AN ASSESSMENT OF THE QUALITY OF DOMESTIC DRINKING WATER IN KUMUL, XINJIANG PROVINCE, CHINA

by

Dilibai Yunusi

A Thesis submitted to the Faculty of Graduate Studies
of The University of Manitoba
in partial fulfillment of the requirements
of the degree of

MASTER OF ENVIRONMENT

Environment and Geography
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October 2013

THE UNIVERSITY OF MANITOBA
FACULTY OF GRADUATE SUTDIES
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ABSTRACT

The purpose of this research was to improve understanding of the quality of drinking water for domestic consumption in the City of Kumul, China. The guidelines for drinking water testing in the City of Kumul were assessed and compared with actual practices. Local households in the urban center were interviewed in order to assess public attitudes towards drinking water. The results showed that the quality of treated water did not pose a direct threat to human consumers, but there were opportunities for improvements in the areas of source water protection, water treatment processes, and communication between authorities and the public. 74% of urban households personally treated their tap water prior to consumption, most commonly by boiling, to improve drinking water quality. It is recommended that the local government should seek to improve communication between the water treatment authority and the public to ensure water quality in the City of Kumul.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank the committee members Dr. Mary Benbow, Dr. Mark Hanson, Professor Thomas Henley and Dr. John Sinclair, for their time, comments, feedback and all the efforts they have put into this research for the last three years. I thank the Dean of Clayton Riddell Faculty of Environment, Earth and Resources Dr. Norman Halden for funding this research. I thank Professor Thomas Henley for his guidance that has been instrumental for completing this research. I thank Dr. Mark Hanson, Dr. John Sinclair and Dr. Fikret Berkes for their financial support so that not only could I go on my field trips to China, but I could also complete my study in Canada. I thank Ms. Julie Anderson for her time and professional editing for improving the overall quality of the paper. I appreciate that she not only carefully checked grammar and punctuation but also provided many constructive comments. I also thank my friends from different departments, faculties and professions for their insights that have contributed to my work, for those meaningful conversations we had. Lastly, I would like to give my special thanks to my mom, Aishem Ibrahim, for her constant support and encouragement, and for her unconditional love.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
BOD_5	Biochemical oxygen demand, milligrams (mg) of oxygen consumed per liter of sample during 5 days of incubation
CB	Construction bureau
COD	Chemical oxygen demand, milligrams (mg) of organic compounds found in surface water or wastewater
COD_{Cr}	Chemical oxygen demand, using potassium dichromate ($K_2Cr_2O_7$) as oxidizing agent
EPA	Environmental protection agency
EPS	Epidemic prevention station
FAO	Food and Agriculture Organization of the United Nations
IPCC	Intergovernmental Panel on Climate Change of the United Nations
KWAG Ltd.	Kumul Water Affairs Group Limited Company
LCEB	(Kumul) Local Chronicles Editorial Board, compiled Kumul Yearbooks 2009-2011
MEP	Ministry of Environmental Protection of the Government of China, formally the State Environmental Protection Administration (SEPA)
MOC	Ministry of Construction of the Government of China, also known as the Ministry of Housing and Urban-Rural Development (MOHURD)
MWR	Ministry of Water Resources of the Government of China
NBSC	National Bureau of Statistic of China
PP-R	Polypropylene random copolymer type 3 pipe
PVC	Polyvinyl chloride pipe made of plastic and vinyl combination material
UNICEF	United Nations Children's Fund, originally the United Nations International Children's Emergency Fund
USEPA	United States Environmental Protection Agency
WCB	Water conservancy bureau
WHO	World Health Organization of the United Nations
WPP	Water purification plant

1 INTRODUCTION

1.1 Preamble

This research was focused upon an analysis of drinking water quality for domestic consumption in the City of Kumul in Xinjiang Province, China. China has committed to improving environmental management generally, with particular attention to air and water quality. Like other major cities in China, the City of Kumul has been growing rapidly in terms of population, urbanization, and industrialization during recent years (Municipal EPA, 2009). There is high water demand from industry, agriculture, and domestic consumption and the demand is only increasing as Kumul's economy continues to grow and develop at a rapid pace (Municipal EPA, 2009). On the other hand, there is a dramatic decrease in the average water resource availability per capita (Municipal EPA, 2009), leading to uncertainty as to whether limitations on water quantity have impacted water quality. Urban populations in Kumul generally believe that all water must be boiled prior to consumption, which suggests that water quality and safety are concerns for consumers. This research project aimed to help gain a better understanding of drinking water quality in the urban area of the City of Kumul, which can inform decision-making by the public and water managers.

1.2 Background

Xinjiang Province is the largest province in China, and covers 1/6 of China's total territory, with a population of more than 20 million (Travel China Guide, 2013). Xinjiang is China's bridge to Western and Central Asia (Figure 1.1), playing a significant role culturally and economically, and is bordered by eight countries: Russia, Mongolia, Kazakhstan, Kyrgyzstan, Tajikistan, Afghanistan, Pakistan and India (Travel China Guide, 2013).

Figure 1.1 Geographical position of Xinjiang Province (circled in red) in China.
(Retrieved from: www.maps.google.ca, accessed on: October 27, 2013)

Xinjiang is a culturally diverse region, and has populations of 47 distinct ethnic groups including Uyghur, the major ethnic group in Xinjiang (Travel China Guide, 2013). Like other provinces in China, Xinjiang Province has its own local government and a Communist Party of China regional committee headed by a Secretary (Regional EPA, 2008). The province is well known as a region rich in natural resources such as oil, natural gas, coal and minerals, and is one of the largest natural gas-producing provinces of China (Benewick and Donald, 2009). Xinjiang Province has unique landforms and geomorphology described as alternating between mountains and plains. Six tall mountains alternate with basins and plateaus that are connected with plains. Even though Xinjiang is the largest province in China, the land area suitable for human habitation is only about 4.3% of the province (Travel China Guide, 2013).

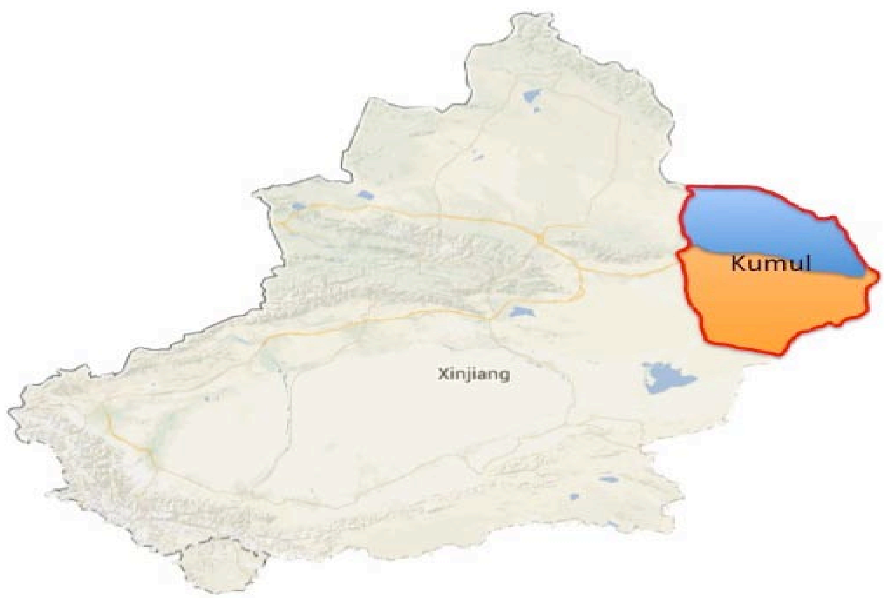

Figure 1.2 Geographical position of the Region of Kumul (circled in red) in Xinjiang. (Retrieved from www.maps.google.ca, accessed on: October 27, 2013)

Drought has traditionally represented a major local issue and has resulted in extreme water scarcity in most parts of Xinjiang (Regional EPA, 2008). Despite flood mitigation approaches, rapid development and the pressure of a growing population have further increased the drought risk in this area.

Kumul is located in Xinjiang Province and has a population of 520,000 (Municipal EPA, 2009). The Administrative Region of Kumul lies in the south belt of the Tangri Mountains, covering an area of 85,000 km^2 (Municipal EPA, 2009). However, most of the region is the Gobi desert so the only areas that are suitable for human habitation are the oases scattered from west to east in a belt-like pattern (Figure 1.3) (Municipal EPA, 2009).

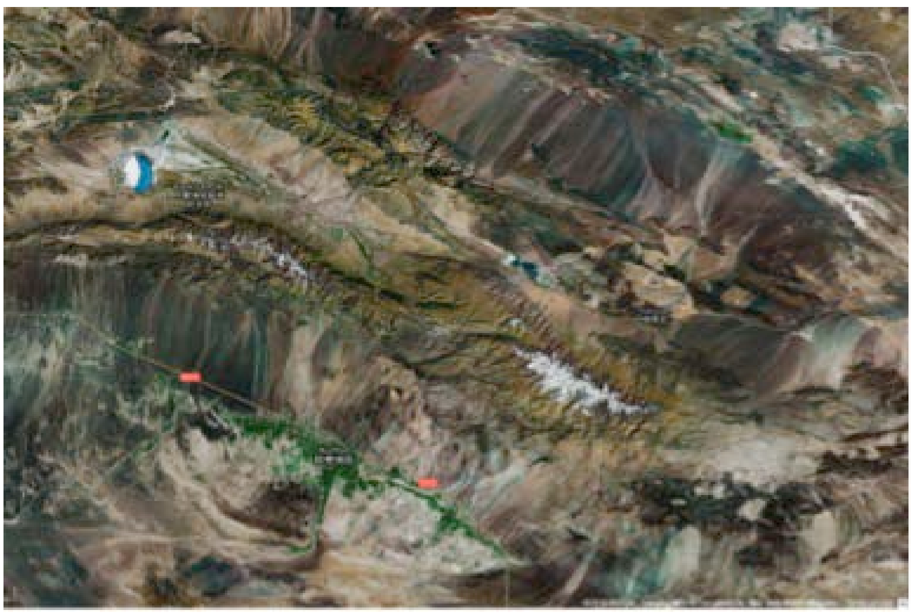

Figure 1.3 Satellite photo of the Region of Kumul. (Retrieved from www.maps.google.ca, accessed on: October 27, 2012)

The Region of Kumul is generally divided into two areas (Figure 1.2), a mountainous region to the north and a city center to the south (Figure 1.4). Both counties of Kumul, Aratork County and Barkol County, are located in the mountain area, with a combined population of 120,000 (Municipal EPA, 2009). The urban district covers approximately 23 km^2 and is home to more than 400,000 people (Municipal EPA, 2009).

The noted Turpan Depression, which is the second lowest basin in the world, is located in the Turpan-Kumul basin (Regional EPA, 2008). Kumul has a temperate continental climate, and experiences a wide range of seasonal temperatures varying from harsh, cold winters to hot summers with long hours of sunshine and little precipitation (Regional EPA, 2008).

Figure 1.4 Satellite photo of urban district of the City of Kumul. (Retrieved from www.maps.google.ca, accessed on: October 27, 2013)

According to meteorological statistics, the highest annual temperatures in the City of Kumul can reach 44°C or more while the lowest temperatures get down to -32°C (Regional EPA, 2008). The annual precipitation of the City of Kumul is only 39.1 mm while annual evaporation reaches up to 3300 mm (Regional EPA, 2008). Other notable climate characteristics include windy spring and autumn seasons and substantial temperature differential between day and night (Regional EPA, 2008).

The ‘Go West’ campaign is a new strategy of China’s government to open up the potential hinterland in the western part of the country, including Xinjiang Province, and the campaign has brought large-scale industrial manufacturing to the area (Benewick and Donald, 2009). Kumul is also abundant in natural mined resources such as coal, iron ore, copper, nickel, gold, tungsten, salt, mirabillite, gemstones, jade, oil, and natural gas (Regional EPA, 2008). A long-term development strategy has been mapped out to transform the city into a resource-based industry, with emphasis on raw material industries (Regional EPA, 2008). As a result, the economy is expected to shift to a greater reliance on the natural resources sector with an accompanying reduction in agriculture and an increase in urban population.

Kumul’s people have long been facing drought conditions, and water scarcity has become of great local concern (Municipal EPA, 2009). Therefore, water resources management according to best practices is crucial to Kumul’s present and future development. Local government and institutions under government supervision have started to focus not only on water acquisition but also on water conservation. Seepage-preventing channels have been constructed, and the implementation of dripping irrigation in agriculture and reutilization of wastewater in construction are also contributing to water conservation (Regional EPA, 2008). In Kumul, tap water was introduced into houses and apartments in the early 1980s, due to a rapid increase in population at a time when many personal wells were being exhausted (personal communication with local experts and residents, August 2011).

1.3 Problem Statement

Water is an essential resource, and is required not only for fulfillment of basic personal needs for the local population, but also for an expanding industry and for agricultural irrigation networks. Water operators must consider both water quantity and quality requirements in water provision for meeting current and predicted demand (Spellman and Drinan, 2000).

As for water quantity, a growing population further increases the demand for water and decreases the annual average water resource availability per capita. Kumul's average water resource availability was about 1500 m^3 per annum on a per capita basis in 2008 (Municipal EPA, 2009), which was 27% lower than China's average of 2060 m^3 per person (FAO, 2013) and lower than a proposed threshold of 1700 m^3 per capita per year (Falkenmark, 1989). Kumul's annual average water resource availability falls between 1000 m^3 and 1700 m^3 per capita, which indicates that Kumul is a water stressed area, according to the Falkenmark indicator (Table 1.1). In a global context Kumul's per capita water availability was exceptionally low, comparing to the U.S. average of 9802m^3/person/yr (FAO, 2013). Rainfall can be captured from runoff and streams in the foothills for use in industrial and agricultural operations. However, Kumul's climatic conditions of low precipitation and high evaporation have made it almost impossible for this region to rely on atmospheric water resources. As a result, the city is experiencing an extreme shortage of water resources, and the scarcity is a major issue that affects economic development in the City of Kumul (Municipal EPA, 2009).

Table 1.1 Falkenmark water stress index (Falkenmark, 1989)

Index (m^3 per capita per year)	Category
>1700	No Stress
1000-1700	Stress
500-1000	Scarcity
<500	Absolute Scarcity

As for water quality, in Kumul, boiling tap water before consumption demonstrates the distrust of local residents in the quality of their tap water. In their book, Spellman and Drinan (2000) have defined drinking water as an outcome of strict water practices from source to tap, which require various treatment procedures to reach the updating standards and meet the public's needs with authorities' and jurisdictions' complete assurance but with no threats to life. Kumul's two main water sources for urban consumption are snow/ice melt from mountaintops and groundwater. Drinking water quality may be at risk if any key steps in water provision fail. These steps, including source water protection, water sampling and testing, and water distribution, together with the jurisdiction's adoption of drinking water guidelines and standards, reporting of water information, and training of water practitioners, determine the quality of Kumul's drinking water.

Boiling tap water before its consumption has long been a common behavior of local residents in this region; therefore, this study aimed to understand this behavior and whether it was part of the local custom or if it was due to people's concerns about the quality of their tap water.

1.4 Research Purpose and Objectives

The purpose of this research was to assess the quality of drinking water for domestic consumption in the City of Kumul, Xinjiang Province, China. The research objectives were to determine water quality guidelines adopted in the City of Kumul; to identify changes in water quality since the water purification plants were built in the City of Kumul; to assess attitudes of residents towards water quality issues; and to provide recommendations for enhancement of water quality management in the City Kumul.

1.5 Methods

A mixed method approach consisting of collecting both qualitative and quantitative data was employed to meet each objective. Table 1.2 describes the implications and interactions of all the methods with respect to the objectives. These methods include literature review, search of databases, a household survey, and expert interviews, with the support of numeric and non-numeric data. Related literature was reviewed to understand and outline China's water issues in terms of water availability, water use, and water policy and management. The search of databases was completed by collecting various water-related data form local published or unpublished books/reports, and official websites such as AQUASTAT Database of the Food and Agriculture Organization (FAO) of the United Nations and Statistical Yearbooks of the National Bureau of Statistics of China (NBSC).

Table 1.2 Implications of mixed (qualitative and quantitative) methods with respect to research objectives

Qualitative Method	Literature Review	Household Survey	Expert Interviews
	Objective 1), 4)	Objective 2), 3),4)	Objective 1), 2)
Quantitative Method	Search of Database	Household Survey	Expert Interviews
	Objective 2)	Objective 2), 3)	

To our knowledge, there have been no previous studies that considered local residents' attitudes towards drinking water issues in Kumul. Therefore, a structured household survey was prepared and conducted in order to assess attitudes and to identify if there were any changes in water quality over the past several decades. One-on-one interviews with locals and experts also brought valuable insights that helped provide recommendations for enhancing water quality management in the City of Kumul. Maps, photos, charts, graphs, figures, and tables were used to present various data.

1.6 Organization of the Thesis

The focus of this research was established in Chapter 1. In Chapter 2, literature related to the quality of drinking water at national and provincial levels in China was reviewed. In Chapter 3, detailed methods for this research were described; specifically, methods for the way in which data were collected and analyzed. In Chapter 4, data analysis and results were presented. In Chapter 5, research findings and implications were discussed in the context of the literature review. In Chapter 6, a summary, conclusions, and recommendations were provided.

2 Review of Related Literature

2.1 Introduction

This chapter was organized into five sections. The first section briefly addresses the decreasing water availability in China, the trends of water use in different sectors, and the correlation between climate change and water in China. Section 2 focuses on China's current surface water, groundwater, and source water issues, with emphasis on drinking water quality. Section 3 examines China's water resource management systems through the lens of various policies, regulations, and guidelines adopted in recent years, structure and function of water-related institutions, and drinking water treatment and distribution. Section 4 emphasizes the significant role of water operators in providing sufficient volumes of water that meet standards for quality and the importance of transparency in providing information to the public regarding water. Finally, the last section briefly discusses the consumption of other types of drinking water such as bottled or purified water.

2.2 Water Availability, Water Use and Climate Change

China's role as one of the world's largest exporters, particularly in consumer products such as personal computers, cell phones, and cars, has had significant impacts on China's environment (Benewick and Donald, 2009). These environmental impacts from industrial activities are particularly harmful to China's water systems, and the extent and speed of growth in demand for water have become ever more evident (Benewick and Donald, 2009).

2.2.1 ***Water Availability and Water Use***

In China, many major cities, industrial-based centers, and agricultural regions have been suffering from water shortages for years, resulting in widespread impacts on the nation's economy, environment, and communities.

Water availability can be defined differently among scholars according to study area's climatic, geographical, and water source conditions; however, based on the description of Aquastat Database of FAO (2013) and China Statistical Database of NBSC (2012), it is defined here as a region's available natural freshwater resources for sustaining consumption per person per year. Also in these databases, China's water availability refers to the sum total of surface water, surface runoff, melt-water of glaciers, and shallow groundwater available for consumption. The accessible data on China's total renewable water resources were collected and are shown in Table 2.1 (FAO, 2013). There has been little change in China's total renewable water resources from 1993 to 2012; however, national water resources per capita showed a steady decline. The concept of water availability is always closely linked to the evaluation of whether or not a region is water-stressed. By 2011, China's average water resource availability per capita had dropped to 2060 m^3 from 2243 m^3 in 1997 (Table 2.1). At this rate, China could soon be one of the water-stressed countries in the world, according to the Falkenmark (1989) indicator introduced in Chapter 1, with availabilities below a threshold of 1700 m^3 per capita per year. China's water resource availability shows an uneven allocation throughout the nation. According to the Ministry of Water Resources (MWR) of China

(2003), the lowest water availability was only 170 m^3 per capita in regions that were experiencing severe water shortages, while the highest availability was 2600 m^3 per capita in regions where water supplies were in a comfortable position as of 2003. In 2002, it was reported that two-thirds of 668 major cities, including about 100 of the most populous cities in China, such as Beijing, Tianjin, and Xi'an, were experiencing different levels of water shortages and had inadequate water supplies (MWR, 2002).

Table 2.1 China's total renewable water resources (FAO, 2013)

Year	1993-1997	1998-2002	2003-2007	2008-2012
Total renewable water resources (10^9 m^3/year)	2840 (1997)	2840 (2002)	2840 (2007)	2840 (2011)
Total renewable surface water (10^9 m^3/year)	2739 (1997)	2739 (2002)	2739 (2007)	2739 (2011)
Total renewable groundwater (10^9 m^3/year)	828.8 (1997)	828.8 (2002)	828.8 (2007)	828.8 (2011)
Total renewable water resources per capita (m^3/inhab/yr)	2243 (1997)	2159 (2002)	2101 (2007)	2060 (2011)

In China, water sources are mainly surface water and partially groundwater. In 2006, China's total water supply was 578.9 billion m^3, of which the withdrawal of surface water and groundwater were 81.2% and 18.3%, respectively, with 0.5% of volume comprised of other water sources (MWR, 2007). Zhang et al. (2006) summarized the average water resources in northwestern China, including Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang during the period from 1994 to 2000 (Table 2.2). They concluded that the volumes of both surface water and groundwater decreased in northwestern China over that period, except in the region of Xinjiang. Zhang et al. (2006) also offered reasons for challenges that these regions faced in water resource exploitation and utilization: uneven distribution of water resources, less water availability per area, and the geographical separation of headwaters and consumption area. As shown in Table 2.2, comparing the means of water resource availabilities within 7 years from 1994-2000 among northwestern provinces, Xinjiang had the highest total water resource availability and the second highest per capita water availability. The data varied due to the differences in provincial land area, population, geology, and hydrology. Compared to Shaanxi Province, where the land area is about 8 times smaller but with twice the population of Xinjiang Province, Xinjiang's per capita water availability was much more sufficient during those years.

Table 2.2 The average water resource availability in northwestern China from 1994-2000 (Zhang et al., 2006), provincial land area and population as of 2000 (NBSC, 2012)

Province	Total Water Resource Availability 10^8 m^3	Surface Water Availability 10^8 m^3	Groundwater Availability 10^8 m^3	Per Capita Water Availability m^3/person	Land Area 10^6 km^2	Population (x10,000)
Shaanxi	295.2	265.9	128.7	828	0.21	3618
Gansu	202.2	191.9	132.3	821	0.45	2543
Qinghai	574.4	567.0	249.4	11680	0.72	510
Ningxia	10.2	8.5	29.0	190	0.07	543
Xinjiang	913.8	858.0	610.4	5368	1.66	1774

Water use refers to the measurement of water withdrawal to meet the demand of agricultural, industrial, and municipal consumption sectors. China's agricultural, industrial, and municipal water withdrawal from 1993 to 2007 is summarized in Table 2.3 (FAO, 2013). The evident increase in water demand for industry and decrease for agricultural uses over that timeframe further demonstrates China's current trend in promoting industrialization.

