last year (May-October 2013)?

☐ Yes ☐ No

9.12.1 If yes, when? ____________________________

9.13 Was he/she hospitalized? ☐ Yes ☐ No

9.14 What is your cost per month for health care services (hospital costs, medicines etc.)? _____________

9.15 What is your cost per month for mosquito control? Dry season_________ Wet season_________

9.16 How much money are you willing to spend per month to control dengue mosquito (*Aedes*)?_____________

9.17 How do you control the mosquitoes (all types) at your home (multiple ans. acceptable)?

☐ Coils	☐ Indoor spraying	☐ Window screening	☐ Air conditioning
☐ Fans	☐ Using electronic gadgets	☐ Covering water containers	☐ Mosquito repellent
☐ Bed net	☐ Putting chemicals in water	☐ Do not use anything	☐ Others (specify)

9.18 Do you take any specific control measures regarding *Aedes* mosquito (multiple ans. acceptable)?

☐ Coils	☐ Indoor spraying	☐ Window screening	☐ Air conditioning
☐ Fans	☐ Using electronic gadgets	☐ Covering water containers	☐ Mosquito repellent
☐ Bed net	☐ Putting chemicals in water	☐ Do not use anything	☐ Others (specify)

9.19 What does the Government do to control all types of mosquitoes (multiple ans. acceptable)?

☐ Spraying	☐ Fogging	☐ Checking the water containers
☐ Educating people	☐ Nothing	☐ Others (specify)_____________

9.20 Does the Govt. take any specific control measure regarding *Aedes* mosquito (multiple ans. acceptable)?

☐ Spraying	☐ Fogging	☐ Checking the water containers
☐ Educating people	☐ Nothing	☐ Others (specify)_____________

9.21 How often do you have fogging outside your residence?

☐ Every month	☐ Every 3 months	☐ Every 6 months
☐ Every year	☐ Never	☐ Do not know

9.22 How often do you have fogging inside your residence?

☐ Every month ☐ Every 3 months ☐ Every 6 months
☐ Every year ☐ Never ☐ Do not know

9.23 How frequently a health inspector visits your locality/neighbourhood?

☐ Every month ☐ Every 3 months ☐ Every 6 months
☐ Every year ☐ Never ☐ Do not know

9.24 What can you do to prevent mosquito breeding around/outside your house?

☐ Eliminating stagnant water ☐ Covering water containers container ☐ Putting chemicals in water
☐ Removing solid waste ☐ Removing larvae ☐ Others (specify) ____________

9.25 What options are you going to consider and adopt to be safe from dengue fever? ____________

Appendix 4.B – Informed Consent Letter (English)

Informed Consent for Questionnaire Survey

UNIVERSITY OF MANITOBA

Natural Resources Institute
303-70 Dysart Road
University of Manitoba, Winnipeg,
MB, Canada R3T 2M6
Ph: 204-474-8373 Fax: 204-261-0038
Email: nriinfo@umanitoba.ca

Research Project Title: "The Threat of Dengue Fever in Bangladesh: *Effects of Climate Variability and Ecological Factors on Dengue vector Abundance and Dengue Disease Occurrence***".**

Principal Investigator (PI) and contact information:
Sabrina Islam
Natural Resources Institute, University of Manitoba
303-70 Dysart Rd, Winnipeg, Manitoba, Canada R3T 2N2
Tel: (204) xxx-xxxx
E-mail: xx

Research Supervisor and contact information: Dr. C. Emdad Haque, Professor
Natural Resources Institute, University of Manitoba
303-70 Dysart Rd, Winnipeg, Manitoba, Canada R3T 2N2
Tel.: (204) xxx-xxxx
E-mail: xx
Sponsor: International Development Research Centre (IDRC), Canada

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

****This informed consent will be read in Bengali to the participants.**

My name is Sabrina Islam, a PhD student at the Natural Resources Institute of University of Manitoba, Canada. I am writing to inform you that a research project of International Development Research Centre (IDRC) in collaboration with the University of Manitoba titled: "*Climatic*

Variability, Social-Ecological Changes, and Dengue Disease in Bangladesh" is now underway and I am working as a PhD research student on a component of this bigger project. The research project in which I am the principal investigator under the mentioned umbrella project is "The Threat of Dengue Fever in Bangladesh: *Effects of Climate Variability and Ecological Factors on Dengue vector Abundance and Dengue Disease Occurrence*". In this context, the proposed research aims to determine the relationships between climatic variability, societal and ecological changes, human interaction and the spread of dengue virus, as a case of Emerging Infectious Diseases (EIDs), in Bangladesh. A total of three wards are selected for in-depth study from the 90 wards of the city of Dhaka.