Table 2.3 China's water withdrawal (10^9 m^3/year) (FAO, 2013)

Year	1993-1997	1998-2002	2003-2007
Total water withdrawal	525.4 (1993)	*N/A*	554.1 (2005)
Agricultural water withdrawal	407.7 (1993)	*N/A*	358 (2005)
Industrial water withdrawal	92.55 (1993)	*127.7 (2000)*	128.6 (2005)
Municipal water withdrawal	25.16 (1993)	*34.72 (2000)*	67.53 (2005)

**Data of year 2000 were modeled by AQUASTAT.* *N/A: Data not available*

Figure 2.1 illustrates China's total water demand and allocation to different sectors for 1993 and 2005. In general, agricultural irrigation comprised a larger proportion of water use than other sectors, although agricultural water withdrawal dropped by 7% over the decade while industrial and municipal shares increased by 5% and 7% respectively. In their research, Zhou and Tol (2005) observed an increasing trend, from east to west, in China's provincial use of water by agriculture, but a decrease in industrial and domestic consumption. Especially in northwestern agriculture-centered regions such as Xinjiang, Ningxia, Tibet, and Inner Mongolia, the water use for irrigation can represent more than 85% of total water use (Zhou and Tol, 2005).

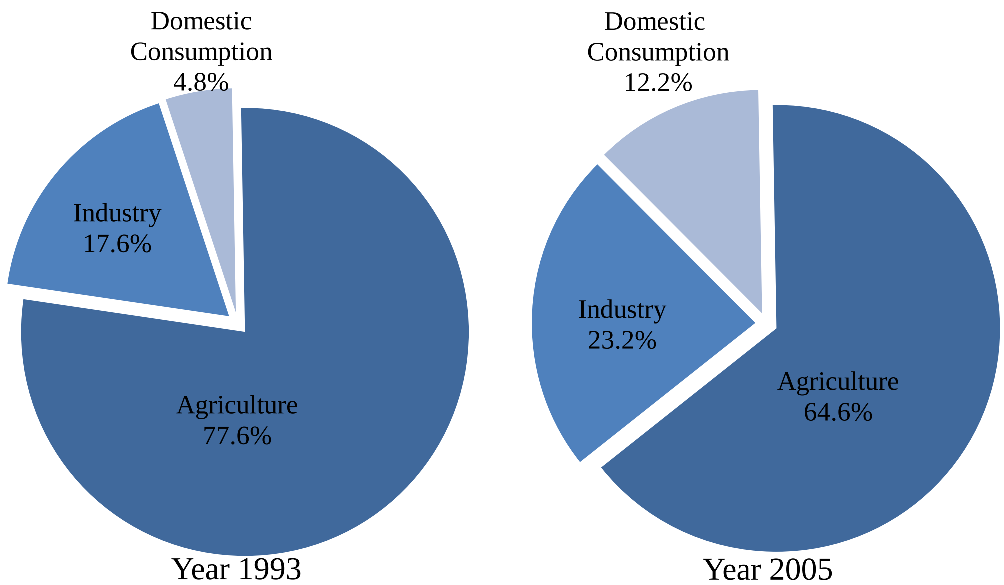

Figure 2.1 China's water demand by sector in 1993 and 2005 (FAO, 2013)

2.2.2 ***Population Growth***

The growing population poses significant and direct impacts on per capita water availability (Shalizi, 2006). China's population growth has been steady from 1.21 billion in 1995 to 1.34 billion in 2010 (Table 2.4) (NBSC, 2012). Xinjiang's population also showed a steady increase from 16.61 million in 1995 to 21.81 million in 2010 (Table 2.4). Zhang et al. (2006) concluded that it would be impossible for Xinjiang to continue to concurrently increase water demand with growing population due to this region's limited water resources.

Rural-to-urban population mobility is evident in Table 2.5. In 1995, only 29% of the national population resided in urban areas, which rose to 47% in 2010. Rapid population mobility will presumably increase the burden of a region's municipal water supply, and shift this region's water distribution. As shown in Table 2.3 above, municipal water demand nearly tripled within a decade as a result of China's growing population.

Table 2.4 National and Xinjiang's total population and growth rate (NBSC, 2012)

	Total Population			Natural Growth Rate %	
Year	1995	2002	2010	1955	2002
National	1.21 billion	1.28 billion	1.34 billion	10.55	6.45
Xinjiang	16.61 million	19.05 million	21.81 million	12.45	10.87

Table 2.5 China's urban and rural population (NBSC, 2012)

	Population					
Year	1995		2002		2010	
	million	%	million	%	million	%
Urban	351.74	29	502.12	39	629.67	*47**
Rural	859.47	71	782.41	61	710.05	53

**Data was retrieved from The World Factbook of Central Intelligence Agency.* www.cia.gov

2.2.3 ***Climate Change***

In the scenario of global warming, mountain glacier coverage of the world's land-areas is expected to decreased with an increase of 0.6°C in global average surface temperature within a century (IPCC, 2001). In northwestern China, significant warming has occurred over the past 50 years, with average temperature increased by 0.7°C and the glacier area reduced by 1400 km^2, resulting in a 7% increase in Xinjiang's annual glacial runoff (Shi et al., 2007b). Based on the increasing flow from mountain streams, precipitation is predicted to increase as well. Shi et al. (2007b) suggested that in northern Xinjiang, the average annual precipitation increased by 36 mm from the 1960s to 2000. However, according to the data collected by NBSC (2012) and Zhang et al. (2006), Tarim, Turpan and Qaidam basins in Xinjiang were considered extremely arid areas with an annual precipitation of less than 25 mm, and high evaporation in this region indicated low efficiency in water recharge from precipitation. Although there is some disagreement about the causes of global warming among different scholars, the Intergovernmental Panel on Climate Change (IPCC) of the United Nations (2001) reported that human activities contributed the most to worldwide warming phenomena. Climate change is globally occurring and has been noticeable in regions like Xinjiang, which has experienced extreme climate events (IPCC, 2001; Shi et al., 2007b). Shi et al. (2007b) described flood disasters that took place in Xinjiang, one of which destroyed large water reservoirs. The authors suggested that these flooding events resulted from glacier snow-ice melt affected by climate change, and that the frequency of these extreme floods increased by a factor of 3 within 50 years (Shi et al., 2007b). In Xinjiang, the distribution of runoff was seasonal and the water resource systems and farming were most vulnerable to floods from June to August (Zhang et al., 2006). Even though flooding seemed to provide abundant water for irrigation in a high flow season (Zhang et al., 2006), the overflow amount and the quality of flood water could cause harm to crops. A recent flood event that took place in Kumul destroyed the cantaloupe fields, and resulted in a poor harvest (researcher's personal experience and local newspaper report, July 27, 2007).

2.3 Water Quality in China

In recent years, many water bodies in China were considered severely polluted. In particular, the deterioration in drinking water quality for domestic consumption has drawn attention at an international level. Therefore, it is important to identify the major driving forces in such environmental degradation, and to address China's current water quality issues and resource management regime.

2.3.1 ***Driving Forces***

Much research on China's water pollution has focused on some heavily industrialized centers, major lakes/reservoirs, and the seven big rivers including the Yangtze River, Yellow River, and Pearl River (Currell et al., 2012; Liu et al., 2001; MEP, 2007-2011). Based on available literature, China's growing population, expanding urbanization and industrialization, increasing vulnerability to geological and hydrological conditions in some regions, and climatic impacts were the major driving forces not only in reducing water availability, but also in deterioration of water quality in general (Currell et al., 2012; Scull, 2009; WHO/UNICEF, 2012; Yu et al., 2007). China's rapid economic growth has been impressive since the nation started recovering from the heavy poverty of the 1960s (Benewick and Donald, 2009). Almost from the same time, the nation faced criticism about the considerable environmental degradation accompanying its fast economic development. However, in their research, Tang and Bi (1996) found that water quality trends differed dramatically from those of economic development, thus there was little correlation between water pollution and economic growth.

2.3.2 ***Surface Water, Groundwater and Drinking Water Quality***

The literature review on water quality was mainly focused on surface water and groundwater in northwestern China. According to the Environmental Quality Standards for Surface Water Quality [GB3838-2002], China's surface water quality is categorized into five grades; the higher the grade, the worse the quality. Water of Grades I-III is considered to be suitable for centralized drinking water, while Grade Ⅳ is used for industrial and recreational purposes and Grade V for agricultural practices.

Table 2.6 Surface water quality of the areas under national monitoring program in northwestern China from 2007 to 2010 (MEP, 2007-2011)

Year	Number of monitored surface water section	Grade I-III	Grade IV	Grade V
2007	28	82.1%	14.3%	3.6%
2008	28	92.8%	3.6%	3.6%
2009	26	73.1%	19.3%	3.8%
2010	28	92.8%	3.6%	3.6%

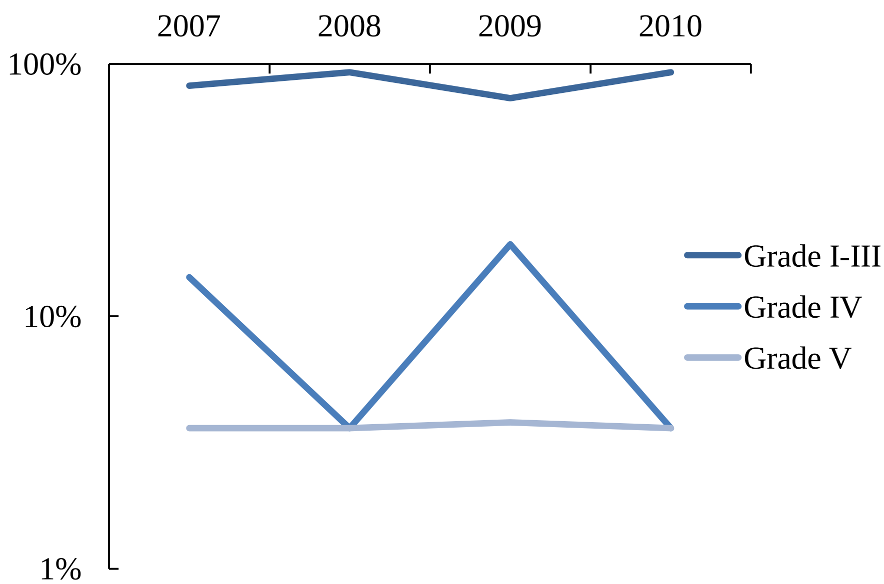

Figure 2.2 Changing trend in surface water quality of the monitored areas in northwestern China (MEP, 2007-2011), Y-axis values graphed on a logarithmic scale with a base of 10

Surface water quality in the areas under national monitoring program in northwestern China from 2007 to 2010 (Table 2.6) were evaluated by the Ministry of Environmental Protection (MEP, 2007-2011) of China with the standards described above. In general, most of the areas had good surface water quality while an average of 3.7% of all sections had water quality of Grade V over those years. The changing trend of surface water quality in these areas is presented in Figure 2.2. The percentages of the areas rated as

Grade I-III showed an obvious fluctuation, with a decrease of approximate 20% in 2009 compared to the previous year and an increase in 2010 (MEP, 2007-2011).

Within the last 30 to 40 years, groundwater withdrawal in northern China exceeded its recharge, causing a dramatic decline of the aquifer water table by 0.5-3 m per year (Currell et al., 2012). The depletion rate was especially fast within groundwater-fed municipal and irrigation areas (Liu et al., 2001), where major depression cones formed (Foster et al., 2004). Furthermore, evaporation and transpiration surpasses precipitation in arid areas of northwestern China, which causes a water/salt imbalance in shallow groundwater and runoff (Currell et al., 2012). Accelerated groundwater depletion reduces the interface between shallow and deep aquifers, and salinizes groundwater where underlying freshwater level drops and lowers the upper saline water level (Liu et al., 2001). Surveys of China's groundwater quality were conducted at a national level by MEP (2007-2011) from 2007 to 2011, and the analyzed results were accessible in the reports on the State of the Environment (except for 2008). The survey conducted in 2009 applied the five-grade indicator system described in the previous section to assess groundwater quality of 641 wells in northwestern China (MEP, 2007-2011). Results showed that only 2.3% of the wells fell between I-III and had suitable water quality for drinking (MEP, 2007-2011). Up to 73.8% of the monitored wells showed water quality either Grade IV or Grade V, which indicated inadequate water source for human consumption (MEP, 2007-2011). In 2010, a similar survey was performed in 182 cities, including 4110 monitored sites across the county, grading groundwater quality as Excellent, Good, Relatively Good, Relatively Poor, and Very Poor (MEP, 2007-2011). The results (Table 2.7) showed that groundwater quality in 10.2% of the monitored cities was rated as Excellent while 16.8% was Very Poor. Across the country, 40.4% of the monitored cities had Relatively Poor groundwater quality (MEP, 2007-2011). This indicated that there was room for improvement and it could be challenging for China to guarantee better groundwater quality. MEP (2007-2011) compared the groundwater by year and by region, and concluded that the quality in northern, northeastern, and northwestern China was worse, less stable, and had less improvement compared with the rest of the nation over those years. In general, deep groundwater aquifers were inherently better-protected; therefore, the quality of deep-layer groundwater was better than that of shallow-layer (MEP, 2007-2011). Moreover, groundwater in heavily exploited areas showed greater vulnerability to pollutants than the groundwater in areas with more minor exploitation (MEP, 2007-2011).

Table 2.7 Groundwater quality of 182 cities across China, 2010 (MEP, 2007-2011)

	Grades									
Sites	Excellent		Good		Relatively Good		Relatively Poor		Very Poor	
	n	%	n	%	n	%	n	%	n	%
4110	419	10.2	1134	27.6	206	5.0	1661	40.4	690	16.8

China’s water quality is threatened by the contamination of surface water and groundwater, which is caused by excessive use of agricultural pesticides and fertilizers, residential waste, and emissions and discharges from industrial and commercial facilities (Chen et al., 2005; MEP, 2007-2011; Sampat, 2000; Scull, 2009; Yu et al., 2007). Nitrate contamination in groundwater or surface water results from runoff or irrigation return water of farmlands where agricultural fertilizers are dosed, and also from septic systems or animal waste (USEPA, 2009). One of the recognizable health effects from continuous exposure to nitrate is ‘blue-baby syndrome’, which may cause death in infants if not treated (USEPA, 2009). In their research, Chen et al. (2005) reported that among 295 sampled wells in northern China, nitrate was detected in 33% of the wells tested and the nitrate concentration in 9.5% of the wells exceeded the drinking water safety standard of 45 mg/L set by the World Health Organization (WHO, 2006).

In 2008, MEP and fellow departments of the State Council supervised the application of environmental control measures to a total of 4661 urban drinking water sources within protected areas, and publically identified 845 environmental violators who had undertaken illegal constructions and discharged pollutants excessively within source water zones in China (MEP, 2007-2011). Table 2.8 summarizes discharges of major pollutants in wastewater during 2006 to 2011 (MEP, 2007-2011). The total wastewater discharge increased over those years, due primarily to a dramatic increase in domestic wastewater discharge from 296.6 million tons in 2006 to 379.8 million tons in 2011. On the other hand, China's industrial discharge was controlled and stabilized over that period (MEP, 2007-2011). In 2009, the major contaminants detected in China's overall surface water were petroleum, ammonia, and biochemical oxygen demand (BOD_5), while total hardness, ammonia, nitrate, iron, and manganese were detected in groundwater across the country (MEP, 2007-2011).

Table 2.8 Quantity of major pollutants discharged in wastewater during 2006-2011 (MEP, 2007-2011)

	Wastewater Discharge (100 million t)			COD Discharge (10,000t)			Ammonia Nitrogen Discharge (10,000t)		
Year	Total	Industrial	Domestic	Total	Industrial	Domestic	Total	Industrial	Domestic
2006	536.8	240.2	296.6	1428.2	541.5	886.7	141.3	42.5	98.8
2007	556.8	246.6	310.2	1381.8	511.1	870.8	132.3	34.1	98.3
2008	572.0	241.9	330.1	1320.7	457.6	863.1	127.0	29.7	97.3
2009	589.2	234.4	354.8	1277.5	439.7	837.8	122.6	27.3	95.3
2010	617.3	237.5	379.8	1238.1	434.8	803.3	120.3	27.3	93.0
2011	652.1	N/A	N/A	1293.7	355.5	938.2	175.8	28.2	147.6

There is a large volume of data available on the quantity of China's water provided by many administrative institutes; however, access to data regarding investigation and assessment of China's drinking water quality with specific numerical figures was limited in general. As mentioned earlier, China's water quality has been affected by pollutant discharges to water bodies including surface and groundwater sources, which together with the salinization of depleted freshwater could eventually over burden water treatment processing and impact drinking water quality (Liu et al., 2001; MEP, 2007-2011; WHO/UNICEF, 2012).

WHO and the United Nations Children's Fund (WHO/UNICEF, 2012) reported progress on sustainable access to reliable drinking water and essential sanitation, and the improvement in sanitary facilities in individual households. In this report, WHO/UNICEF defined 'improved drinking water' as the usage of piped water into a dwelling/yard, public tap water, tube-well, etc., and defined 'improved sanitation' as the application of flush to sewer system/septic tank, ventilated pit latrine, composting toilet, etc. Implementing these definitions, WHO/UNICEF (2012) concluded that, in China, 457 million people had gained access to improved drinking water while 593 million gained access to improved sanitation from 1990 to 2010. WHO/UNICEF (2012) also stated that even though China was on the right path to make progress, there were still 119 million people who had no access to improved drinking water and 477 million without access to improved sanitation as of 2010. Table 2.9 demonstrates the increasing proportion of China's population gaining access to enhanced facilities within two decades. Compared to urban population access, which increased from 48% of the population with access in

1990 to 74% in 2010, people in rural areas lacked access to better sanitary facilities (WHO/UNICEF, 2012).

Table 2.9 Proportion of national, urban, and rural populations that had access to sanitation facilities classified as 'improved' in China in 1990, 2000, and 2010 (WHO/UNICEF, 2012)

Year	National	Urban	Rural
1990	24%	48%	15%
2000	44%	61%	35%
2010	64%	74%	56%

Providing safe drinking water is fundamental and crucial to the health of a nation. Drinking water quality in China not only is threatened by water pollution caused by various human activities described earlier, but also by natural contamination of water resources. Chronic exposure to high arsenic concentration causes skin damage or circulatory system problems, and may increase the risk of cancer (USEPA, 2009). The standard limit for arsenic in drinking water set by the US Environmental Protection Agency (USEPA) is 10 μg/L (USEPA, 2009). A large scale study on health effects caused by exposure to natural arsenic in groundwater in China was conducted by Yu et al. (2007). During 2001-2005, they tested 445,638 wells across 16 provinces including Xinjiang and found that 21,155 wells, accounting for 5% of those sampled, contained arsenic greater than 50 μg/L, putting an estimated of 582,769 people at risk of consuming water with high arsenic concentrations (Yu et al., 2007). In the same study, 903 of the 29,747 sampled wells in Xinjiang were found to contain arsenic greater than 50 μg/L, placing an estimated of 100,000 people at risk of being exposed to natural arsenic via drinking water. As a result, Xinjiang was ranked as one of the top five arsenic-containing regions in China (Yu et al., 2007).

Owing to the natural occurrence of fluoride in aquifers of arid regions, it was estimated by WHO that drinking water of 70 million people in northern China contains elevated fluoride concentrations (Sampat, 2000). WHO (2004) reported more than 26 million people with dental fluorosis and a million cases of skeletal fluorosis due to excessive exposure to high concentrations of fluoride in drinking water in China.

Natural characteristics of the hydrological cycle make Xinjiang vulnerable to a number of naturally occurring water-related problems, such as excessive arsenic concentration, high levels of fluoride, and low levels of iodine (Scull, 2009). People in Xinjiang who were exposed to water with low iodine levels suffered from goiter, a disease resulting from iodine deficiency that was considered endemic in the 1990s due to its high rate of occurrence among children prior to iodization of table salt (Scull, 2009).

2.4 Water Resource Management

Literature on China's water resource management was reviewed with a focus on three aspects: 1. Water resource policies, regulations and guidelines implemented to cope with increasing water shortages, and water quality degradation, particularly in the northwestern part of the country; 2. Current institutional structures and embedded water resource management; and 3. Drinking water treatment processes, from water sample collection to water distribution, with both management and consumption viewpoints.

2.4.1 ***Policies, Regulations and Guidelines***

China has been facing water resource management challenges due to water shortage, recharge/withdrawal imbalance, and water quality degradation problems, and in order to cope with these water issues, the Chinese government established key tasks to employ the theories of sustainable water resource management under the guiding principles of ‘scientific development’ and ‘harmonious society’ in the National 11th Five-Year Plan (2006-2010) for Environmental Protection (Jiang, 2009; MEP, 2008). These tasks included prioritizing and facilitating the prevention and control of water pollution, ensuring safe drinking water for urban and rural populations, and enhancing water use efficiency in different sectors (MEP, 2008; Jiang, 2009). Some of the action plans of China’s development in environmental science and technologies were: augmenting water allocation to adjust water supply, establishing quality monitoring networks for surface water and groundwater at the national level, enhancing industrial and urban wastewater discharge treatment, and achieving chemical oxygen demand (COD) reduction by improved urban sewage treatment facilities (Jiang, 2009; MEP, 2008). Although China, to some extent, managed to control industrial pollution over the past few decades by reinforcing and implementing various laws, regulations, and policies, rapid urbanization has increased the residential water pollution (MEP, 2007-2011; The World Bank, 2006).

As briefly mentioned in Chapter 1, the ‘Go West’ campaign was China’s western socio-economic development policy implemented in order to develop and modernize the western regions (Benewick and Donald, 2009). Although the policy consisted of ecological and environmental protection-oriented strategies such as reforestation and prevention of desertification, other development strategies that brought in massive industrial manufacturing and infrastructure construction dramatically increased the water demand, evoking inter-sector water conflicts and overexploitation of aquifers (Zhang et al., 2006). In order to address an agricultural water use efficiency of only 40% in northern and northwestern China, plus the severe water shortage issues in these regions, water-saving practices such as sprinkler and drip irrigation techniques were applied to reduce water use while also increasing crop yields (Deng et al., 2006). Compared with traditional irrigation systems, sprinkler and drip irrigation techniques reduce annual agricultural water demand by more than 50% (Deng et al., 2006); however, various types of water-saving techniques were adopted for use on less than 30% of China's irrigated farmland (Jin and Young, 2001). Water transfer from south to north is to be achieved via a hydrologic engineering project for transporting approximately 35.8 billion m^3 water annually to northern and northeastern China starting in 2014 (Currell et al., 2012; Jaffe and Schneider, 2011). However, initiation of the project has raised concerns as to whether there would be sufficient water supplied to arid northern and western China (Jaffe and Schneider, 2011). Zhang et al. (2009) estimated that in North China Plain, there would be a water deficit of 9.1 billion m^3 by 2020, and this gap would still exist with a water deficit of 2.1 billion m^3 even with additional water being transferred across regions from south to north.

Financial investments by the Chinese Central Government and local governments in various water resource projects have been increasing, with a focus on major river/lake/reservoir constructions, water allocation, irrigation infrastructure, and rural water supply, in order to increase water use efficiency (MWR, 2007). Some efforts were also made to protect and upgrade water quality. For example, locally-initiated projects were established with the help of experts and authorities to educate famers and reduce excessive fertilizer and pesticide use in farming (Currell et al., 2012). As a result, there was not only a fruitful harvest and reduced water demand, but also water resources were protected from chemical contamination (Currell et al., 2012). Although in recent years there was increasing attention directed at water quality monitoring with respect to arsenic and wastewater contaminants, Currell et al. (2012) suggested in their report that more comprehensive measures and reliable data report on other quality standards such as fluorine (F), nitrate (NO_3), etc., were essential and should be put in place. Currell et al. (2012) also emphasized the correlation between water use and water quality, and the need for legal reinforcement in order to reach a harmonious relationship among water resources, humans, and the environment as a whole.

2.4.2 ***Institutional Structure***

As national properties, water resources are administered and protected by the State Government of China according to The Water Law (2002), and water-related institutes such as the Ministry of Environmental Protection (MEP), the Ministry of Water Resource (MWR), and the Ministry of Construction (MOC), which are national-level institutes directly under the State Council that contribute to water resource management (Feng et al., 2006; The World Bank, 2006). As the central institute, MEP supervises local-level institutes such as the Environmental Protection Agencies (EPAs), and is in charge of the management of water pollution, while other national institutes are responsible for other aspects of water management (The World Bank, 2006). The same governmental structure is repeated at a local administrative level (i.e., provincial, municipal and county-level governments), and forms a top-down institutional framework implemented in water resource management (The World Bank, 2006). The framework and its legal basis are outlined in Table 2.10, with institutes' water-related tasks included. Feng et al. (2006) and the World Bank (2006) both pointed out that in such traditional top-down institutional structures, there tends to be a lack of horizontal and vertical coordination due to poor communication among agencies, the functions and responsibilities of different ministries overlap in terms of water resource management, and that China had been facing challenges working in such system, in balancing limited water resources and high demand, and in preventing further degradation of the nation's water environment.

Table 2.10 Institutional framework and its legal basis in water resource management (The World Bank, 2006)

Legal Basis	Governmental Institute	Tasks
The Environmental Protection Law	MEP	- coordinates supervision and management of water resource protection - establishes national standards for water quality and for discharge of pollutants
	MWR	- supervises the management of water resource protection
The Water Pollution Protection and Control Law	MEP and EPAs	- supervise and manage the prevention and control of water pollution - are responsible for water monitoring - protect water sources for consumption
The Water Law	MWR	supervise water quantity management

2.4.3 ***Drinking Water Treatment***

The ultimate goal of a public water system is to provide potable water to a community by implementing a treatment process appropriate for the size of the community being served and the quality and type of source water available to this community (USEPA, 2012). Lots of groundwater systems reach the quality standards of drinking water without any treatment, and some may require additional chlorine disinfection or other treatments that are necessary but not as complex as treating surface water systems (USEPA, 2012). Traditionally, the most commonly used drinking water process for treating surface water includes coagulation/flocculation, sedimentation, filtration, and disinfection (USEPA, 2012). Each and every step of the process flow has its unique purpose and function, as shown in Table 2.11.

Table 2.11 Traditional drinking water treatment process flow and the purposes and functions of each process (USEPA, 2012)

Process	Purpose and function
Coagulation/Flocculation	- neutralize the negative charges on the particles - attract the dirt particles in order to form flocs by adding chemical (e.g. alum) - efficiently remove the larger particles in the later processes of sedimentation and filtration
Sedimentation	- settle the flocs to the bottom of the sedimentation basin
Filtration	- filter out the smaller particles with sand and gravel (clogged sand must be backwashed)
Disinfection	- kill microbial pathogens, bacteria and viruses

An estimated 1.8 million people die from diarrheal diseases every year, of which 88% of cases are due to unsafe drinking water or poor sanitation and hygiene facilities (WHO, 2004). The majority of the reported cases are children in developing countries, where sanitizing water with chlorine and upgrading water facilities could reduce diarrhea morbidity by 37.5% and 21%, respectively (WHO, 2004). Compared to the drinking water safety of many developed countries, developing countries lack the ability to effectively deliver good quality water to local households due to poor water utilities, and inability to manage risks (Hrudey et al., 2006). There are many challenges for water suppliers in removing contaminants from water, even when the most appropriate series of processes are applied. For example, disinfection byproducts can occur when disinfectants react with the materials in the water and these byproducts pose risks to public health (USEPA, 2012).

According to a benchmarking study conducted by the World Bank and the MOC of China in 2004, the majority of the 12 water supply utilities in surveyed cities in China struggled with low water pressure, and a couple cities did not have continuous water supply, meaning water was not being supplied 24 hours per day year round, due to water shortages and financial limitations (Browder and Xie, 2007). The same report also concluded that old-fashioned treatment technology, highly contaminated source water, poor monitoring systems, and a lack of reliable and accessible quality data were the main contributors to poor drinking water quality in many Chinese cities (Browder and Xie, 2007).

China has been continuously adjusting laws, regulations, and guidelines to work towards improving drinking water quality and provision. China's first urban tap water supply standard used 11 quality indicators at its introduction in 1950, and has undergone six revisions until the most recent version where the Ministry of Health issued the Hygiene Standard for Drinking Water with up to 96 indicators (Shen, 2006). Details of regulatory parameters and the standards for surface water and drinking water quality in China are described in Appendix E. As an example of some of these indices and their standards for surface water quality from the Surface Water Quality Standards [GB3838-2002], Table 2.12 shows the comprehensive organic contaminant index standard values. The water quality of centralized supply intake should be consistent with surface water environment quality Grade II.

Table 2.12 Comprehensive organic contaminant index standard values of drinking water

Comprehensive Organic Contaminant Index	Standard Value
COD_{Cr}	15 mg/L
BOD_5	3 mg/L
Permanganate	4 mg/L

COD, BOD, and turbidity are the main parameters used to characterize water quality in China (Wang, 2006). High oxygen consumption in drinking water indicates large amounts of organic compounds, and the greater the concentrations of organic contaminants, the poorer the water quality (The World Bank, 2006). According to a statistical document on drinking water in 35 Chinese cities during 1985-1994, drinking water quality in 23% of target cities did not meet water quality standards due to excessive COD levels, and the author predicted that COD levels would continue to increase (Wang, 2006). However, COD discharges from industrial and urban domestic wastewater have in fact decreased since 1995 (OECD, 2007), owing to China's pollution prevention acts mentioned in Section 2.4.1. The turbidity standard was revised in the China Standards for Drinking Water Quality [GB5749-2006] from 3 NTU (Nephelometric Turbidity Units) to 1 NTU. The stringency toughened the quality requirement for water suppliers, yet the rust and corrosion of water distribution pipes can increase turbidity even if it was controlled to within the standard in treatment plants (Wang, 2006). The benchmark study by Browder and Xie (2007) also reported that 5 out of the 12 surveyed cities had turbidity levels that exceeded 1 NTU.

Escherichia coli (E. coli) plays an important role as an indicator in microbiological safety of drinking water and the maximum acceptable concentration of *E. coli* in drinking water is non-detectable per 100 mL (Health Canada, 2006). China's Standards for Drinking

Water Quality [GB 5749-2006] lists the same standard value for *E. coli* as non-detectable per 100 mL. The occurrence of coliform and heterotrophic bacteria reproduction after the treatment process constitute biologically unstable and unsafe drinking water, and the bacterial regrowth within the distribution systems should be reduced to a minimum through appropriate biological pre-treatment processes in the plants (Hu et al., 1999). Chlorine dioxide and liquid chlorine are two forms of disinfectants applied in water treatment to kill bacteria like *E. coli*, though the efficacy of chlorine dioxide was demonstrated to be better than liquid chlorine (Huang et al., 1997).

2.4.4 ***Drinking Water Distribution***

China's earliest urban water supply can be traced back to 1879, and up until the foundation of the People's Republic of China, about 9 million people were documented to have access to tap water in 72 cities, consuming 2.4 million tons daily (Shen, 2006). After more than a century, in 2003, a water capacity of 239.7 million tons was supplied daily to an urban population of 291.4 million (MOC, 2004). Table 2.13 presents the basic statistics of tap water supply systems in the City of Beijing and Xinjiang province, and shows the changes in tap water production from 1999 to 2004. Within only five years, Beijing's daily tap water supply capacity tripled with a twofold increase in the length of water pipelines. Compared with Beijing, Xinjiang showed a lower rate of increase in overall tap water supply, although, over the years, the length of pipelines had a slight reduction, for which no explanation was given. There was a decrease in Beijing's daily tap water consumption per capita from 1999 to 2004, while in Xinjiang, daily consumption per capita increased from 160.5L to 206.3L.

In many populous cities in China, urban water pipelines are accessed by a large number of consumers living in apartment blocks, resulting in uneven water supply distribution systems (Browder and Xie, 2007). The number of pipe breaks is high in China, with a breakage rate of 2 breaks/km/year due to outdated and poor pipe materials. This figure is much higher than that of other countries such as the UK (0.2 breakage rate) and Russia (0.5 breakage rate), demonstrating poor water utility performance in Chinese cities (Browder and Xie, 2007). High water losses were also reported due to the large scale of water pipe leakages; therefore, the overall net financial income of municipal water utilities has declined since 1997 (Browder and Xie, 2007).

Table 2.13 Basic statistics on tap water in Beijing and Xinjiang in 1999 and 2004 (NBSC, 2012)

	Beijing		Xinjiang	
Year	1999	2004	1999	2004
Production capacity of tap water (10000 t/day)	507.25	1504.3	286.74	360.3
Length of water supply pipelines (km)	8068	17017.6	4244	4088.9
Total annual volume of water supply (10000 t)	110744	150206	47771	65908
Residential use	73459	98252	23562	37106
Productive use	27863	38361	19871	22074
# of residents with access to tap water (10,000)	764.10	1187.0	402.13	492.9
Per capita daily tap water consumption (residential) (L)	263.36	226.8	160.53	206.3

2.5 Water Operators and Water Services

In China, a water operator is a private company providing water services through an agreement with local government, and the water supply systems in many Chinese cities are owned by private companies, which are part of the China Water Works Association (Browder and Xie, 2007). According to the agreement made between a company and local government, water operators can be categorized into different types of contracts, which are partially summarized in Table 2.14 (adapted from Browder & Xie, 2007). Some companies are owned by government and some are not, but they all share the same goal of seeking maximum profits (Browder and Xie, 2007). Also in the report by Browder and Xie (2007), it was concluded that the information delivered by the utilities regarding the quality of drinking water was not transparent, owing to weaknesses in jurisdiction supervisory and governance, as well as a lack of community-based reporting systems.

As grass-root organizations, residential committees play an important role as the linkage between authorities and the public in Chinese society (Mok, 1988). The growth of urban residential committees has been dramatic and the number reached 84,689 in 2009 (China Daily, 2010). Residential committees were initially developed to offer public services, maintain harmonious neighborhoods, and authorize regular public hearings, and in recent years, their duty had been broadened in regards to public safety, employment, social insurance, etc., with the aim of providing more democratic rights to urban residents (China Daily, 2010).

Table 2.14 Water operators in China and their contracts with government (partial) (Browder and Xie, 2007)

Water Operator	Contract detail
Joint venture or Mixed Capital Company	- operator is partly owned by the contracting authority - two parties jointly share most of the risks
Management Contract	- operator provides management services to the utility in return for a fee
Operate and Maintain Contract	- operator operates and maintains water assets at its own expense but does not finance investment in infrastructure assets - the government delegates the management of the water service to the operator in return for a specified fee, often based on the volume of water sold - the private company's profit is equal to revenue from the fee, less operating and maintenance costs
Lease Contract	- operator operates and maintains water assets at its own expense but does not finance investment in infrastructure assets - operator retains revenue from the customer tariff and pays the contracting authority a specified lease payment

2.6 Bottled Water

Snyder et al. (2005) examined perchlorate concentrations in 11 natural water bodies providing water for 21 brands of bottled water, and found that perchlorate contamination existed in most of the water samples. However, in another study, Shi et al. (2007a) analyzed 29 samples of the bottled water brands most frequently purchased by Chinese consumers, including 22 natural mineral water samples and 7 purified water samples and found 14 samples with low perchlorate concentrations, and 15, including all the purified water samples, with non-detectable perchlorate concentrations (Shi et al., 2007a). Bottled and home-treated (filtered) waters are generally low-mineral waters lacking macronutrients such as potassium, sodium, calcium, and magnesium, and also micronutrients such as zinc, selenium, iodine, fluorine, chlorine, etc., so it has been suggested that drinking water quality guidelines for bottled or central supply water should indicate minimum concentrations of essential nutrients (Kozisek, 2005).

3 METHODS

Data were collected from existing sources through a literature review, and through on-site surveying. In order to employ these measures, a mixed method approach is introduced in the first section of this chapter. Details of various measures, such as interviewing local households, communicating with water experts and practitioners, and researcher's observations, are described in the following sections.

3.1 Introduction

In order to reach a holistic understanding of drinking water quality in the City of Kumul, a mixed methodology (Creswell, 2008), which combined the strengths of both quantitative and qualitative approaches, was employed to address research objectives outlined in Chapter 1. The purpose of this research was to analyze the quality of drinking water for household consumption; therefore, both quantitative and qualitative methods were prioritized to collect data on water quality, and to assess people's attitudes towards drinking water. In this research, quantitative data were presented and supported by qualitative data to provide statistically analyzed results of open-ended questionnaires with an in-depth description.

3.2 Data Collection

The following steps were taken to collect and analyze data: (1) gathering China's water-related regulations and guidelines, (2) visiting the study area, conducting interviews with local households, and meeting with water experts/practitioners to collect drinking water data available to outside researchers, and (3) analyzing collected data using a mixed method approach. Details of the data analysis and results are given in Chapter 4. Questionnaires used in scheduled interviews are attached as Appendix A and Appendix B.

3.2.1 ***Existing Sources of Information***

Research data were retrieved from a review of relevant sources such as publications, government documents, news outlets, and/or official webpages. For example, China's current water situation and water quality standards were studied in advance in order to better prepare the interview questions. Knowledge gained in the process allowed for the transfer of valuable water information to households and also created a rapport with participants. Reviewed documents included the following contents that were important to this research:

- A comprehensive introduction to Kumul's water resources for consumption
- Technical reports on delineating drinking water source protection areas in the City of Kumul
- Records of Kumul's drinking water quality testing from previous years
- Process flow charts of the purification plants

Examples of key existing resources include:

- Water Quality Standard for Urban Water Supply [CJ/T206-2005] (2005, in Chinese)
- Research and Evaluation on the Environment of Source Water for Drinking in Kumul Region (Kumul Regional EPA, 2008)

- ❖ Technical Report on Division of Source Water Conservation Area for Drinking Water in the City of Kumul (Kumul Municipal EPA, 2009)
- ❖ Protection Planning of Source Water for Drinking in Rural Area of Kumul Region (Kumul Regional EPA, 2008)

Primary indicators of water quality for domestic consumption and different criteria for determining potability of the water were provided in Chapter 2. Due to China's confidentiality policies around revealing water quality data, only some testing results of water quality documented by local institutes were accessed and used to assess if there was an upgrade in drinking water quality after the main water purification plants were built. Relevant regulations and guidelines employed by Kumul's water institutes were addressed as part of the assessment.

3.2.2 ***On-site Learning***

The research on the attitudes of local households towards the quality of their tap water and the custom of their daily water use was conducted through on-site learning and interviewing local households, as well as water experts and water practitioners. The field study was completed during two trips to Kumul, China (March-August, 2011 and January-March, 2012). During the first trip, interview data collected before receiving the human ethics certificate issued by the University of Manitoba were considered invalid. The mistake was made because of a lack in communication between the researcher and the University due to an inconsistent and unstable Internet access in study area. As a result, a second trip was scheduled with a Research Ethics Board Certificate (Appendix C).

A complete water purification process must consider every step, from source water to tap water, including source water protection, water sampling, water testing, and water distribution (Spellman and Drinan, 2000). The researcher visited the relevant local water affairs institutes, company, and markets. As the ‘frontline’ of drinking water provision, three water purification plants were visited most often.

Throughout on-site learning, Kumul’s water-related institutional structures and their functions were identified and illustrated with diagrams. Spatial distributions of reservoirs and water pipes in Kumul region were mapped to show where major water sources were. Various industrial, agricultural, and human activities near drinking water sources and their effects on water quality were identified. Water quality for domestic consumption was assessed by participating in water quality testing at purification plants that supply tap water on a larger scale in the City of Kumul. Tested water samples included target source water, processed water at the purification plant, and the treated water from the distribution pipelines. Test results for water quality were compared to the documented standard values to identify water suitability for domestic consumption. Exceeded values were identified, and the trends or changes in water quality were determined. A comprehensive diagram of Kumul’s water provision system illustrated the positions of water supplier, tap water pipeline system, and the locations of interviewed households in a map. Operation of Kumul’s water purification plants was studied and the best practices of water purification plants were assessed. A summary statistics approach was used to analyze household survey results and demonstrate public opinion regarding the available local tap water, by calculating the proportions of participant selection of single- and multiple-choice survey questions, and by representing the results in charts.

3.3 Research Participants

Interviews, as mentioned earlier, were used to collect qualitative data as inputs to support quantitative data. Therefore, information gathered from interviews was able to fill any knowledge gap where numerical data alone could not address a particular issue in depth. Interviews were conducted with the participation of local households, water experts, and practitioners working at the purification plants.

3.3.1 ***Local Households***

There were 65 respondents living in the urban area of Kumul where tap water was supplied to the households that voluntarily participated in this research. Research Ethics Board Approval Certificate was obtained and attached as Appendix C. Among these 65 participants, 45 were interviewed face-to-face, and the rest completed the questionnaires individually by writing down their answers. Research participants were recruited, using snowball sampling, starting from researcher’s family and friends, and finally building up to 65 households in total. The household interview questionnaire was based on the Drinking Water Survey report submitted by Ipsos Reid Public Affairs to Metro Vancouver in 2008. Questions were modified and further developed according to Kumul’s water environment and water situation. The questionnaire included 26 multiple-choice questions and 5 open-ended questions. These questions were focused on participants’ attitudes and opinions associated with tap water and its quality issues such as: whether or not they boiled tap water before consumption, whether or not they preferred bottled water to tap water, whether or not they had been practicing water conservation in daily life, their awareness of water regulations in Kumul, etc. Participants were sorted into groups based on their standards of living, ages, and house locations. A sample questionnaire is attached as Appendix A.

Throughout the face-to-face interviews with the locals, the consumption of tap water was witnessed at a primary level, and the behaviors of local people when using tap water and their perceived water conservation practices were examined. These observations provided insights into understanding local customs regarding drinking water.

Photo 1 Interviewing a tap water consumer

3.3.2 ***Experts and Water Practitioners***

In this study, 'experts' were people who currently held positions in water-related institutes and/or companies involved in drinking water provision, including leaders and managers at different water management levels. Participating experts and practitioners included: directors of water-affairs institutes or companies, managers of water purification plants, water technicians and engineers with solid background knowledge and rich experience, and licensed water practitioners in charge of different operating units at purification plants.

15 face-to-face meetings were scheduled with experts and practitioners, including a semi-structured survey questionnaire attached as Appendix B. Four local specialists participated in follow-up interviews with more open-ended questions.

Photo 2 Expert from the Kumul Water Affairs Group Ltd.

The contents of the meetings were accurately translated and transcribed by the researcher. The important conversations were quoted and are cited in later chapters. The expert and practitioner interviews were conducted in the following subject flow:

- ❖ Kumul's water environment, drinking water sources, and source water protection planning
- ❖ Drinking water purification process and laboratory testing

- Kumul's water distribution system, including the materials of water pipes and the usage of water meters
- Kumul government's investment and action plans for improving drinking water quality/quantity and its management, and the deficiencies in implementing any policies, regulations, approaches, and restrictions

Some of the related figures and the preliminary findings were obtained directly through the conversations on these topics. All findings and results are expounded in Chapter 4 and are discussed further in Chapter 5.

3.3.3 ***Other Measures***

This research focused on local residents' attitudes towards the quality of their tap water, and was conducted from a perspective of assessing Kumul's drinking water provision practice at a level of authority. Interacting with individuals played a crucial role in perceiving issues that had been ignored, and in becoming aware of the challenges ahead. In Kumul, there has been no research regarding drinking water conducted with consideration of public participation. The findings of this study can help to pass a message to local authorities about the need to consider water issues from the public's point of view and increase trust and perception of credibility among consumers while ensuring safe drinking water quality.

Besides the confidentiality statements mentioned in the Letter of Consent (Appendix C), participants' photographs taken during the field study were included only as a demonstration of this research for members of the evaluation committee. Quotations of the participants were translated by the researcher with no personal judgment, and were included in later chapters. The analyzed results of collected data were presented with authenticity and discretion, and the confidentiality of authorities and members of the public were fully respected.

Firsthand information i.e., observational data, can sometimes be more reliable than secondhand information acquired during an interview. As someone who was born and raised in Kumul, the primary researcher was well aware of the local custom and culture, and communicated with local people in Uyghur, a language widely spoken by Uyghur ethnic people, and in Mandarin Chinese.

4 RESULTS

4.1 Introduction

In order to closely align with the research purpose and objectives, the reporting of results followed a logical framework. First of all, the administrative functions in Kumul region, and the regulations and guidelines adopted by local jurisdiction were addressed. Secondly, the main water resources for consumption in the City of Kumul were identified. Thirdly, Kumul's water quality management was examined throughout the water supply system, from the very front-line source water to the distribution pipeline. Fourthly, water practitioners' performances in water purification plants were observed. Lastly, the transparency and accountability of water reporting services, and the communication between authorities and the public were examined.

4.2 Summary of Results

Integrity in water supply and sanitation practices consists of guaranteeing sufficient water supply and safe water quality. In order to provide a clear picture of Kumul's drinking water issues, four key results can be summarized as follows:

1. Tap water was not directly consumed by 74% of the local households in urban area (i.e., treatment was applied to tap water before consuming);
2. There were gaps and deficiencies in communication between authorities and the public, which led to general mistrust of authorities;

3. There were flaws throughout the drinking water supply process in terms of outdated treatment equipment/devices and poorly trained practitioners; and
4. Government did not hold full responsibility for water resources, so the roles of relative institutes in water resource management overlapped and the relationships and interactions among these institutes were complex.

Overall, Kumul appeared to be implementing industry-centered development strategies and following the same steps as many major industrialized cities in China in the sense of environmental degradation resulting from a ‘first pollute, then control’ behavior (Municipal EPA, 2009). Interview results did not show much public confidence in Kumul’s drinking water quality and supply systems, partially due to a lack in authorities’ reporting on water information to the public.

4.3 Water Resource Management in Kumul Region

The on-site learning experiences helped identify the administrative functions of water-related institutes and their relative roles in managing water resources. There were three water purification plants supplying drinking water for households in the City of Kumul, and these were run by Kumul Water Affairs Group Ltd. (KWAG Ltd.). Therefore, KWAG Ltd. (Photo 3) was the most appropriate place to associate with and conduct observations.

Photo 3 Kumul Water Affairs Group Ltd.

4.3.1 ***Institutional Functions***

Local governments (Photo 4) were established at region, municipality, township, and town levels. The water-related institutes, each institute's functional internal departments, and each department's tasks are presented in Table 4.1. Only the departments associated with water affairs are listed in the table. In general, governmental institutes were responsible for supervising water quality and coordinating water use. The main focus of Kumul Regional Environmental Protection Agency (EPA) was the quality testing of drinking water for the two counties (Barkol and Aratork) in the mountain area, and also monitoring the quality of groundwater and supervising the two wastewater treatment plants. Both Regional and Municipal EPAs did not have any departments or units entitled 'Water Quality Management', but together with Water Conservancy Bureaus (WCBs), their tasks involved water resource management projects focused mainly on the reasonable distribution of water resources. Urban water supply and the protection of groundwater within the planning areas were guided by the Regional Construction Bureau (CB). Municipal EPA also participated in supervising and monitoring the quality of drinking water for domestic consumption. Water samples collected by individuals and work units who had concerns about their well water or tap water were also tested by Municipal EPA.