For this purpose, a questionnaire survey will be taking place. This will have some general and particular questions about your household information (nothing too personal will be asked), knowledge about season and weather, diseases, dengue and dengue prevention strategies. This will be a one-time survey and the interview session will take place for about one hour. You will be contacted later for the feedback session. However, you can withdraw anytime and the inclusion is totally voluntary for the study. No recording devices will be used at the study. There is no direct benefit to you and there is no potential risk for you if you participate.

There will be two mini workshops organized towards the end of the research where I will verify all the information collected during the research process. You will have an option to disagree to any information, in which case, the information would be suitably modified with your inputs. A summary (1-3 pages) of the results will be provided to you (around September 2014) through a community meeting. You can also choose to get the brief summary through email or a printed copy mailed to your address. Please specify your option to the researcher/field investigator. The means for result dissemination will be through public seminars, town-hall meetings/workshops and publications in refereed journals.

All data and personal information will remain under the strict supervision of the researcher (principal investigator) and stored in a secured location, such as all the papers relating to the research will be kept under lock and key and all the computer copies of the files will be stored in the personal computer of the researcher with password protection. Anonymity of the data will be assured by taking the measures of **not** publishing or sharing any identifier information in any form. The confidential data will be destroyed as soon as the doctoral thesis will be finished (tentatively December 2015).

You will be asked to verbally confirm that that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. Signatures will not be required as it may not be suitable for the culture and/or

literacy level of all participants. Your verbal consent will be documented in presence of a witness along with the address of the witness. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the Joint-Faculty REB. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at xxx-xxxx**. A copy of this consent form has been given to you to keep for your records and reference.**
****Please be advised that the staff at these offices speak English only.**

____ __________

Researcher's Signature Date

Name of the Witness:

Address of the Witness:

Appendix 4.C - Informed Consent Letter (Bengali)

প্রশ্নাবলী সার্ভের জন্য অনুমতি

UNIVERSITY OF MANITOBA

ন্যাচারাল রিসোর্সেস ইনস্টিটিউট
৩০৩-৭০ ডাইসার্ট রোড
ইউনিভার্সিটি অফ ম্যানিটোবা, উনিপেগ, ম্যানিটোবা, ক্যানাডা আর ৩ টি ২ এম ৬
ফোন (ক্যানাডা)- +x-xxxxxxxxxx
ফোন (লোকাল)-: + xx-xxxx-xxxx-xxx
nriinfo@umanitoba.ca

রিসার্চ প্রজেক্ট শিরোনাম: "বাংলাদেশে ডেঙ্গু জ্বরের হুমকিঃ ডেঙ্গু মশার প্রাচুর্য ও ডেঙ্গু রোগ সংঘটন এর উপর জলবায়ু পরিবর্তনশীলতা এবং পরিবেশগত পরিবর্তন এর প্রভাব"।

প্রিন্সিপাল তদন্তকারী (পি আই) এবং যোগাযোগের তথ্য:
সাবরিনা ইসলাম
ন্যাচারাল রিসোর্সেস ইনস্টিটিউট
৩০৩-৭০ ডাইসার্ট রোড
ইউনিভার্সিটি অফ ম্যানিটোবা, উনিপেগ, ম্যানিটোবা, ক্যানাডা আর ৩ টি ২ এন ২
টেলিফোন (ক্যানাডা): +x-xxx-xxx-xxxx
টেলিফোন: (স্থানীয়) + xx-xxxx-xxxx-xxx
ই-মেইল: xx

রিসার্চ সুপারভাইজার এবং যোগাযোগের তথ্য:
ডঃ সি এমদাদ হক, অধ্যাপক
ন্যাচারাল রিসোর্সেস ইনস্টিটিউট, ইউনিভার্সিটি অফ ম্যানিটোবা
উনিপেগ, ম্যানিটোবা, ক্যানাডা আর ৩ টি ২ এন ২
টেলিফোন: +x-xxx-xxx-xxxx
ই-মেইল: xx

পৃষ্ঠপোষক: ইন্টারন্যাশনাল ডেভেলপমেন্ট রিসার্চ সেন্টার (IDRC), ক্যানাডা

এই অনুমতি ফর্ম গবেষণা এর জন্য অনুমতি প্রক্রিয়ার শুধু অংশ মাত্র। আপনার রেকর্ডের এবং রেফারেন্সের জন্য এর একটি কপি আপনাকে দেওয়া হবে। এটি আপনাকে গবেষণা কর্ম সম্পর্কে মৌলিক ধারণা দিবে এবং আপনার অংশগ্রহণ এর বিস্তারিত ধারণা প্রদান করবে। আপনি যদি কিছু সম্পর্কে আরও বিস্তারিত জানতে চান যা এখানে উল্লেখিত নেই, তা আপনি কোনো দ্বিধা ছাড়াই জিজ্ঞাসা করতে পারেন। দয়া করে সময় নিয়ে সাবধানে পড়ে এইখানে দেওয়া তথ্য বুঝে নিন।

** এই অনুমতি পত্র সকল অংশগ্রহণকারীদেরকে বাংলায় পড়ে শুনানো হবে।

আমার নাম সাবরিনা ইসলাম। আমি, কানাডার ইউনিভার্সিটি অফ ম্যানিটোবা এর প্রাকৃতিক সম্পদ ইনস্টিটিউটের একজন পি.এইচ.ডি এর ছাত্রী। ইউনিভার্সিটি অফ ম্যানিটোবা এবং ইন্টারন্যাশনাল ডেভেলপমেন্ট রিসার্চ সেন্টার (IDRC) এর সহযোগিতায় একটি চলমান গবেষণা প্রকল্প: "আবহাওয়া পরিবর্তনশীলতা , সমাজ-প্রাকৃতিক ভারসাম্যের পরিবর্তন, এবং বাংলাদেশে ডেঙ্গু রোগ" এর একটি কম্পোনেন্ট এর উপর আমি কাজ করছি পি.এইচ.ডি গবেষণা এর অংশ হিশেবে। আমি উল্লেক্ষ প্রকল্পের অধীনে প্রধান তদন্তকারী, যে গবেষণা প্রকল্প এর নাম: "বাংলাদেশে ডেঙ্গু জ্বরের হুমকিঃ ডেঙ্গু মশার প্রাচুর্য ও ডেঙ্গু রোগ সংঘটন এর উপর জলবায়ু পরিবর্তনশীলতা এবং পরিবেশগত পরিবর্তন এর প্রভাব"। এই প্রসঙ্গে, প্রস্তাবিত গবেষণা বাংলাদেশে সংক্রামক রোগ এর একটি কেস হিসাবে, জলবায়ুর পরিবর্তনশীলতা, সামাজিক এবং পরিবেশগত পরিবর্তন, মানুষের মিথস্ক্রিয়া এবং ডেঙ্গু ভাইরাসের বিস্তার মধ্যে সম্পর্ক নির্ধারণ করবে। ঢাকা শহরের নব্বইটি ওয়ার্ড এর থেকে তিনটি ওয়ার্ড কে এই বিস্তারিত গবেষনা কর্মের জন্য নির্বাচন করা হয়েছে।