Photo 4 The government building of the City of Kumul

KWAG Ltd. was part of the Changyuan Group Ltd. of China, and was in charge of all water purification plants that supplied drinking water for urban areas in Kumul. Local government did not hold full control over water resources, and control over the municipal water supply was split between Kumul's governments and Changyuan Group Ltd. about fifty-fifty. According to the categories of water operators described in Section 2.5, KWAG Ltd. showed characteristics of both "operate and maintain" and "lease" contracts.

Local governments delegated to KWFG Ltd. the management of water services, including water provision, billing, and collection of customer tariff, in return for a certain fee based on the amount of water sold. At the same time, KWFG Ltd. retained customer revenue and maintained water operation at the company's own expense.

Table 4.1 Summary of Kumul's water-related institutes and their internal departments and tasks

Institute	Internal departments	Tasks
Regional EPA	Pollution Control and Monitoring Management	- supervises control work of water pollutant and pollutant source - supervises wastewater treatment plants
	Monitoring Station	- monitor water quality at regional level
Regional WCB	Capital Construction	- coordinates construction and project acceptance of key hydraulic engineering - organizes comprehensive management and exploitation of rivers and reservoirs in the region - guides drinking water supply at regional level
	Farmland Water Conservancy	- guides farmland water conservancy and water-saving irrigation
Municipal EPA	Pollution Control and Monitoring Management	- supervises drinking water supply in the city
Municipal WCB	Water Management	- manages reservoirs that supply water for township
	Water Administration and Supervision	- supervises water quantity and quality work at city level
	Planning Team	- plans and programs water conservancy construction at township level
Regional CB	Public Service Management	- manages urban water supply, water sewage and afforestation - guides urban water use and conservation - guides the exploitation and protection of groundwater within planning areas
Municipal EPS	Monitoring Laboratory	- supervises drinking water quality for domestic consumption - tests individuals' water samples

The laws, regulations, and guidelines adopted by the local jurisdiction are listed in Appendix E. With the implementation of these documents, details on Kumul's delineation of source water protection areas and the analysis of accessible data on water quality are described in Sections 4.3.4 and 4.4.2.

4.3.2 ***Water Resource Availability and Water Use***

In Kumul Region, the total volume of water resources in 2008 (Table 4.2) was 1458 million m^3, of which 1067 million m^3 was surface water, and the total amount of groundwater withdrawal was 82 million m^3 (Regional EPA, 2008). The average water availability in Kumul Region was 2500 m^3 per capita per year; for urban populations, the average water availability was only 1500 m^3 per capita per year (Regional EPA, 2008). Kumul Municipal EPA (2009) predicted that the urban population, which was 410,000 in 2009, would reach 498,200 and 657,800, and the annual water availability per capita would drop to 1280 m^3 and 970 m^3 by 2010 and 2020, respectively.

Table 4.2 Total renewable water resources and per capita water availability in China in 2011 (FAO, 2013) and in Kumul in 2008 (Regional EPA, 2008)

	National	Kumul
Total renewable water resources (10^9 m^3/yr)	2840	1.458
Total renewable surface water (10^9 m^3/yr)	2739	1.067
Total renewable groundwater (10^9 m^3/yr)	828.2	0.082
Total renewable water availability (m^3/person/yr)	2060	1500

Figure 4.1 shows the percentages of water use in four different sectors in Kumul. Agricultural demand for water took 88% of Kumul’s water resource, while industrial and domestic demands took 2.7% and 5.4%, respectively; the rest was used to promote afforestation of Kumul (Municipal EPA, 2009).

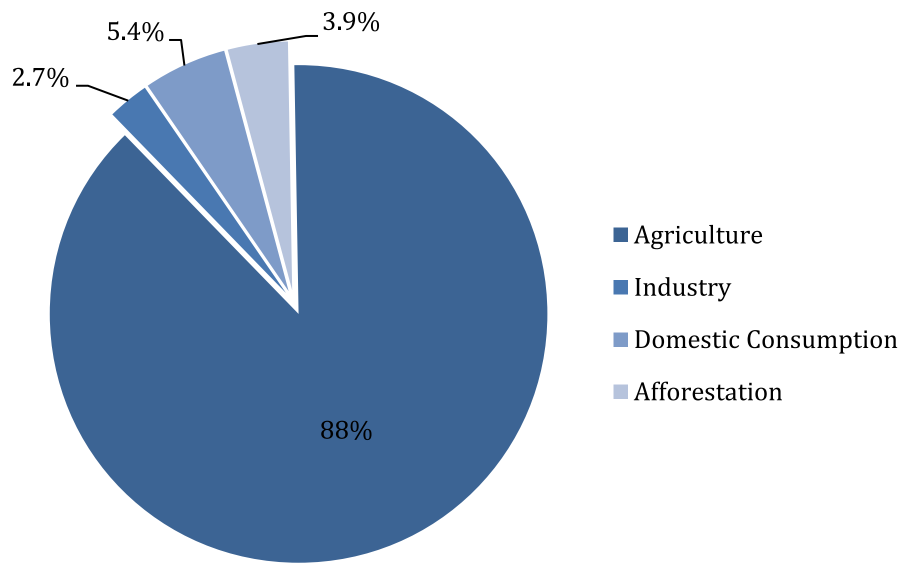

Figure 4.1 Water use for four different sectors in Kumul (Municipal EPA, 2009)

*4.3.3 **Water Sources and Water Supply***

The main drinking water sources of Kumul were from groundwater and reservoirs. Due to extremely low precipitation, runoff coming from reservoirs was the only available source for aquifer recharge in Kumul. Rainwater flowed to sewers directly and was lost as urban runoff. Kumul's natural reservoir, artificial reservoir, sky reservoir (snow, rain or storm), and aquifer were described by a local water expert as being in a "disharmonious situation". Kumul Yearbooks edited by Kumul Local Chronicles Editorial Board (LCEB) (2009-2011) summarized the drinking water resources for urban consumption, referring to data provided by Kumul Municipal WCB. The results presented in Table 4.3 are the means of recorded data from three years, except for the data on groundwater withdrawal.

Table 4.3 Data on Kumul's water resources as drinking sources for urban consumption (Kumul LCEB, 2009-2011)

Water Sources		Amount (10^6 m^3)
Surface Water	Total surface water	454
	Main rivers as runoff	407
Groundwater	Total Groundwater recharge	721
	Exploitable groundwater	404
	Total groundwater withdrawal	415
	Pumping well withdrawal	363

In Table 4.3, total groundwater withdrawal was recorded as 415×10^6 m^3 for urban consumption, and the data was retrieved from Kumul Yearbooks 2010 and 2011. In 2009, the groundwater withdrawal was recorded as only 37×10^6 m^3, which was much lower than that of the following years. From the reported values, groundwater withdrawal appears to have increased dramatically by more than 10 times within a year.

In Kumul, there were two main reservoirs supplying drinking water, Yu Shu Gou and Shi Cheng Zi. There were three functioning water purification plants, named No.1, No.2, and No.3 Water Purification Plant (WPP). Table 4.4 summarizes the information on the three functioning water purification plants with their main water sources. No.1 and No.2 WPP treated groundwater, while No.3 WPP (Photo 5) treated Yu Shu Gou reservoir water. No.4 WPP was proposed and recently built, but is not yet functioning and was established to treat Shi Cheng Zi reservoir water. There was also a water tank station within the urban area that supplied groundwater to nearby households. Figure 4.2 was designed to illustrate the water provision by three WPPs in Kumul, including institutional structure and its functions, which were introduced in the previous section.

Photo 5 No.3 Water Purification Plant (on the left)

Table 4.4 Summary of the water sources treated by three water purification plants

WPP	Year plant was built	Treated source water
No.1	1980	Groundwater as main water source
No.2	1991	Groundwater as main water source
No.3	2008	Surface water as main water source Purifies open reservoir (Yu Shu Gou) water
No.4	Proposed and built in 2011	Surface water as main water source Will purify open reservoir (Shi Cheng Zi) water

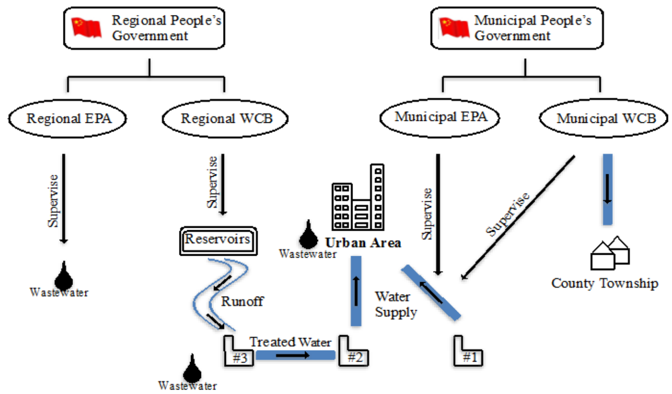

Figure 4.2 Illustration of institutional structure and water provision in Kumul

Both reservoirs were open reservoir water systems and were recharged by snow-ice melt from the mountaintop. Since they were both located in the mountain area where the temperature was lower in general, the evaporation was not high. Treated water from No.3 WPP joined to the water from No.2 WPP, and together they supplied drinking water for most of the southwest urban area. No.3 WPP also supplied water for industrial water use. No.1 WPP was located within the northeast urban area, supplying water to its surrounding households, and functioned as supplementary to the greater water supply system. The average drinking water supply capacity of No.1 WPP was approximately 26,000 m^3 per day, accounting for around 20% of overall water supply for domestic consumption. No.2 and No.3 WPPs supplied about 52,000 m^3 and 30,000 m^3 per day, respectively, together accounting for up to 80% of water for domestic consumption. Therefore, the daily drinking water supply capacity of all three WPPs was expected to reach up to 108,000 m^3 in total (Table 4.5). These data were provided by experts during interviews, and were based upon their experience and training. However, the information differed from the data collected in Kumul Yearbooks from 2009 to 2011 by Kumul LCEB (2009-2011) on water supply capacities of the three WPPs, and Table 4.5 shows the comparison among these data.

Table 4.5Comparison of data on total water supply (m^3/year) for urban consumption in Kumul from 2009 to 2011, provided by local experts and retrieved from Kumul LCEB (2009-2011)

	Year	Expected Water Supply (m^3 per day)	Actual Water Supply (m^3 per day)	Total Water Supply (10^6 m^3 per year)
Kumul Yearbooks	2009	130,000	80,000	12.25
	2010	130,000	87,000	10.27
	2011	130,000	87,000	14.65
	Mean	130,000	83,500	
Experts	2009	Not available	Not available	12.50
	2010	Not available	Not available	13.94
	2011	108,000	72,000	15.95

In Table 4.5, the data provided by experts showed a 2×10^6 m^3 increase in water supply per year. The maximum water supply of three WPPs could reach up to 72,000 m^3 per day, according to the experts; however, the expected daily water supply was 130,000 m^3 based on the data from the Yearbooks. Therefore, in order to achieve the desired water supply, the No.4 WPP was designed and planned to increase the daily supply capacity up to 180,000 m^3 (according to the 12th Five Year Plan Outline for National Economic and Social Development, 2011-2015). Due to the geographical conditions of this region, which allowed gravity flow, the water distribution process did not need a strong pumping system.

4.3.4 ***Source Water Protection***

The quality of groundwater was graded as favorable overall in Kumul (Municipal EPA, 2009). Adopting The Environmental Protection Industry Standard of the People's Republic of China: Technical Guideline for Delineating Source Water Protection Areas [HJ/T338-2007], in 2009 Kumul Municipal EPA scored the source water protection areas according to the quality results of groundwater and surface water supervised by both Regional and Municipal EPAs. As a result, a surface water source protection area was designed for the Yu Shu Gou reservoir system (Kumul Municipal EPA supervised). The groundwater source protection areas were as followings:

- No.2 Water Purification Plant Area (Kumul Municipal EPA supervised)
- Ya Man Su Town Area (Kumul Regional EPA supervised)
- Qi Jiao Jing Town Development Zone (Kumul Regional EPA supervised)
- Er Pu Town Water Purification Plant Area (Kumul Regional EPA supervised)

As the main focus of this research was urban area drinking water quality, the discussion focused on No.2 WPP Area and Yu Shu Gou Reservoir System. The coverage of these two protection zones are reported in Table 4.6. As mentioned above, No.1 WPP was located in the urban area and supplied groundwater to households. The groundwater within the area of No.1 WPP was not classified as a protection target for source water.

Table 4.6 Coverage of source water protection areas (Municipal EPA, 2009)

Source water protection area	Coverage
No.2 Water Purification Plant (groundwater)	Primary protection area: 0.053568 km^2 Secondary protection area: 0.009991 km^2
Yu Shu Gou reservoir system (surface water)	Primary protection area: 0.006323 km^2

There were seven wells that supply groundwater for No.1 WPP, three of which were discarded and four which were functioning. Within No.2 WPP Area, there were six wells supplying groundwater. In 2008, total urban groundwater recharge in Kumul was 247 million m^3 per year, of which 157 million m^3 was exploitable, and there was an 18 million m^3 groundwater deficit per year, which caused groundwater levels to drop by 0.37 m annually (Regional EPA, 2008). Many locals and experts recalled that about twenty to thirty years ago, freshwater could be found by drilling down to 10 m below ground, but in recent years, it had to be drilled as deep as 100 m down to reach freshwater. According to a local technician, groundwater within the area of No.2 WPP could be found around 50 m under the surface (personal conversation with local experts, August 2011).

The assessment of contaminants within the source water protection areas by the Kumul Municipal EPA (2009) reported that there was a crematory to the north, three sandstone ranches to the south, and a farmland to the southwest of No.2 WPP. Also, within No.2 WPP protection area there was a small-scale chicken farm, 3500 tons of construction waste, and 200 tons of domestic waste. Within the protection area of Yu Shu Gou reservoir system (water treated in No.3 WPP), there were three villages distributed along the upstream of the reservoir. Therefore, water quality of No.3 WPP could be contaminated with human or animal feces by surface runoff.

4.4 Drinking Water Purification and Distribution System

In Kumul, main concerns for source water purification were the sand and silts in groundwater and the turbidity of surface water. In general, water purification in Kumul applied physical and/or chemical methods. Purification processes varied amongst the three water plants, but Kumul's groundwater was treated using physical processes for the most part. No.1 and No.2 WPPs both used sedimentation to remove sediment particles such as sands, silts, clay, etc.

Photo 6 Mechanical stirring process in No.3 WPP

Unlike groundwater, open reservoir water was not naturally protected; therefore, No.3 WPP had a more complex purification process compared to other two plants. Process flow of No.3 WPP was: source water ⇒ coagulation ⇒ sedimentation ⇒ filtration ⇒ disinfection. Coagulation was the first step used in the process to remove dirt from source water via the addition of chemical aids. Polyaluminium chloride was added to reduce water turbidity, using chemical feeding equipment. Disinfection was the final step, completed by applying liquefied chlorine gas to treated water that was ready for distribution. The amounts of chemical aids used in the process were mostly determined by the quality of source water. Therefore, it is very important to sample and test water throughout the process at different stages. The purification process, water sampling, and quality testing were observed, participated in, and studied during many visits to No.3 WPP over the course of the current study.

4.4.1 ***Water Sampling and Quality Testing***

Photo 7 Lab technician taking source water sample with a plastic bottle

In No.3 WPP, samples of water were taken during the purification process at four different sites within the plant: the source, the clarifier tanks, the central control room where water was processed through filtration, and the clean water tanks where treated water was stored. Water sampled from these sites was tested daily. Other than the sampling sites within the purification plant, samples were also taken from pipeline systems where water was ready to be distributed, and from taps in private residences. There were about 14 other sites where was water sampled in pipelines or taps throughout

Kumul's urban area, among which water samples from two to three sites were selected for daily and/or weekly tests. However, according to the data provided by KWAG Ltd. and published in Kumul Yearbooks, the number of water sample sites for quality monitoring were 18 within the urban area in 2009, and up to 26 sites in the subsequent years (Kumul LCEB, 2009-2011). Water samples were taken and tested within a required time limit of 1-2 hours. Glass bottles were used for taking samples of treated water and were regularly disinfected in a drying cabinet at 160°C for 2 hours.

Photo 8 Lab technician operating total bacterial colony count test

There were 28 quality indices tested yearly, of which 8 indices were determined daily: color, turbidity, smell/odor, visible substances, pH, total bacterial colony count, total coliform group, and residual chlorine (free chlorine). Color, smell/odor, and visible substances can be observed with the naked eye. For example, when filling out the form for daily tests, the characteristics of a typical water sample were described as: colorless, odorless, liquid, and no abnormal conditions. The researcher personally participated in the determination processes of other five other indexes described in Appendix F, including total bacterial colony count, turbidity, pH, total coliform, and residual chlorine.

4.4.2 ***Source Water Quality***

Quality monitoring of surface water included 28 indices tested every year. Quality data for Yu Shu Gou Reservoir Water System from tests conducted by KWAG Ltd in September 2007 are shown in Table 4.7. The table also represents the monitoring report completed by the laboratory of KWAG Ltd. The evaluation of source water quality followed the National Standards for Drinking Water Quality [GB 5749-2006]. In this investigation, 22 out of 28 criteria were tested and the other 6 water quality criteria (iron, copper, fluoride, selenium, free chlorine residual, and fecal coliform) were not included. The results showed that the color, visible matter, turbidity, total coliform bacteria, and total *E. coli* were not in compliance with the standards. However, the quality of treated water from purification plants was reported to achieve 100% compliance with standard values (Kumul LCEB, 2009-2011). The main concern about surface water was its turbidity, though it could be reduced to within the standard value during treatment. Members of the local public expressed concern about the hardness of their tap water, stating evidence such as the furring of kettles or boilers. However, according to a lab technician from Municipal EPS, there has not been much change in water hardness over the years and the measured values for hardness have stayed around 100 mg/L, which is within the standard value of 400 mg/L.

Table 4.7 Single-item surface water quality of Yu Shu Gou Reservoir Water System

Monitoring Department		Kumul Mengxiang Water Quality Monitoring Center (No.3 WPP Laboratory)		
Sampling site		Source water inlet line at No.3 WPP (Photo 7)	Sampling date	Sep 7,2007
Sample description		No odor, minor turbidity	Testing date	Sep 7,2007
No.	Item	Standard value	Monitoring value	Single-item Judgment
1	Color (Pt-Co color unit)	15	20	Does not comply
2	Odor and taste	No strange odor & peculiar taste	No strange odor & peculiar taste	Complies
3	Visible matter	None	A small amount of impurities	Does not comply
4	Turbidity (NTU-Nephelometric Turbidity Units)	1 or 3	34.3 NTU	Does not comply
5	pH	6.5~8.5	7.64	Complies
6	Total hardness (mg/L)	450	79.2	Complies
7	Chloride (mg/L)	250	10.8	Complies
8	Sulfate (mg/L)	250	11.4	Complies
9	Manganese (mg/L)	0.1	0.07	Complies
10	Zinc (mg/L)	1.0	<0.20	Complies
11	Volatile phenol (mg/L)	0.002	<0.002	Complies
12	Anion synthetic detergent (mg/L)	0.3	<0.025	Complies
13	Total dissolved solid (mg/L)	1000	113	Complies
14	Cyanide (mg/L)	0.05	<0.002	Complies
15	Arsenic (mg/L)	0.01	<0.01	Complies
16	Mercury (mg/L)	0.001	<0.001	Complies
17	Cadmium (mg/L)	0.005	<0.005	Complies
18	Chromium (six, mg/L)	0.05	<0.004	Complies
19	Lead (mg/L)	0.01	<0.01	Complies
20	Nitrate (mg/L)	10 or 20 (groundwater limited)	0.40	Complies
21	Total coliform bacteria (MPN/100mL or CFU/100mL)	Shall not be detected	109 CFU/mL	Does not comply
22	Escherichia coli (MPN/100mL or CFU/100mL)	Shall not be detected	7 CFU/mL	Does not comply

Table 4.8 Single-item measurements of groundwater quality of No.2 Water Purification Plant in Kumul (Municipal EPA, 2009)

No.	Groundwater Quality Monitoring Index	Standard Value	2008 (year)	
			Monitoring Value	Single-item Judgment
1	pH	6.5~8.5	7.1	Complies
2	Fluoride	1.0 mg/L	0.19 mg/L	Complies
3	Sulfate	250 mg/L	17.3 mg/L	Complies
4	Chloride	250 mg/L	19.3 mg/L	Complies
5	Total coliform group	Must not be detected	Not detected	Complies
6	Total bacterial count	100 CFU/mL	3 CFU/mL	Complies
7	Total hardness	450 mg/L	125.2 mg/L	Complies
8	Free residual chlorine	≤ 0.3 μg	Not detected	Complies
9	Nitrate nitrogen	20 mg/L	0.63 mg/L	Complies
10	Chroma	15	10	Complies
11	Smell and taste	No peculiar	No peculiar	Complies
12	Visible material	None	None	Complies
13	Turbidity	1 NTU	0.86 NTU	Complies

In 2008, an investigation into groundwater quality of No.2 WPP was conducted by Kumul Municipal EPA. Table 4.8 presents the single-item measurements and values compared to The Groundwater Quality Standard [GB/14848-93] Grade III. The results demonstrate that the quality of groundwater was compliant with quality standards (Municipal EPA, 2009). The measurements of the surface water quality of Yu Shu Gou Reservoir System were not reported in this research.

Local household interview results showed that the majority (74%) of consumers did not drink water directly from the tap, and 65% were concerned about the quality of their tap water. Overall, tap water quality was rated as good by 45% of the households, but none regarded it as excellent, while the water supplier reported that tap water quality complied 100% with standard values and rated it as favorable.

4.4.3 ***Water Distribution System***

In Kumul, tap water was introduced in the early 1980s when many personal wells were starting to become exhausted (personal communication with local experts, August 2011). Water quality distribution in Kumul appears to be non-uniform. For example, water quality in some sensitive areas such as schools, governmental offices, etc., was enhanced by management practices (personal communication with local experts, August 2011).

Water samples were collected according to the distribution of supplying pipes. Cast-iron pipes had not been completely abandoned yet and had been gradually replaced with PVC, PP-R, or ductile iron pipes, according to consumers' requests. These new pipes are low-cost and corrosion resistant. However, local experts stated that leakages of main water pipelines and the secondary contamination of drinking water due to the degradation in pipe quality were important concerns.

Table 4.9 displays the water distribution in Kumul's urban area. The data was received form Kumul Yearbooks (Kumul LCEB, 2009-2011). The number of consumers increased from 160,000 to 250,000 over the three-year period. There was also a dramatic increase in secondary pipeline leakage accidents.

Table 4.9 Water distribution and pipeline leakage in Kumul's urban area (Kumul LCEB, 2009-2011)

Year	Number of consumers	Total length of pipelines	Supply area	Number of main water pipeline leakages	Number of secondary water pipeline leakages
2009	160,00	102.5 km	44 km^2	80	122
2010	180,000	102.5 km	44 km^2	12	345
2011	250,000	173 km	44 km^2	Not available	Not available

Figure 4.3 below illustrates the distribution of the pipeline system (red lines) and the distribution of the interviewees (blue pins) that participated in this research. The figure also shows the location of the three main purification plants that supply drinking water to the area. Pipe systems cover most part of the urban area and all the interview participants had access to tap water in their houses/apartments.