এই কাজের জন্য, একটি জরিপ করা হবে। এই জরিপের প্রশ্নাবলীতে আপনার পরিবারের তথ্য (খুব ব্যক্তিগত কিছুই জিজ্ঞাসা করা হবেনা), ঋতু এবং আবহাওয়া সম্পর্কে জ্ঞান, রোগ, ডেঙ্গু ও ডেঙ্গু প্রতিরোধ হিসাবে রিপোর্ট প্রকাশের কৌশল সম্পর্কে কিছু সাধারণ এবং নির্দিষ্ট প্রশ্ন থাকবে। জরিপ একবার-ই করা হবে এবং ইন্টারভিউ এর জন্য প্রায় এক ঘন্টা সময় দরকার হবে। আপনি চাইলে যে কোন প্রশ্নের উত্তর দেয়া থেকে বিরত থাকতে পারেন অথবা গবেষণা থেকে যে কোনো সময় আপনার দেয়া তথ্য বাদ দেয়ার আবেদন করতে পারেন (যেমন জরিপ ফলাফল বিশ্লেষণ এর পর আপনি আপনার তথ্য বাদ দেয়ার আবেদন করতে পারেন) এবং গবেষণা কাজে আপনার অন্তর্ভুক্তি সম্পূর্ণ ঐচ্ছিক। কোন রেকর্ডিং ডিভাইস এই গবেষণায় ব্যবহার করা হবেনা। এতে অংশগ্রহণ এ আপনার প্রত্যক্ষ বা পরোক্ষ কোন লাভই হবেনা এবং এই অংশগ্রহণের ফলে আপনার কোন সম্ভাব্য ঝুঁকি নেই।

গবেষণা প্রক্রিয়ায় সংগৃহীত সব তথ্য যাচাই করার জন্য গবেষণার শেষ দিকে দুটি ছোট কর্মশালা থাকবে। আপনাকে এতে যোগ দেয়ার জন্য যোগাযোগ করা যেতে পারে এবং সেক্ষেত্রে আপনার ফলাফল এর সারসংক্ষেপ এর প্রেক্ষিতে কিছু ইনপুট প্রদান এর একটি সুযোগ থাকবে যা বিবেচনা করা যেতে পারে। আপনাকে যদি একজন প্রধান তথ্যদানকারি হিসেবে নির্বাচিত করা হয়, তাহলে ফলাফল এর সংক্ষিপ্ত বিবরণ (১-৩ পৃষ্ঠা) একটি কমিউনিটি মিটিং এর মাধ্যমে (সেপ্টেম্বর ২০১৪ এর কাছাকাছি সময়ে) আপনাকে সরবরাহ করা হবে। এছাড়াও আপনি ইমেলের মাধ্যমে সংক্ষিপ্তসার বা আপনার ঠিকানায় একটি ছাপানো কপি পাওয়ার উপায় বেছে নিতে পারেন। এ ক্ষেত্রে গবেষক/তদন্তকারীকে আপনি আপনার বিকল্প উল্লেখ করুন। গবেষনা লব্ধ তথ্য পাবলিক সেমিনার, সভা / কর্মশালা এবং জার্নাল এর মাধ্যমে প্রকাশিত হবে।

এই গবেষণা কর্মের সমস্ত তথ্য এবং আপনার ব্যক্তিগত তথ্য গবেষক এর কঠোর তত্বাবধানে (প্রধান তদন্তকারী) থাকবেঃ যেমন গবেষণা সংক্রান্ত সকল কাগজপত্র তালাবদ্ধ করে একটি নিরাপদ অবস্থান এ রাখা হবে এবং কম্পিউটারের সকল ফাইল পাসওয়ার্ড সুরক্ষা এর সঙ্গে গবেষক এর ব্যক্তিগত কম্পিউটারে সংরক্ষণ করা হবে। তথ্যের গোপনীয়তা নিশ্চিত করা হবে এবং আপনার নাম এবং অন্যান্য ব্যক্তিগত তথ্য এই গবেষনা ছাড়া অন্য কোন কাজ এ ব্যাবহার করা হবেনা। ডকটরাল থিসিস শেষ হবার সাথে সাথেই আপনার গোপন তথ্য নির্মূল করা হবে (সম্ভবত ডিসেম্বর ২০১৫ এর কাছাকাছি সময়ে)।