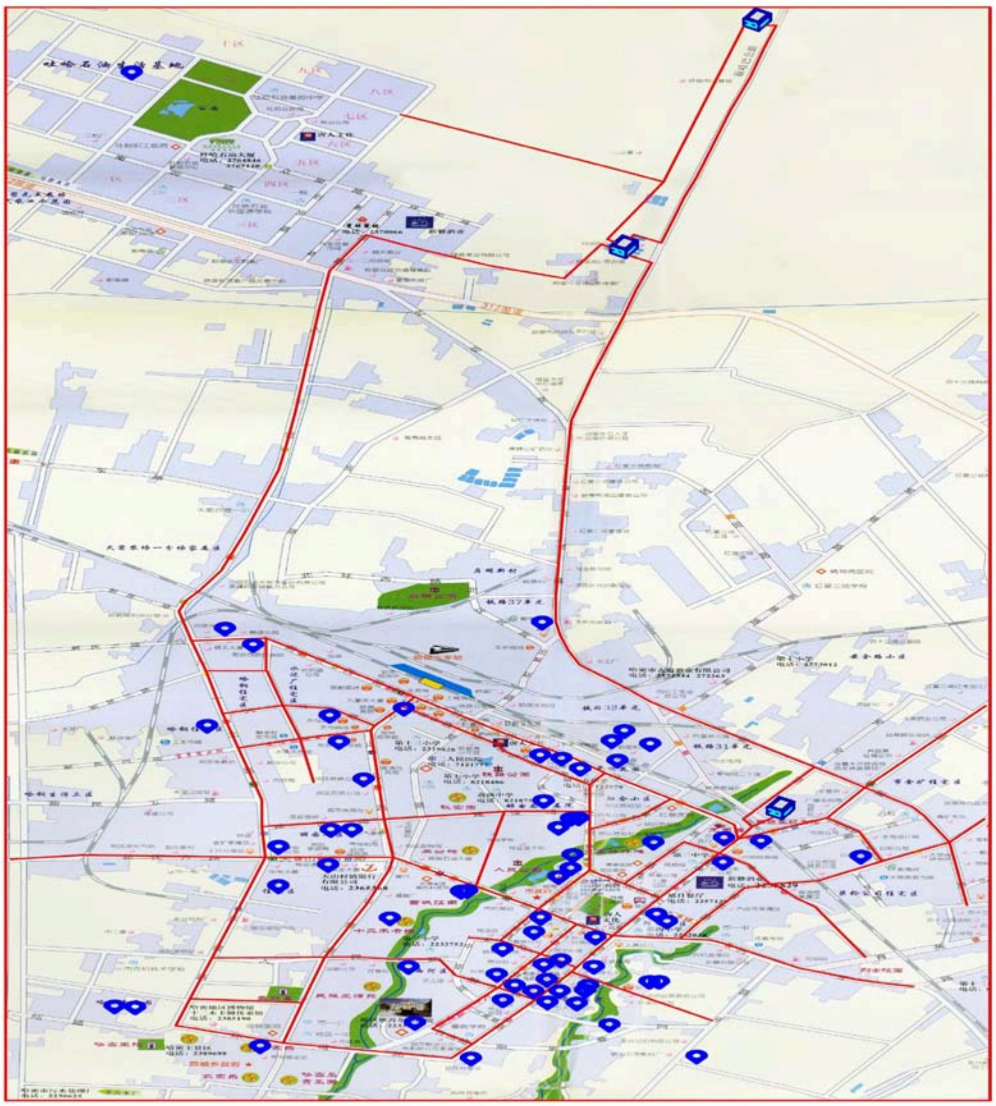

Figure 4.3 Distribution of Kumul's pipelines (red lines) and interview participants at household level (blue pins). Pipeline system was accessed during visits to KWGA Ltd.

4.5 Kumul's Water Services

The urban area of the City of Kumul is divided into five districts, and the residents in every district are associated with a sub-district office, which is known as 'street office' when translated directly from Mandarin Chinese. There are multiple residential committees established in each district. Some of the residential committees were formed with dwellers within a few blocks, and some were formed based on the community units or neighborhoods within managerial areas of local institutes. In addition, small-scale property management companies were also instituted to provide services on a community basis, and their duties included the maintenance of property, equipment, and other physical assets, maintaining the cleanliness of neighborhoods (e.g. by collection of domestic waste), and also the collection of water and electricity fees. Water fees are collected seasonally by water-meter readers employed by KWAG Ltd. or property management companies. The price of domestic water use at the time of the study was 2.19 Chinese Yuan (¥) per 1000 L (equal to approximately $0.37 CAD as of July 8, 2013) in Kumul, consisting of tap water fee ¥1.36/1000 L ($0.23 CAD) and wastewater discharge fee ¥0.83/1000 L ($0.14 CAD).

In urban areas, the population of households consuming tap water served by No.1, 2, and 3 WPPs was 360,000 (Kumul LCEB, 2009-2011). The majority of the households were still using old-fashioned mechanical water meters to measure the amount of water use. Only 20,000 households, accounting for 0.05% of total households in the urban area, had adopted IC card prepaid water meters (personal communication with local experts, August 2011). Most the apartment buildings constructed in recent years (mainly after 2009) were encouraged to install prepaid water meters (Kumul LCEB, 2009-2011). In general, the replacement rate of traditional water meters with prepaid water meters was low.

In all three water purification plants, water practitioners were on duty 24 hours a day. Practitioners had one of three levels of certification, according to their working duration and experience. These certification levels were: advanced, medium, and elementary water practitioners. For example, in No.3 WPP, 80% of the water practitioners held advanced certificates, 15% held medium, and 5% held elementary water operation certificates.

Water practitioners attended regular lectures, training, and exams to obtain certification. However, the system lacked a comprehensive mandatory certification program for water operation. During the on-site learning, it was discovered that most of the practitioners in purification plants did not have formal educations related to their fields of employment, which perhaps meant that they were unqualified or lacking competencies required for their positions, even though they maintained relatively high professional ethics throughout their duties.

4.6 Reporting and Communication

Reports on water testing results were required annually in the City of Kumul; however, the reports remained within local authorities and water institutes. Transparency in regards to drinking water conditions in the local area was poor. Information on water quality was not available to the public via any channels, including the Internet or newspapers. The interview results showed that the only participants who had heard of or seen the annual reports on water quality were involved in jobs that were within the related institutes.

Authorities also failed to provide an effective list of drinking water advisories or warnings that could inform consumers whether or not they should boil their tap water. Moreover, the terminology was vague and varied among local institutes and units. As stated by a local water manager, the standards of drinking water and *direct* drinking water were different, where *direct* drinking water requires a better piping system in terms of pipe materials.

5 DISCUSSION

5.1 Complexity of Administrative Structure

The functions of local institutes overlapped in the area of water supply and water quality monitoring. As shown in Table 4.1, Regional WCB, Regional CB, Municipal EPA, and Municipal WCB shared responsibility over urban drinking water. The relations among them also seemed to be complex and indistinct, even though the institutional actions were described in different words such as “supervise”, “manage”, and/or “guide”. Other than Regional and Municipal EPAs, Municipal EPS also had the obligation to test Kumul’s drinking water quality for urban consumption. Regional WCB was in charge of surface water (rivers and reservoirs) exploitation, while Regional CB was in charge of groundwater exploitation. The complexity of the current administrative structure could result in weak communication among institutes related to water resources. In Kumul, three WPPs were owned by KWAG Ltd., and the government did not hold full responsibility over water resources. As a private company, the core motivation of KWAG Ltd. was shown to be maintaining a profitable business instead of putting tap water consumers’ need as their primary responsibility. This explains the lack of community-based research conducted by the company or any other local institutes.

5.2 Local Concerns about Drinking Water Quality

Almost all households (97%) in the City of Kumul used tap water as their main source of water. However, 74% of the local households in the urban area did not directly consume water from their taps, and 65% of those households expressed concerns regarding water quality. The results showed that their top concerns about tap water were chlorine levels, bacteria, and contaminants. Many interviewees (43%) believed that the taste of chlorine indicated less safe water. Of 65 interviewed residents, 45% rated the quality of tap water as fair and no one indicated that their tap water quality was excellent. More than half of the participants (55%) thought that the quality of water stayed the same, while 20% felt that it was getting somewhat worse over the decades since the plants were built.

All the interviewees who participated in this research treated their tap water before consumption, and 94% boiled their water in order to make it safer to drink. The main reason for locals to treat their tap water was to ensure safety.

5.3 Weakness in Drinking Water Provision

By following the framework described in Chapter 4, the previous two sections in this chapter discussed the administrative functions and local residents' attitudes towards tap water quality in the City of Kumul. In order to guarantee water quality and provide tap water that poses no threats to human health, every step of the water provision system must be examined and evaluated.

5.3.1 ***Deficiency in Source Water Protection***

Since No.1 WPP, as a supplement, was still functioning, the groundwater within the area of No.1 WPP should also be classified as protected water source. For No.1 and No.2 WPP, classifying the groundwater source within the areas as source water protection zones could be the only effective protection available. The existence of various contaminants within the source water areas could become an extra burden on the water treatment. There was also a potential risk to drinking water sources due to the industrialization trend in Kumul (Regional EPA, 2008).

5.3.2 ***Flaws in Drinking Water Testing***

Water sampling was only required for surface source water and treated water at the distribution system. Due to the contaminants in the groundwater protection areas, groundwater sources needed to be sampled and held to a different set of requirements. The number of water sampling sites and water testing frequency was not enough considering the dramatic increase in urban population. In a global context, particularly comparing with the U.S. and Canadian standards, China's guidelines for drinking water quality generally appeared to be appropriately stringent for most of the parameters, except for hardness. In Table 4.8, the total hardness of groundwater was 125.2 mg/L, which was within China's standard of 450 mg/L; however, it exceeded Canada's acceptable standard range of 80 mg/L-100 mg/L. Local jurisdictions have not fully adopted the full suite of parameters in the national guidelines for water treatment. According to the research conducted by Yu et al. (2007) and Sampat (2000) on natural occurrence of arsenic and fluoride in drinking water (Section 2.3.2), Xinjiang was ranked as one of the top five arsenic-containing regions in China, and millions of people in northern China were exposed to natural fluoride via drinking water. Yet the single-item quality testing of Yu Shu Gou Reservoir conducted in 2007 did not include fluoride (Table 4.7), and the quality testing of groundwater conducted in 2009 did not list arsenic as a required testing parameter (Table 4.8). Moreover, only as of 2011 was *E. coli* added to the list of water quality testing requirements. *E. coli* and total coliform are a group of bacteria naturally carried in the intestines of humans and warm-blood animals (Health Canada, 2006). Drinking water guidelines for *E. coli* developed by Health Canada suggest a maximum acceptable concentration of none detectable in 100 mL of water (Health Canada, 2006). China's drinking water guidelines for these indices were the same standard values.

Photo 9 Wastewater from purification process directly discharged into an empty land

There were also deficiencies in the purification process. No.3 WPP was considered an unqualified construction (personal communication with local experts, August 2011), and the process flow of No.3 WPP did not have on-line monitoring instruments for turbidity testing. Also, there was no equipment for residual chlorine testing. The plant did not include water reuse and sludge collection processes, thus the water that has been used in the purification process could not be treated and reused, and was directly discharged into empty land (Photo 9). When treating surface water in No.3 WPP, the amounts of drugs used in the coagulation process were visually measured according to the chemical reaction between raw water and chemical aids in the stirring tanks by experienced technicians. As stated by the technicians worked with the stirring tanks, much greater volumes of chemicals were used during summer months than winter because during the coldest winter months the formation of ice on top of the open reservoirs protected the source water from contamination.

5.3.3 ***Professional Standards for Water Practitioners***

Though most of the operators/staff working in the plants did not have relevant diplomas, they received training throughout their employment. The local jurisdiction should require a comprehensive mandatory certification program to train and examine the water operators. In particular, the labs for testing water samples need accredited and competent lab technicians. Some unprofessional water quality testing behaviors were observed during visits to the purification plants. For example, source water samples at the inlet line of No.3 WPP were taken with unsanitized plastic bottles that were used repeatedly. The repetitive use of containers without sterilization occurred throughout the treatment process. The contamination could cause unnecessary experimental errors and alter the testing results. A laboratory technician stated that the total count of bacteria sometimes exceeded the standard value due to these types of experimental errors.

5.4 Issues with Water Service

Clustered townships were starting to form with the expansion of both the urban area and small nearby towns/counties. Most of the apartment blocks in the urban area were fully served by property management companies, but these services had not covered all the cluster township areas. The definition of property management was vague in terms of landlord/tenant relations because most of the residents owned their flats in Kumul, as opposed to the situation in other countries such as Canada where the flats in apartment buildings are mostly rented. Service charges of property management companies varied based on the location of a community or neighborhood. Because of the different payment rates, richer communities who paid higher service fees enjoyed better service than poorer ones, meaning that richer communities often received prompt water information while poorer communities were less likely to be informed.

Old-fashioned mechanical water meters are often less accurate than prepaid smart water meters, and yet the prepaid water meter has not been widely accepted by the public. In most cases, the traditional water meter would not run when water was dripping, and some consumers would take the chance and save up the dripping water. This violation of rules is difficult to detect and causes financial losses for the water supplier. In 2009, it was reported that there were 152 law-breaking water use activities, so this is not an uncommon practice (Kumul LCEB, 2009-2011).

5.5 Gaps in Communication

The insufficiency of reporting and informing consumers of the quality of drinking water was the main reason for the public's mistrust of the authorities. The only communication between members of the public and the water supplier is the company's customer telephone hotline system where consumers reach out to the supplier (Kumul LCEB, 2009-2011). The function of the hotline is mainly to resolve issues such as water fees, pipeline leakage, and other technical problems. Household interview results showed that the majority of consumers were concerned about water quality but were unable to get information. Most locals had never seen (and many had never heard of) annually published reports on Kumul's water quality. The circulation of the report was mainly among local governmental employees; therefore, many interviewees who have seen the report were employed in relevant institutions. The older generation would prefer that any water-related messages be passed on to them through their residential committees, property management companies, or TV ads, while the younger generation would also prefer the Internet as an additional channel to gain information.

The use of terminology could be misleading if, as mentioned in Section 4.6, there was a difference between drinking water and *direct* drinking water. Water suppliers are obligated to inform public whether the water can be consumed directly from the tap or not.

5.6 Reasons for Public Boiling Tap Water

Many consumers showed great concern for their tap water quality, and almost all would boil before drinking it. An interesting fact discovered during household level interviews that well demonstrated this behavior was that 43% of the consumers got used to boiling water and stated that it was a custom that had been passed from one generation to another. The other reason could be because majority of the locals drank tea daily and boiling water was necessary for making tea anyway.

The greater hardness in drinking water was commonly noted by locals and is due to Xinjiang's geography. Statements like "water stone (indicating water hardness), kidney stone" were circulating amongst local people, with many assuming that kidney stones were caused by the high level of water hardness and that boiling will reduce it. However, WHO (2006) said that there was no solid evidence that drinking hard water would threaten human health. Hard water has high concentrations of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions and is often indicated by the non-formation of soapsuds and the formation of scale in distribution system (WHO, 2006). In Kumul, it was a very common issue that obvious scale could be seen in kettles that were used to boil tap water. Temporary hardness can be reduced by boiling the water or by the addition of lime, but theses interventions will have no permanent effect on hardness.

6 Summary, Conclusions, and Recommendations

6.1 Summary

The research contained in this thesis sought to assess the quality of Kumul's drinking water for domestic consumption in an urban area and concluded that the drinking water quality in the City of Kumul did not present a direct threat to human consumption. This research further sought to address how local authorities regulated and managed drinking water resources and how the water management system was operated in order to guarantee a safe drinking water environment for local consumers. These data collection methods were applied to meet research objectives and themes with the goal of achieving an understanding of Kumul's drinking water conditions in order to advise regulatory practitioners on what actions needed to be taken to fill any identified gaps and achieve desired drinking water quality.

6.2 Conclusions

Results showed that there was no evidence of significant direct threats to public health. However, Kumul did not meet best practices in drinking water provision and there was certainly room for potential improvements. Tested water quality was claimed to meet the national guidelines, but the system showed deficiencies in water requirements throughout the whole provision process including source water protection, water sampling, testing and supplying. Water quality was also claimed not to have changed significantly in the past few decades, but there was disparity between the stability of water quality reported by authorities and the public's increasing concerns regarding the disinfection process. The total volume of water being treated has dramatically increased over the years along with the growth of the urban population. The individual interviews have resulted in three main findings as followings:

1) In urban areas, 74% of the local households did not consume water directly from tap;
2) The personnel that directly associated with water claimed that the drinking water quality had been stable over the decades; and
3) In urban areas, 65% of the local households who did not directly consume water from their taps had concerns regarding water quality.

One question emerging from the interviews with the public was, "Why do the locals in the City of Kumul boil their tap water before drinking it?" This research has given the possible reasons as followings:

a) A common behavior and part of the local custom;
b) Regional authorities' lack of direct public communication in addressing water quality and availability issues; and
c) Weakness in water resource supervision and management.

Boiling fresh water has long been a common behavior and part of the local custom in Xinjiang Province, China. The reasons for this custom can be attributed to the water authorities' lack of direct public communication in addressing water quality and water availability issues. It can be argued that this mistrust of authority in the region is a result of the weakness in water resource supervision and management.

The vulnerability in urban infrastructure, specifically the outdated water supply facilities, explains why this area is far behind most jurisdictions in monitoring and managing water resources (Regional EPA, 2008). The complexity in administrative structure has resulted in weakness rather than effective communication. In Kumul, the purification plants were owned by a company, which established its nature as making profits, while governmental institutions played their parts as supervisors and regulators.

Not only was boiling water a common behavior, but it also indicated that people have concerns about drinking water quality. The government claimed that drinking water quality met the national standards; however, the communication gap between locals and authorities needs to be filled. The related institutes and company had space for further development in water resource supervision and management. An analysis of the quality of drinking water for domestic consumption in the City of Kumul was based on addressing the city's current water resource management and examining the water quality issues from a local perspective.

6.3 Recommendations

Kumul's administrative agencies embodied traditional top-down institutional framework at all levels, whereby there is a lack of horizontal and vertical coordination. The communication among the related institutes in water management can be improved through a legally binding framework for regulating water protection and supervising water provision. As discussed in Section 5.1, Kumul's surface water exploitation was the responsibility of Regional WCB, while Regional CB managed groundwater exploitation.

However, the interaction between groundwater and surface water demonstrates that changes occurring in either system will affect the other (State of California, 2009). Therefore, groundwater and surface water exploitation should be managed comprehensively and the emphasis should be put on the protection of both systems. As a direct link between authorities and the public, residential committees should increase their communication capacity and fulfill their duty. A stricter licensing plan should be put forth and the licensing process should be strengthened. Other than maintaining their current certification level and the basic knowledge required to manage drinking water, water practitioners must take on legal and ethical responsibilities associated with operating drinking water treatment plants.

Drinking water provision is a process that includes a series of steps from source to tap. An effective way to protect both groundwater and surface water sources from contaminants is to reduce or restrict various industrial, agricultural, or other human activities that may increase risks. Since KWAG Ltd. has equal responsibility over source water, the company should update the source protection plan to require that 100 per cent of water sources be covered and protected with the help of local government, and more strict regulations need to be enforced for environmental violators, even releasing their names if necessary. Water testing frequency needs to be increased to align with the dramatic increase in urban population. Strengthened and stricter quality testing of arsenic, fluoride, and hardness in drinking water is recommended because these cannot be dealt with by boiling. In particular, the occurrence of *E. coli* in surface source water has determined the need for reinforcing *E. coli* testing given that *E. coli* could be fatal if found in drinking water. Old-fashioned quality monitoring instruments need to be upgraded for better testing results. Visual measurement should be replaced by an on-line monitoring system in order to accurately measure the amounts of chemical aids required in the coagulation process.

In summary, the system would be benefit from the following four general approaches:

a) Protecting the source water areas;
b) Improving drinking water sampling, testing, and supplying system;
c) Implementing training and certification programs for water practitioners; and
d) Increasing communication between authorities and the public.

In 1996, Tang and Bi (1996) predicted that China’s water quality would not be improved in the near future, considering the increasing domestic wastewater discharge and lack of sewage treatment and pollution control. After more than a decade, some of these limitations still exist. In Kumul’s water provision industry, there is a need for continued improvement in the approach to water resource management, and a need for a shift in water supplier’s attitudes from maximizing profitability to providing safe drinking water that deserves the trust of consumers.

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APPENDIX A INDIVIDUAL INTERVIEW SCHEDULE

A.1 Demographic Questions:

1) Name:
2) Gender of respondent:
3) Age of respondent:
4) Location/address:
5) Housing type:
    1. Multi-family (Residential)
    2. Apartment building
    3. Other
6) Type of family:
    1. Nuclear
    2. Joint/extended
7) Number of the members in the household:
8) Number of the members that are employed in the household:
9) Monthly household income:
    1. <1000 RMB
    2. 1000-2500 RMB
    3. 2500-5000 RMB
    4. 5000-10000 RMB
    5. >10000 RMB
10) Education level of respondent:

A.2 Water-related Questions:

1) Do you drink water directly from the tap?
    1. Yes
    2. No
    3. I only drink purified water
    4. I only drink filtered water
2) If ‘no’, why not? (Check all that apply)
    1. Taste/Odor
    2. Appearance
    3. Quality
    4. Other
3) What is the main source of water used by your household for cooking?
    1. Tap water
    2. Purified water
    3. Filtered water
4) Would you rate the quality of your tap water as:
    1. Excellent
    2. Very good
    3. Fair
    4. Satisfactory
    5. Poor
5) How do you rate the taste of tap water?
    1. Very good
    2. Good
    3. Fair
    4. Poor
    5. Won’t drink it
6) Do you feel that the quality of water is getting better?
    1. Getting much better
    2. Getting somewhat better
    3. Staying the same

4. Getting somewhat worse
5. Getting much worse

7) What, if any, concerns do you have about drinking water? (Check all that apply)
   1. Contaminants
   2. Purity/cleanliness
   3. Chlorine levels
   4. Bacteria/germs
   5. Taste
   6. Discoloration
   7. Turbidity
   8. Other(s)
   9. None
8) In your experience, the taste of chlorine indicates:
   1. Safe water
   2. Less safe water
   3. Unsafe water
9) Do you treat your tap water in any way to make it safer to drink?
   1. Yes
   2. No
10) If ‘yes’, what do you usually do to make it safer to drink? (Check all that apply)
   1. Boil
   2. Use a water filter
   3. Solar disinfection
   4. Let it stand and settle
   5. Other
11) Why do you treat tap water before drinking it? Any other reasons? (Check all that apply)
   1. To remove impurities
   2. To improve taste
   3. To remove chemicals
   4. To ensure safety

5. Filtered/treated water is healthier
6. Habit/got used to it
7. Make tea/coffee/(hot) beverages with it
8. Was told to do so by someone
9. Other

12) Do you use a water filter for your tap water?
1. Yes
2. No

13) If 'yes', what type/brand of filter do you use?

14) Do you buy bottled water?
1. Yes
2. No

15) If 'yes', why? (Check all that apply)
1. Taste/Odor
2. Appearance
3. Quality
4. Convenience

16) What, if any, concerns do you have about drinking bottled water? Any others? (Check all that apply)
1. Bad for environment
2. Contaminants from bottle
3. Cost
4. Purity/cleanliness
5. In plastic bottles
6. Not sure where it comes from (includes could be tap water)
7. Taste
8. Lack of regulation
9. Where to dispose of bottles/hassle to recycle
10. None
11. Other

17) Please tell me the extent to which you agree or disagree with the following statements about drinking water. Strongly agree/Somewhat agree/Disagree

1. It is expensive to drink bottled water.
2. Bottled water has a negative impact on the environment.
3. Tap water is cleaner and safer than bottled water because it must meet stricter safety regulations.
4. I like the taste of bottled water better than tap water.
5. Tap water is fine for adults, but it’s better to give children bottled water.

18) To the best of your knowledge, where do households in the city get their tap water? That is, what is the source of the tap water that you are consuming? (Check all that apply)

1. Reservoir
2. Mountain snow/ice melt
3. Groundwater
4. Rivers/creeks/streams
5. Dam
6. Other
7. Don’t know/not stated

19) How often do you ask for tap water at a restaurant, bar or hotel?

1. Every time
2. Sometimes
3. Never

20) What is your main water source available in your workplace for drinking?

1. Tap water
2. Boiled tap water
3. Bottled water
4. Filtered water
5. Other

21) What would you prefer the following sources of water to be available at your workplace?

1. Tap water

2. Boiled tap water
3. Bottled water
4. Filtered water
5. Other

22) How would you rate the overall quality of the City of Kumul's tap water? Would you say...?

1. Excellent
2. Good
3. Fair
4. Poor
5. Very poor

23) How satisfied are you with each of the following aspects of the City of Kumul's tap water? Very satisfied/Somewhat satisfied/Unsatisfied

1. Clarity
2. Safety
3. Smell
4. Taste

24) Do you have any other comments to make?

A.3 Water Service-related Questions:

25) What do you think about the water bills that you receive?

1. They are very expensive.
2. They are somewhat expensive.
3. They are not expensive.
4. They are usually accurate.
5. They are not accurate sometimes.
6. They are always not accurate.

26) If there are any messages on water quality, where do you generally see or hear them? (Check all that apply)

1. Media such as newspaper, magazines etc.
2. Outdoor ads, billboards
3. Brochures
4. Television ads
5. Radio ads
6. Internet
7. Annual Water Quality Report published by water-related institutes
8. Residential committees or property management companies
9. Other
10. Never heard or seen any

27) What is the best way for related water institutes to communicate with you about the city's drinking water information? (Check all that apply)

1. Media such as newspaper, magazines etc.
2. Outdoor ads, billboards
3. Brochures
4. Television ads
5. Radio ads
6. Internet
7. Annual Water Quality Report published by water-related institutes
8. Residential committees or property management companies
9. Other

28) Compared to one year ago, would you say that you …

1. are more aware of water quality issues.
2. have about the same level of awareness.
3. are less aware.

29) How are you familiar with the City’s Annual Water Quality Report?

1. I am quite familiar with it.
2. I have heard of it but never seen one.
3. I have never heard or seen any.

30) In what ways do you practice water conservation at home?

31) How much of your home’s total water budget does your shower head use about?

32) Are you familiar with the new technologies available for the selection of water saving devices that reduce your energy bills and save water, e.g. water saving shower heads, toilets or faucets?

1. I am familiar.
2. I am not familiar.

33) What is the volume of your toilet tank?

34) What, if any, kinds of water limiting tools do you use at home in order to save water?

APPENDIX B EXPERT INTERVIEW SCHEDULE

B.1 Water Purification Plants:

1) What do the water purification plants have to take out from the raw water to make it potable for domestic consumption?
2) What are the water treatment processes in the plants?
3) Where is the treated water quality usually tested (water quality testing)?

B.2 Distribution System:

4) What do you believe in the quality of the water distribution system in the City of Kumul?
5) What are the service pipes made of? Cast-iron, Concrete/cement, Clay, Plastic or Metal
6) Drinking water quality can decline if water sits too long in water service line or pluming system. Are there any concerns about drinking water quality due to the material of water pipes?
7) What do you think about the consumers' confidence in water meter accuracy?

B.3 Water Quality Management:

8) What regulations have local jurisdiction put in place over the decades in order to improve the quality of drinking water in the City of Kumul?
9) What differences have these regulations make?
10) Any other Comment?

B.4 Water Quantity:

11) What actions has the City of Kumul taken to improve the efficiency and effectiveness of water allocation?
12) What have been the results of these actions over time?
13) Any other comment?

APPENDIX C RESEARCH ETHICS BOARD APPROVAL

CERTIFICATE

UNIVERSITY OF MANITOBA | Research Ethics and Compliance
Office of the Vice-President (Research and International)

Human Ethics
208-194 Dafoe Road
Winnipeg, MB
Canada R3T 2N2
Phone +204-474-8880
Fax +204-269-7173

AMENDMENT APPROVAL

December 4, 2012

TO: **Dilibai Yunusi**
Principal Investigator

FROM: **Wayne Taylor, Chair**
Joint-Faculty Research Ethics Board (JFREB)

Re: **Protocol #J2011:149**
"Analysis of the Quality of Drinking Water for Domestic Consumption in the City of Kumul, Xinjiang Province, China"

This will acknowledge your request received November 27, 2012 requesting amendment to your above-noted protocol, involving a change of title from "Analysis of the Drinking Water for Domestic Consumption in the Kumul City, Xinjiang Province, China" to the above-noted title.

Approval is given for this amendment. Any further changes to the protocol must be reported to the Human Ethics Secretariat in advance of implementation.

UNIVERSITY OF MANITOBA | Research Ethics and Compliance
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Fax +204-269-7173

RENEWAL APPROVAL

December 4, 2012

TO: **Dilibai Yunusi**
Principal Investigator

FROM: **Wayne Taylor, Chair**
Joint-Faculty Research Ethics Board (JFREB)

Re: **Protocol #J2011:149**
"Analysis of the Quality of Drinking Water for Domestic Consumption in the City of Kumul, Xinjiang Province, China"

Please be advised that your above-referenced protocol has received approval for renewal by the **Joint-Faculty Research Ethics Board**. This approval is 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.

UNIVERSITY OF MANITOBA | Research Ethics and Compliance
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APPROVAL CERTIFICATE

December 21, 2011

TO: **Dilibai Yunusi** (Advisor T. Henley)
Principal Investigator [redacted]

FROM: **Wayne Taylor, Chair**
Joint-Faculty Research Ethics Board (JFREB)

Re: **Protocol #J2011:149**
"Analysis of the Quality of Drinking Water for Domestic Consumption in the City of Kumul, Xinjiang Province, China"

Please be advised that your above-referenced protocol has received human ethics approval by the **Joint-Faculty Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement (2). **This approval is valid for one year only**.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, the auditor requires that you submit a copy of this Approval Certificate to the Office of Research Services, fax 261-0325 - please include the name of the funding agency and your UM Project number. This must be faxed before your account can be accessed.**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

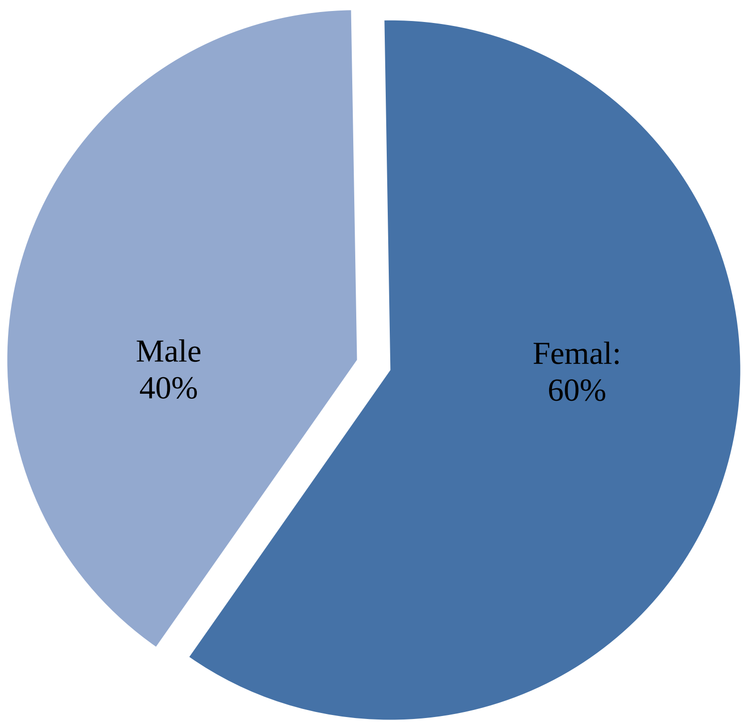
The Research Quality Management Office may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans*.

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/orec/ethics/human_ethics_REB_forms_guidelines.html) **in order to be in compliance with Tri-Council Guidelines.**

APPENDIX D INTERVIEW RESULTS SUMMARIZED

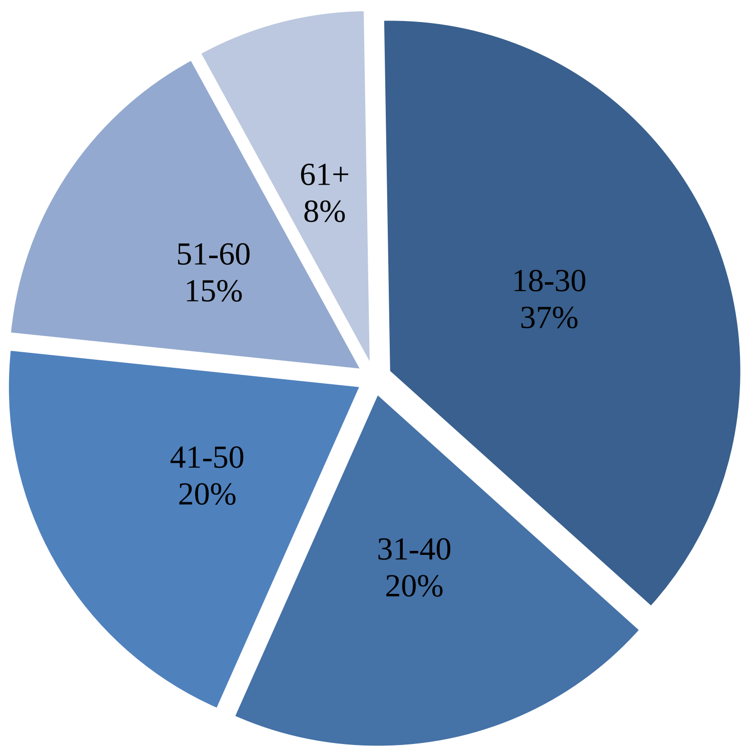
A.1 Demographic Questions:

Q2: Gender of respondents (n=65)	65	Percentage (%)
1. Female	39	60
2. Male	26	40

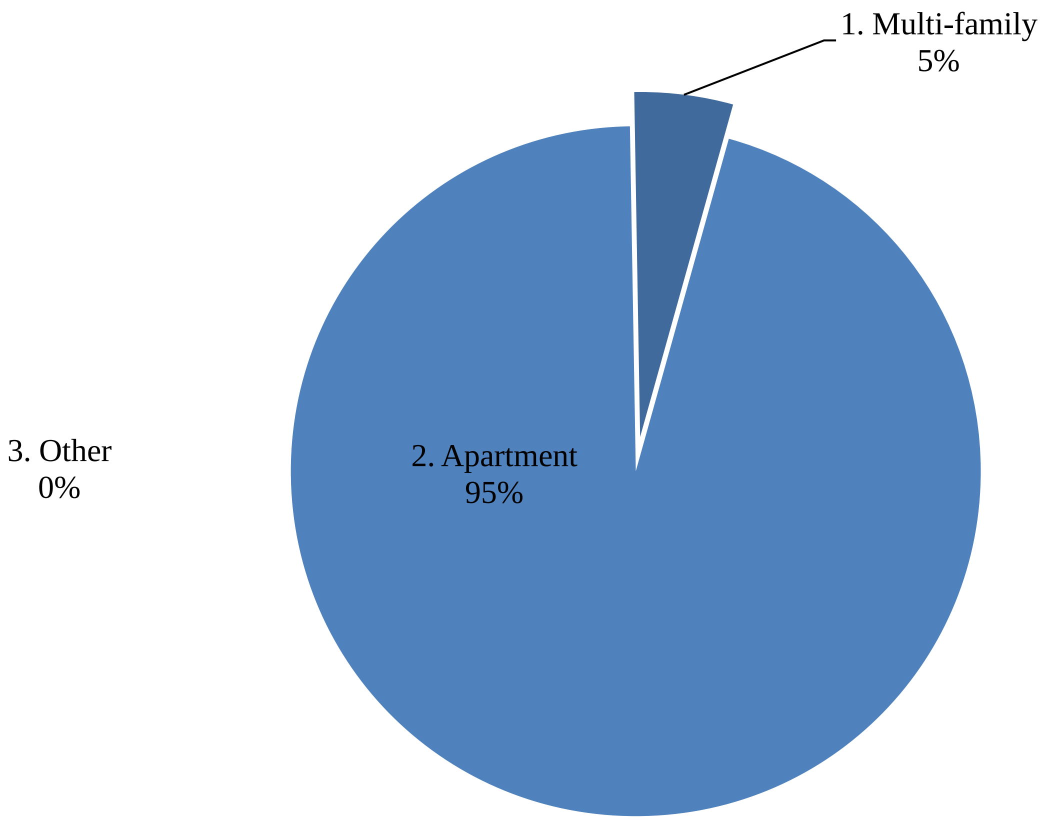


Each respondent represented a household. 60% of the interviewed participants were female, and 40% were male.

Q3: Age of respondents (n=65)	65	Percentage (%)
1. 18-30	24	37
2. 31-40	13	20
3. 41-50	13	20
4. 51-60	10	15
5. 61+	5	8

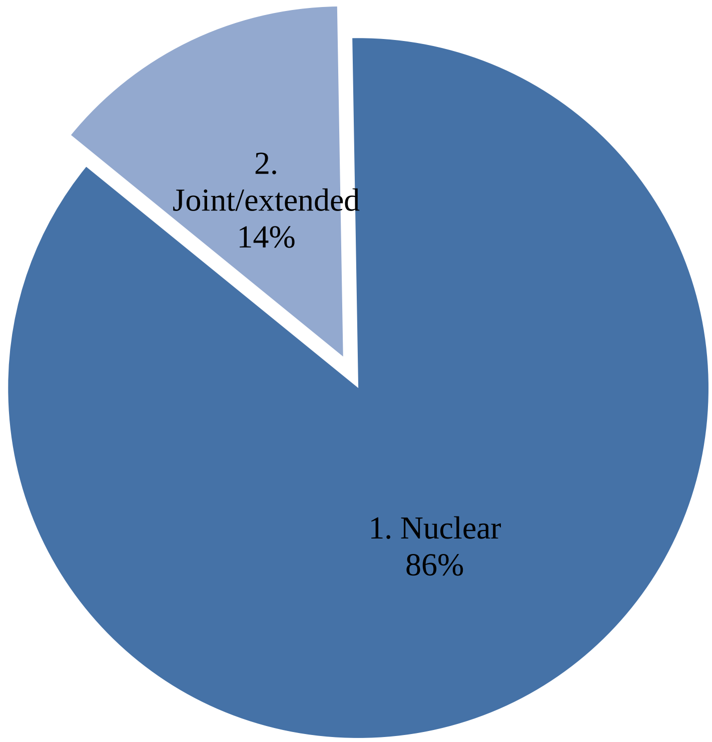


Q5: Housing type (n=65)	65	Percentage (%)
1. Multi-Family (Residential)	3	5
2. Apartment (Building)	62	95
3. Other	0	0



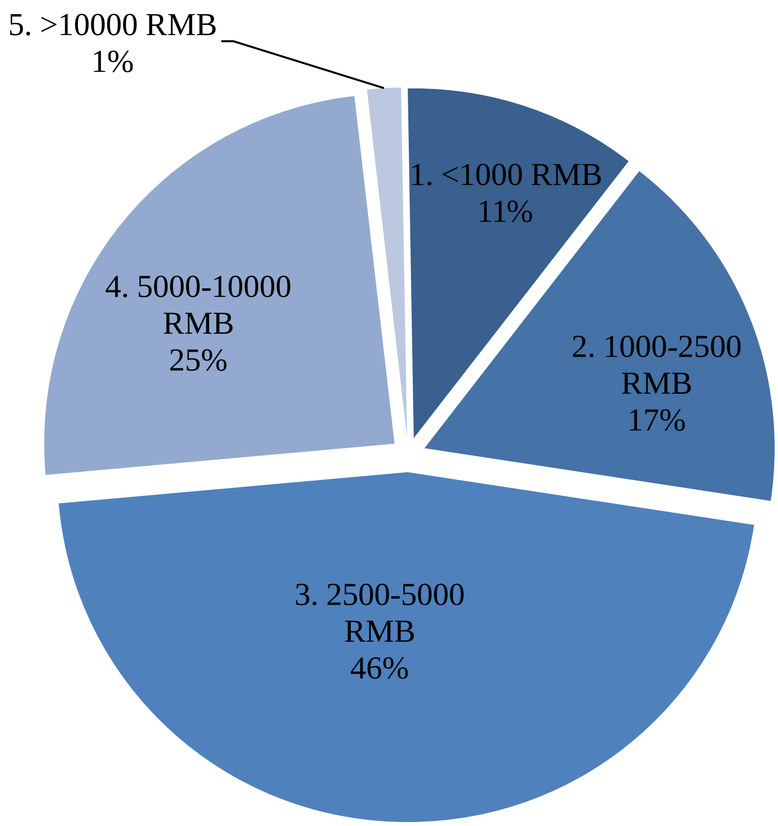
95% participants lived in apartment buildings, and 5% in multi-family (houses).

Q6: Type of family (n=65)	65	Percentage (%)
1. Nuclear	56	86
2. Joint/extended	9	14



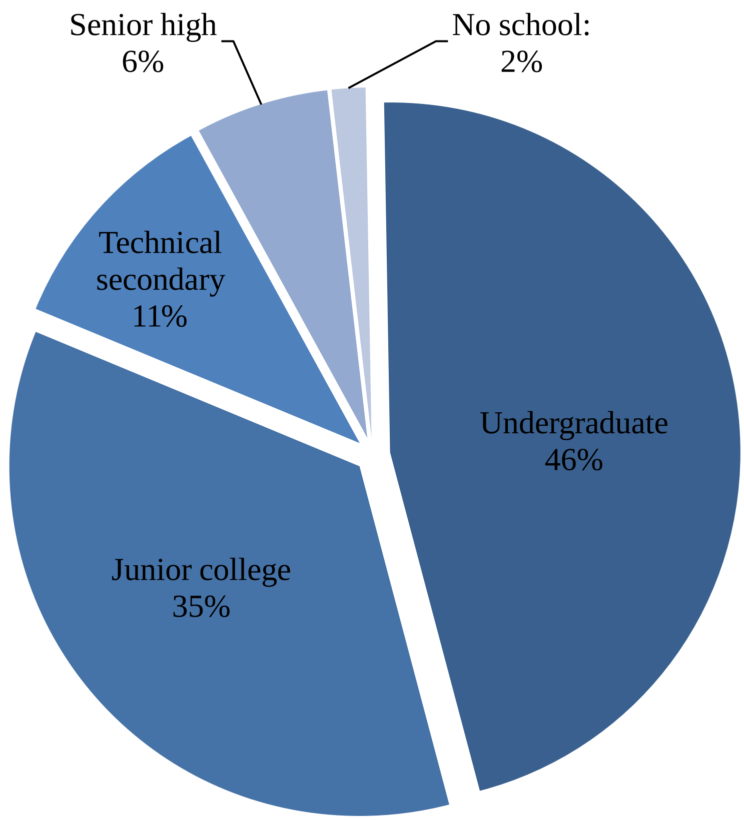
Majority (86%) of the households' family type was nuclear, mainly consisted of parents and children.

Q9: Monthly household income (n=65)	65	Percentage (%)
1. <1000 RMB	7	11
2. 1000-2500 RMB	11	17
3. 2500-5000 RMB	30	46
4. 5000-10000 RMB	16	25
5. >10000 RMB	1	2



Monthly household income was the total income of all employed family members. 46% of the households' total monthly incomes ranged between 2500-5000 RMB, and 25% had higher income, comparing to the rest.

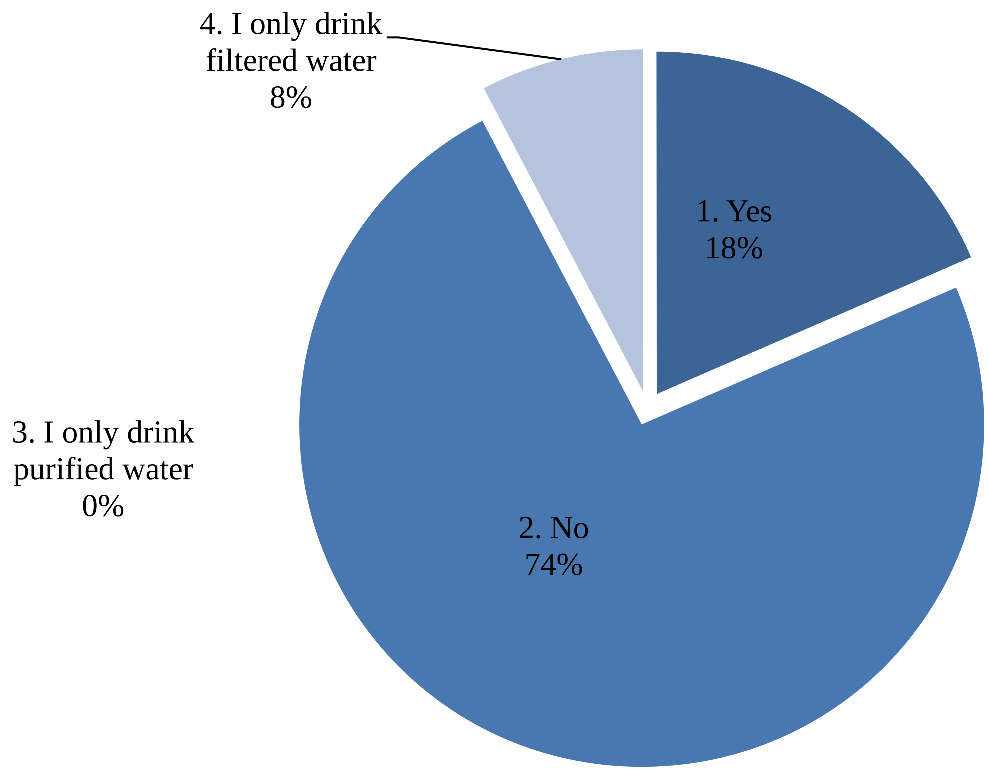
Q10: Education level (at least) of respondents (n=65)	65	Percentage (%)
1. Undergraduate	30	46
2. Junior college	23	35
3. Technical secondary	7	11
4. Senior high	4	6
5. No school	1	2



47% of the interviewees held undergraduate diplomas, 35% went to junior college, and 11% went to technical secondary school. Overall, the education level of urban residents was relatively high.