মৌখিকভাবে আপনার সম্মতি নেয়া হবে যে আপনি এই গবেষণা প্রকল্পে অংশগ্রহণ সংক্রান্ত তথ্য বুঝতে পেরেছেন এবং এতে যে আপনি অংশগ্রহণ করতে ইচ্ছুক তা নিশ্চিত করতে বলা হবে। আপনার মৌখিক সম্মতি একজন সাক্ষীর উপস্থিতিতে নথিভুক্ত করা হবে। এই সম্মতি পত্র কোন ভাবেই আপনার আইনগত অধিকার খনড করবেনা কিংবা কোন আইনি ও পেশাগত দায়িত্ব থেকে গবেষক, উদ্যোক্তা বা প্রতিষ্ঠান কে অব্যাহতি দিবেনা। আপনি যে কোনো সময় গবেষণা থেকে নিজেকে প্রত্যাহার করতে পারবেন এবং যে কোনো প্রশ্নের উত্তর দেয়া থেকে বিরত থাকতে পারেন। আপনার সর্বসম্মতি ক্রমে অংশগ্রহণ করবেন এবং এক্ষেত্রে আপনি গবেষণা এর যেকোন কিছুর সর্বত্র ব্যাখ্যা বা নতুন তথ্য জানতে চাইতে পারেন।

গবেষণা কাজটি নিরাপদ এবং সঠিক ভাবে হচ্ছে কিনা তা বিচারের জন্য ইউনিভার্সিটি অফ ম্যানিটোবা আপনার দেখতে আপনার দেওয়া গবেষণা তথ্য দেখতে পারে।

এই গবেষণা যৌথ অনুষদ রিসার্চ এথিক্স বোর্ড [**Joint-Faculty Research Ethics Board** (JFREB)] দ্বারা অনুমোদিত হয়েছে। আপনার যদি এই প্রকল্প সম্পর্কে কোনো উদ্বেগ বা অভিযোগ থাকে তবে আপনি এই সম্মতি পত্রে উল্লেখিত ব্যক্তি বা মার্গারেট বোম্যান এর সাথে যোগাযোগ করতে পারেনঃ মার্গারেট বোম্যান, হিউম্যান এথিক্স কো-অরডিনেটর (এইচ ই সি), ফোনঃ +x-xxx-xxx-xxxx, অথবা ইমেইল করতে পারেনঃ **xx@umanitoba.ca**। এই অনুমতি ফর্ম একটি কপি আপনার রেকর্ড এর জন্য দেয়া হবে।

** এই অফিসগুলোতে কর্মীরা শুধুমাত্র ইংরেজীতে কথোপকথন করতে পারে।

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গবেষকের স্বাক্ষর তারিখ

সাক্ষীর নাম:

সাক্ষীর ঠিকানা:

Appendix 4.D – Photos of the KAAP Survey

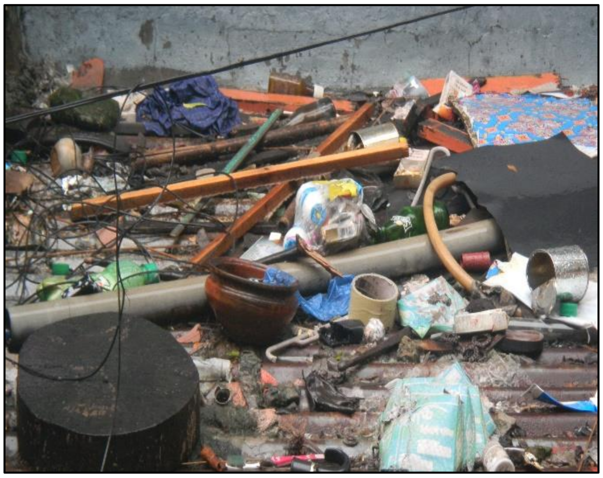

Image 1: Different types of containers and discarded material within household premises (some had rain water)

Image 2: Different types empty plastic containers within household premises

Image 3: Interview for questionnaire Survey (with lidded plastic container at the back)

Image 4: Interview for questionnaire Survey

Image 5: Flower/plant tubs in the yard within household premises (a few had water)

Image 6: Flower/plant tubs and plastic container in the balcony within household premises (a couple had water)

Image 7: Special bed-net used for mosquito control

Image 8: Different types of containers (with lid and open) inside the household – some filled with water and some with different other liquids, a few were empty

Image 9: Plastic containers holding water used to feed poultry within household premises

Image 10: Plastic water jars (with some water) within household premises

Image 11: Earthen flower tubs on the rooftop of a household

Image 12: Plastic containers (buckets) used for waste disposal, storing water and for shopping purposes