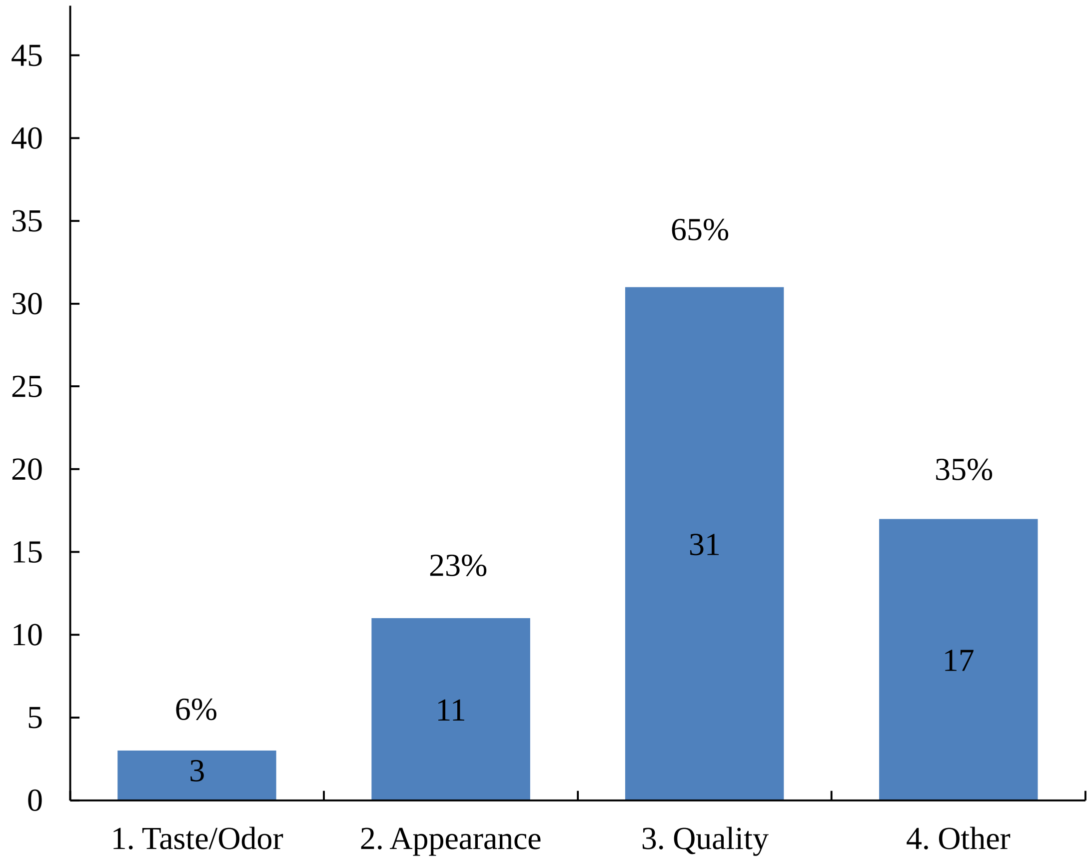
A.2 Water-related Questions:

Q1: Do you drink water directly from the tap? (n=65)	65	Percentage (%)
1. Yes	12	18
2. No	48	74
3. I only drink purified water	0	0
4. I only drink filtered water	5	8



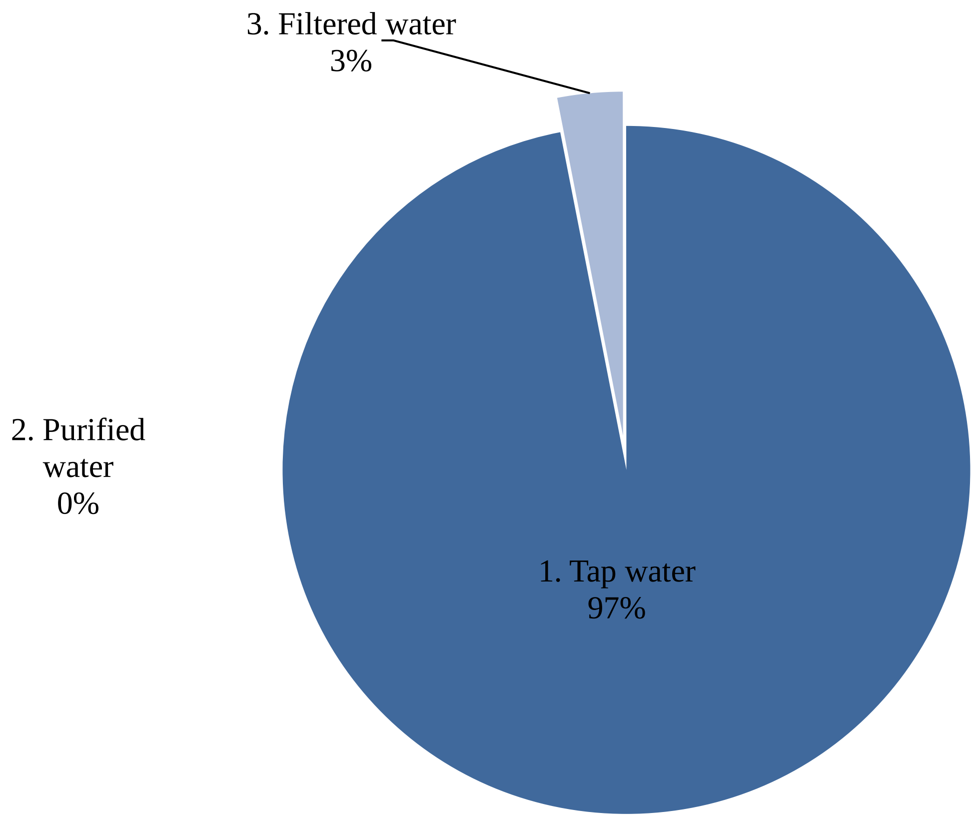
74% of the local households in urban area do not directly consume water from their taps.

Q2: If ‘no’, why not? (Check all that apply, n=48)	48	Percentage (%)
1. Taste/Odor	3	6
2. Appearance	11	23
3. Quality	31	65
4. Other	17	35



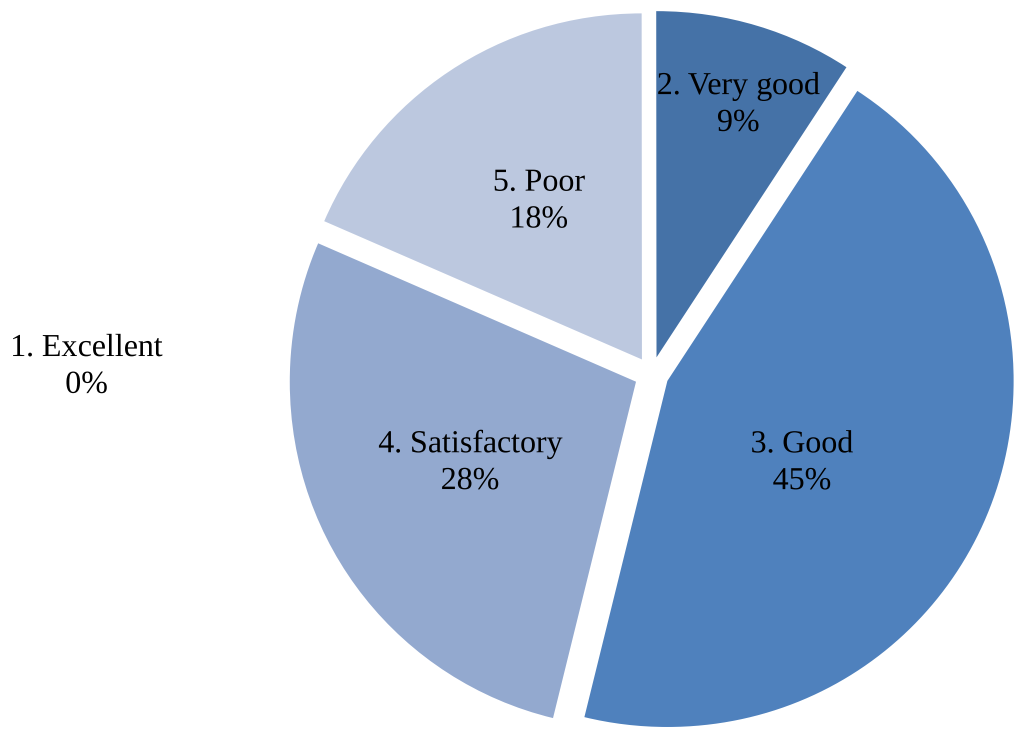
65% of the consumers who do not directly drink water from their taps have concerns on water quality.

Q3: What is the main source of water used by your household for cooking? (n=65)	65	Percentage (%)
1. Tap water	63	97
2. Purified water	0	0
3. Filtered water	2	3



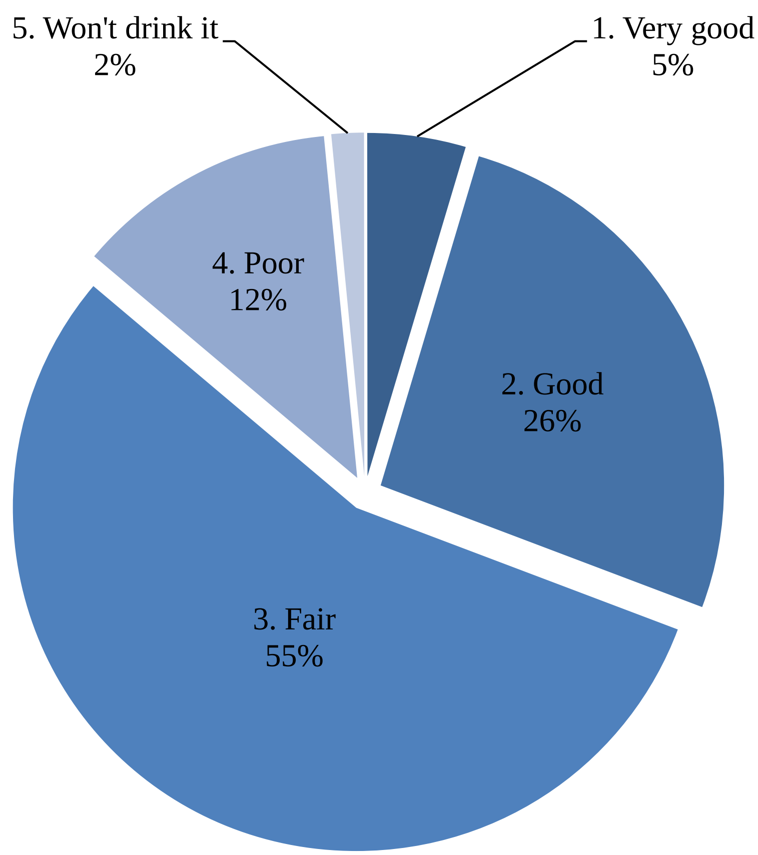
97% of the households used tap water as their main source of water use.

Q4: Would you rate the quality of your tap water as: (n=65)	65	Percentage (%)
1. Excellent	0	0
2. Very good	6	9
3. Good	29	45
4. Satisfactory	18	28
5. Poor	12	18



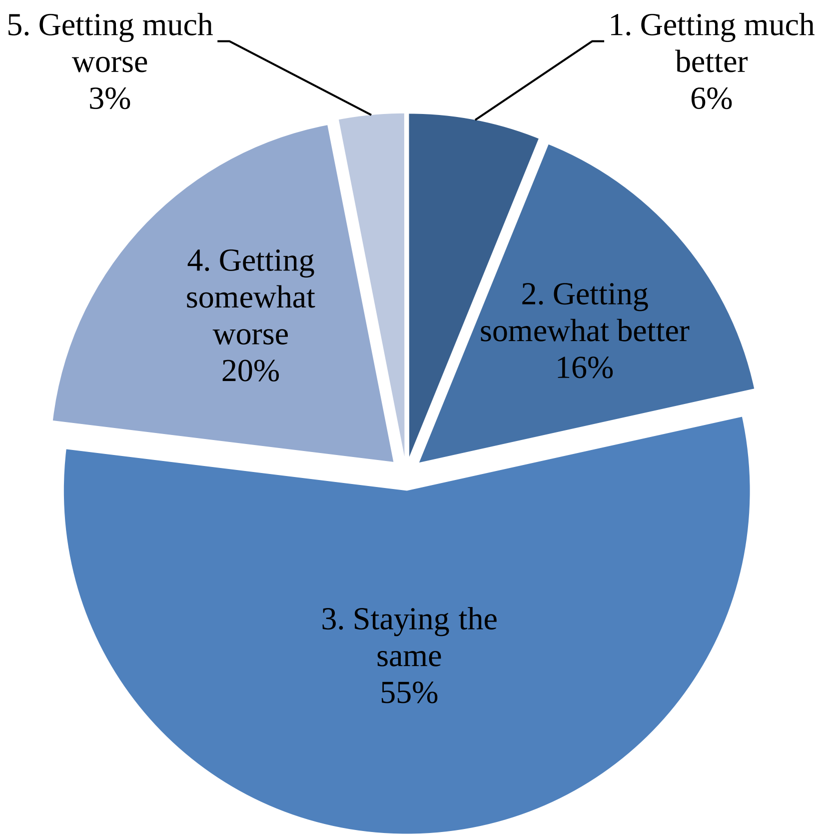
45% of the households rated the quality of their tap water as Good, 18% as Poor, and 0% as Excellent.

Q5: How do you rate the taste of tap water? (n=65)	65	Percentage (%)
1. Very good	3	5
2. Good	17	26
3. Fair	36	55
4. Poor	8	12
5. Won’t drink it	1	2



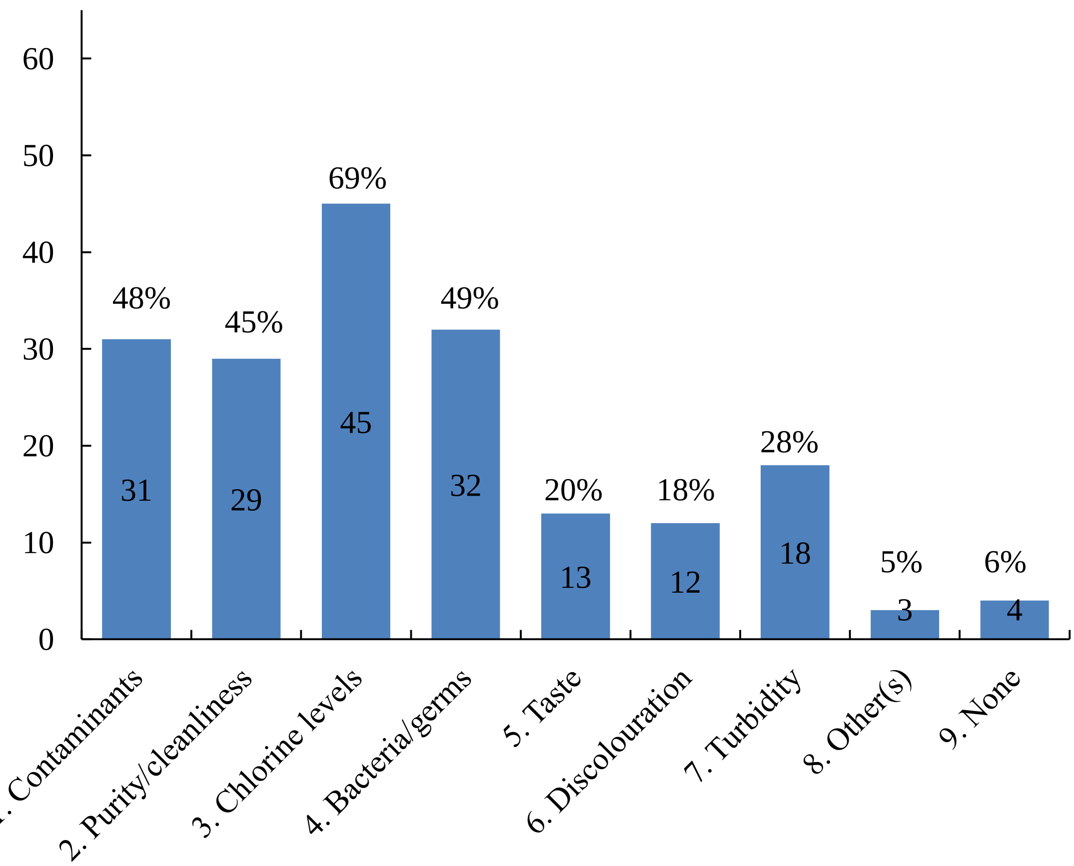
55% of the households rated the taste of their tap water as Fair, 5% as Very Good, and 2% as Won’t Drink It.

Q6: Do you feel that the quality of water is getting better? (n=65)	65	Percentage (%)
1. Getting much better	4	6
2. Getting somewhat better	10	15
3. Staying the same	36	55
4. Getting somewhat worse	13	20
5. Getting much worse	2	3



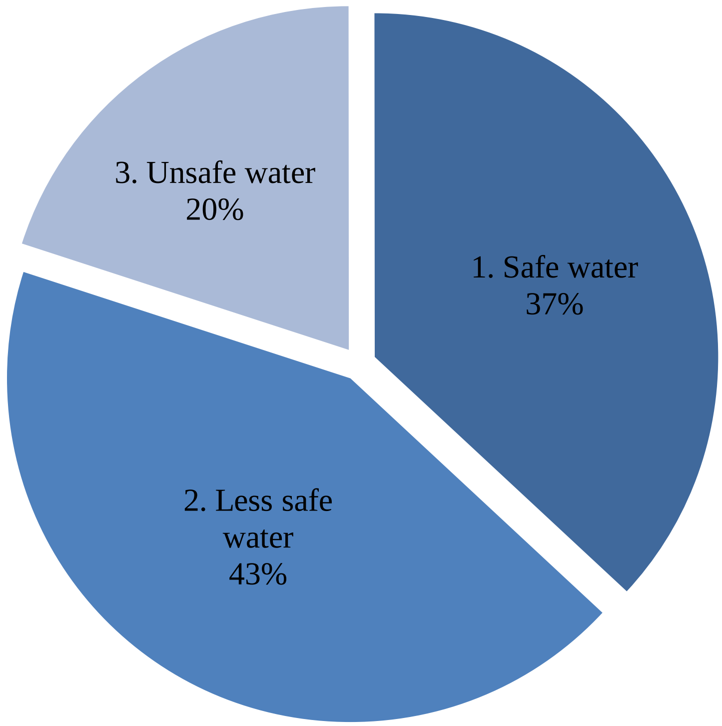
55% of the households thought that the quality of water stayed the same (over the decades)

Q7: What, if any, concerns do you have about drinking tap water? (Check all that apply, n=65)	65	Percentage (%)
1. Contaminants	31	48
2. Purity/cleanliness	29	45
3. Chlorine levels	45	69
4. Bacteria/germs	32	49
5. Taste	13	20
6. Discolouration	12	18
7. Turbidity	18	28
8. Other(s)	3	5
9. None	4	6



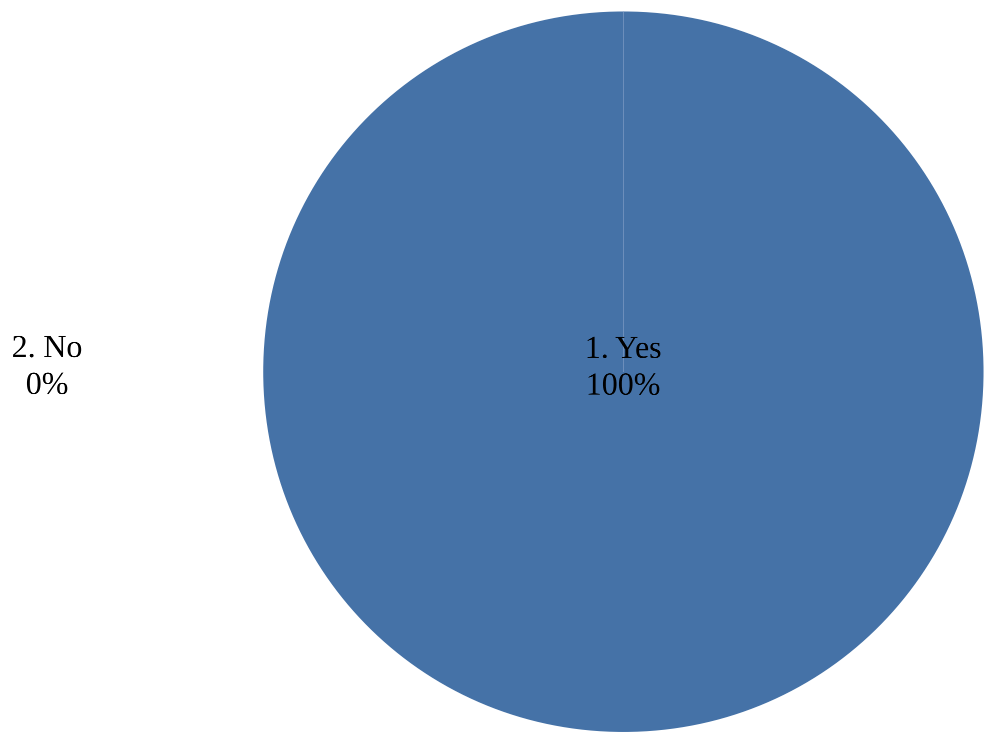
Local households' main concerns on drinking tap water are: Chlorine Levels, Bacteria, and Contaminants.

Q8: In your experience, the taste of chlorine indicates: (n=65)	65	Percentage (%)
1. Safe water	24	37
2. Less safe water	28	43
3. Unsafe water	13	20



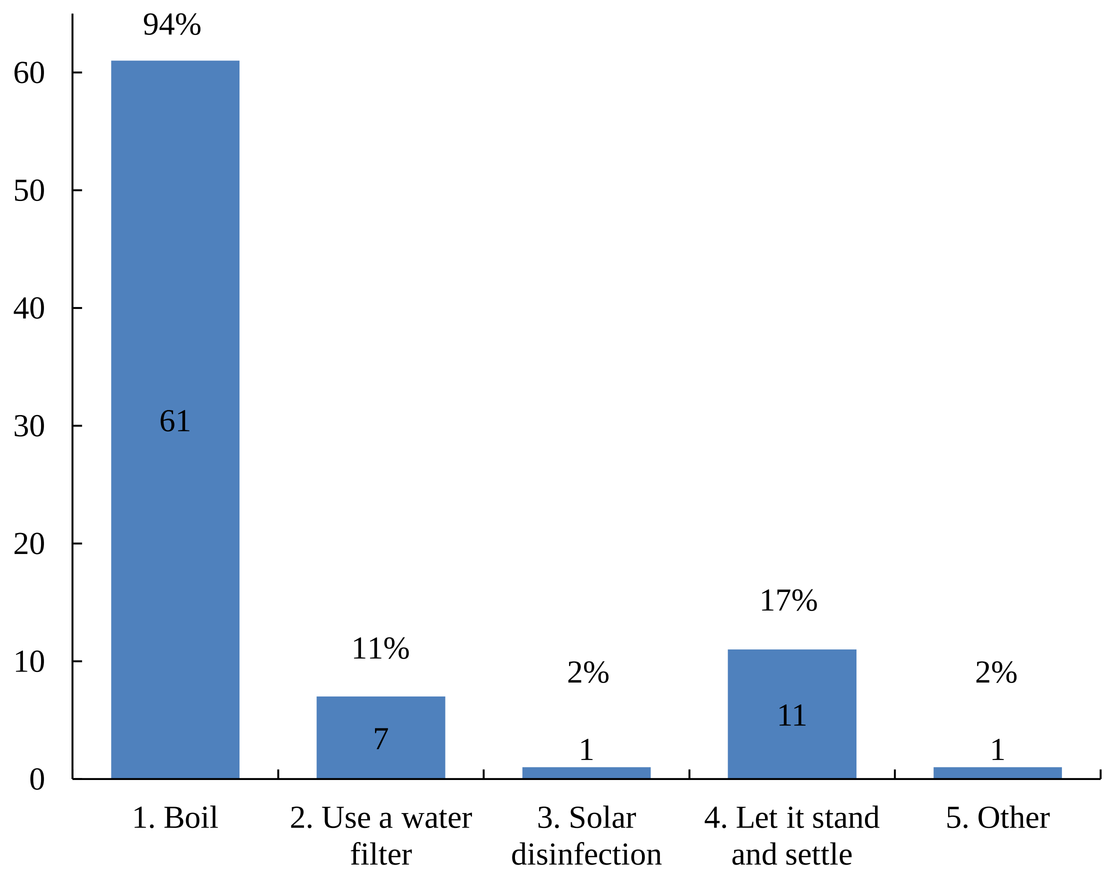
Many (43%) of the households believed that the taste of chlorine indicated Less Safe Water.