Appendix 5.A – Conceptual Framework for Integrated Dengue Management

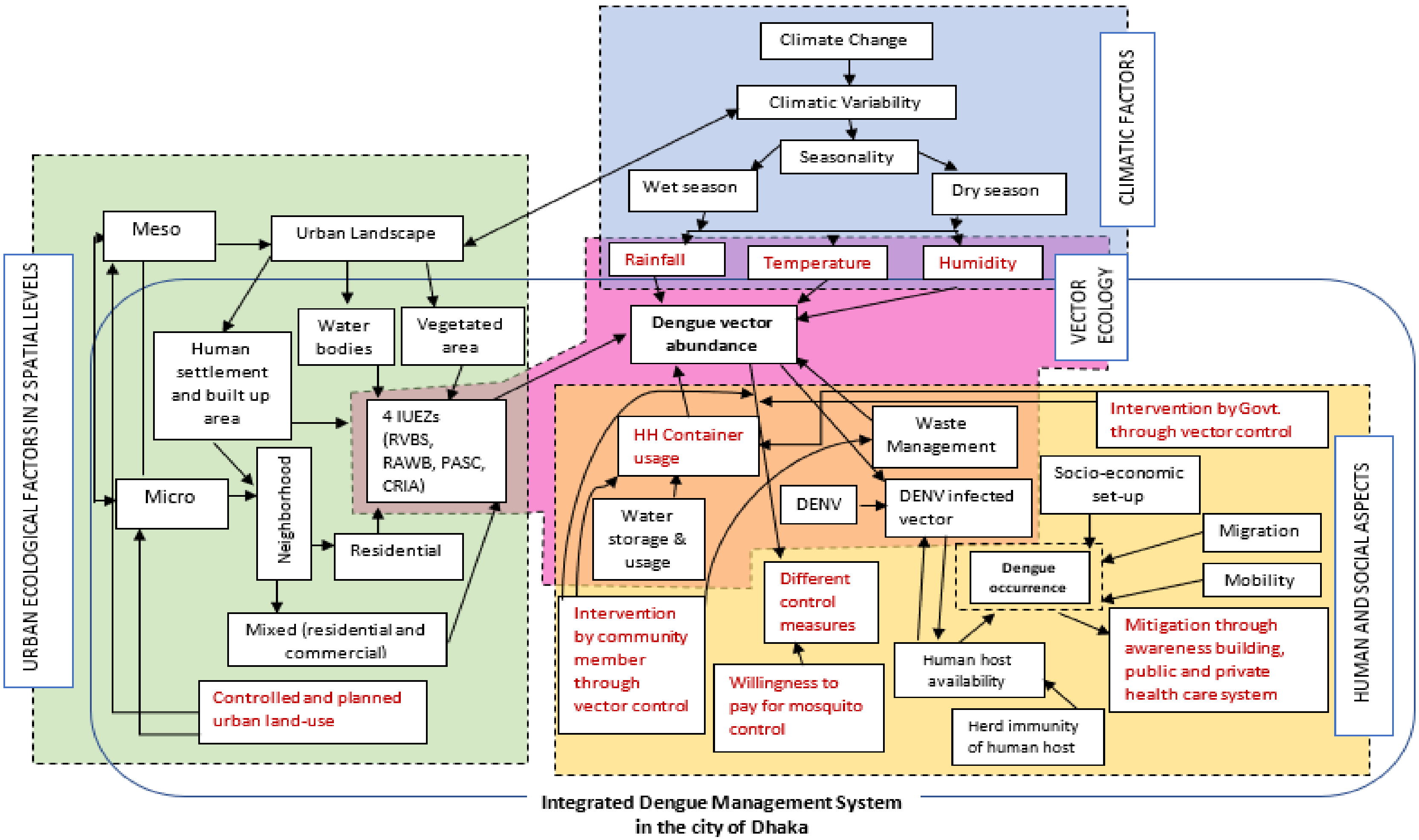

Figure 5.A: Integrated Dengue Management System: coupling between socio-ecological aspects (conceptualized after Lebel, 2003 and Caprara et al., 2009)