Q9: Do you treat your water in any way to make it safer to drink? (n=65)	65	Percentage (%)
1. Yes	65	100
2. No	0	0



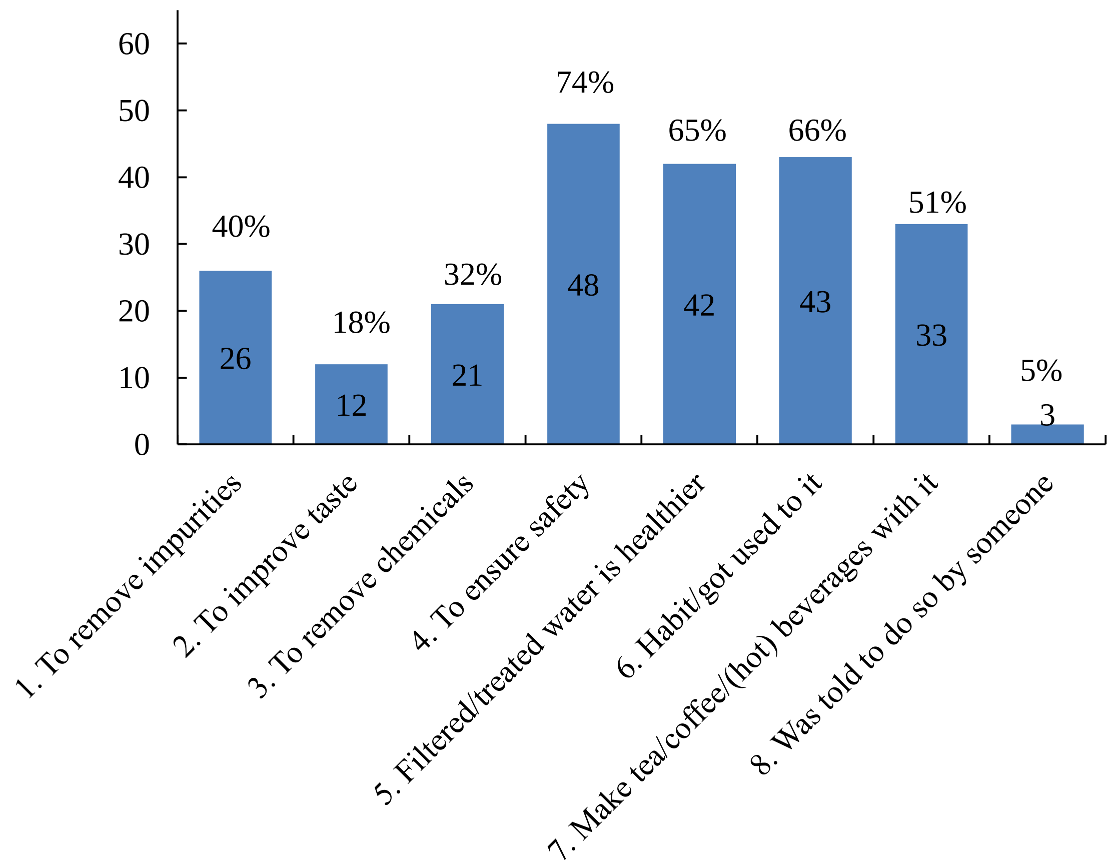
All the participants in this research treated their tap water before drinking it.

Q10: If 'Yes', what do you usually do to make it safer to drink? (Check all that apply, n=65)	65	Percentage (%)
1. Boil	61	94
2. Use a water filter	7	11
3. Solar disinfection	1	2
4. Let it stand and settle	11	17
5. Other	1	2



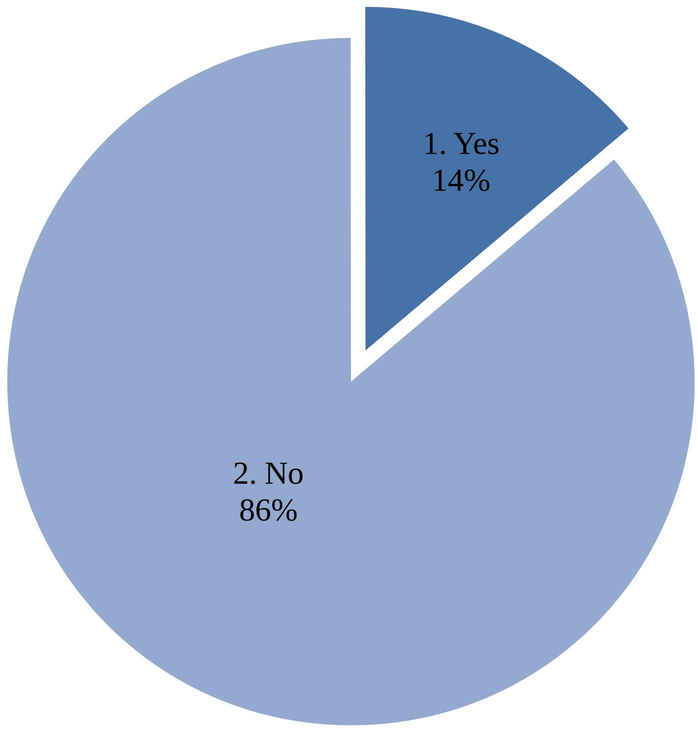
The majority (94%) of the households boiled their water before drinking it.

Q11: Why do you treat tap water before drinking it? Any other reasons? (Check all that apply, n=65)	65	Percentage (%)
1. To remove impurities	26	40
2. To improve taste	12	18
3. To remove chemicals	21	32
4. To ensure safety	48	74
5. Filtered/treated water is healthier	42	65
6. Habit/got used to it	43	66
7. Make tea/coffee/(hot) beverages with it	33	51
8. Was told to do so by someone	3	5
9. Other	0	0



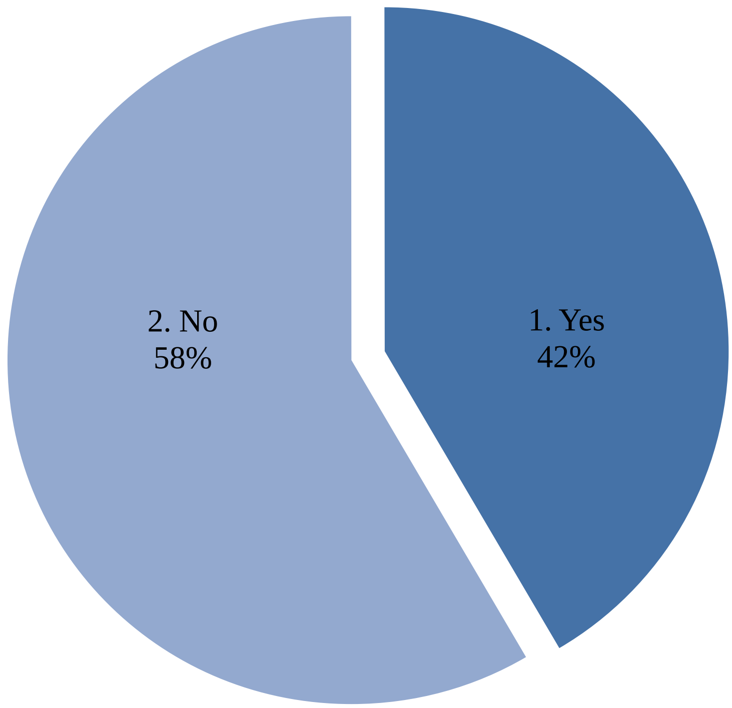
The main reason households treat their tap water before consumption is that they wanted to ensure safety. Many (43%) got used to boiling water and believed that treated water was healthier.

Q12: Do you use a water filter for your tap water? (n=65)	65	Percentage (%)
1. Yes	9	14
2. No	56	86



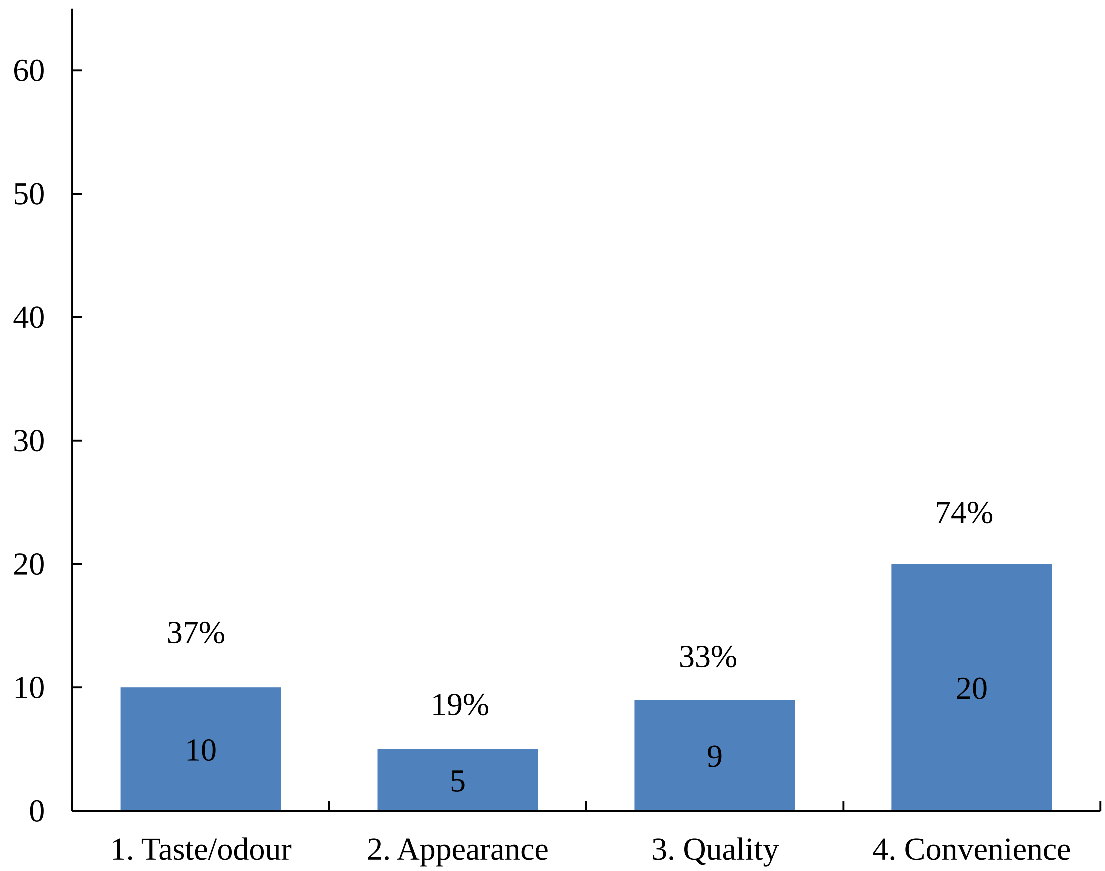
Water filters are not widely used in the City of Kumul; 86% of the households do not filter water.

Q14: Do you buy bottled water? (n=65)	65	Percentage (%)
1. Yes	27	42
2. No	38	58



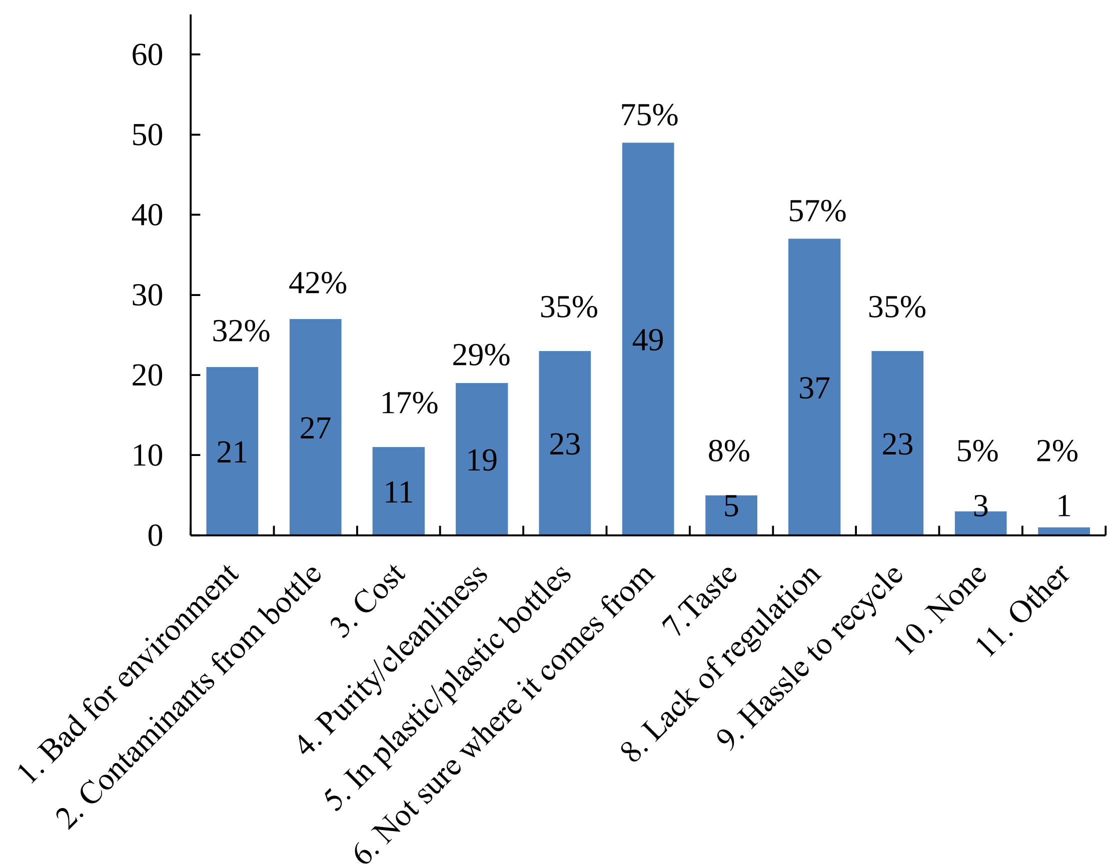
The majority (58%) of the local households do not drink bottled water. However, 42% of the locals purchase bottled water frequently.

Q15: If 'Yes', why? (Check all that apply, n=27)	27	Percentage (%)
1. Taste/odour	10	37
2. Appearance	5	19
3. Quality	9	33
4. Convenience	20	74



The main reason that households purchased bottled water was because it was convenient, and 34% liked the taste of bottled water better.

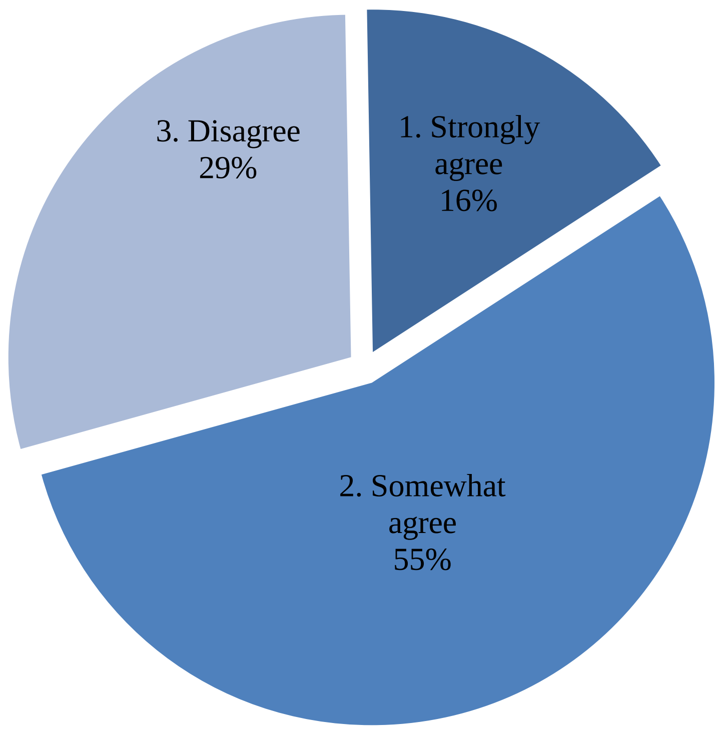
Q16: What, if any, concerns do you have about drinking bottled water? Any others? (Check all that apply, n=65)	65	Percentage (%)
1. Bad for environment	21	32
2. Contaminants from bottle	27	42
3. Cost	11	17
4. Purity/cleanliness	19	29
5. In plastic/plastic bottles	23	35
6. Not sure where it comes from	49	75
7.Taste	5	8
8. Lack of regulation	37	57
9. Hassle to recycle	23	35
10. None	3	5
11. Other	1	2



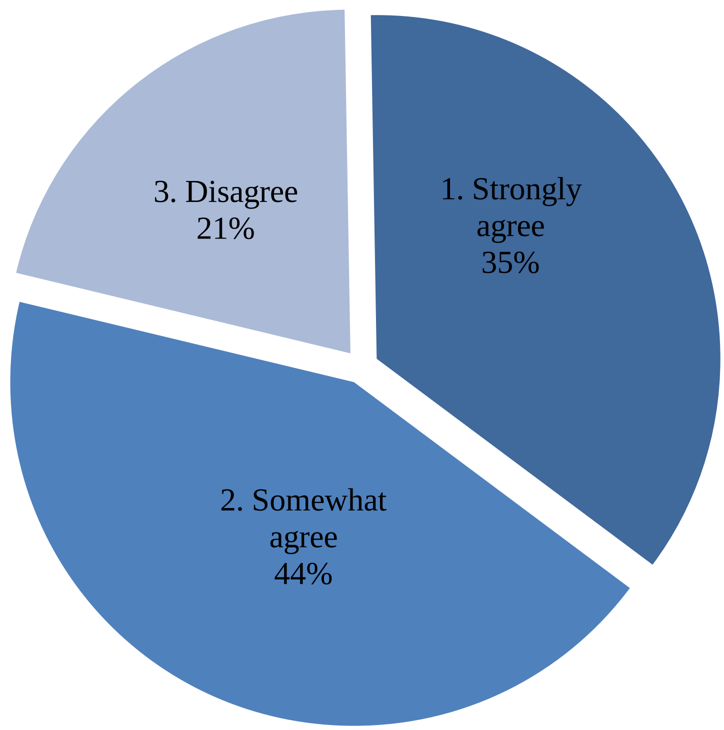
The main concerns that households have on bottled water were the source of water in the bottle, lack of regulation and contaminants from bottle.

Q17: Please tell me the extent to which you agree or disagree with the following statement about drinking water. Strongly agree/Somewhat agree/Disagree

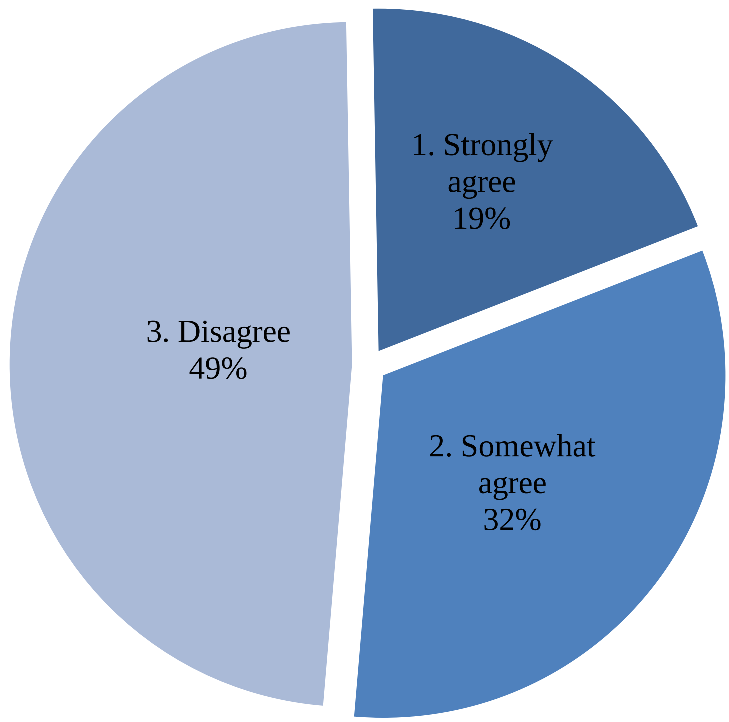
It is expensive to drink bottled water. (n=62)	62	Percentage (%)
1. Strongly agree	10	16
2. Somewhat agree	34	55
3. Disagree	18	29



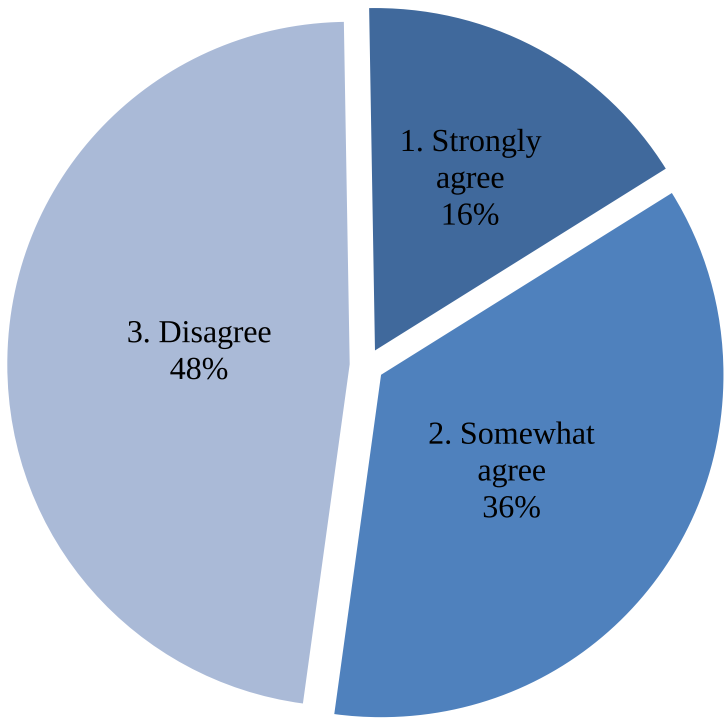
Bottled water has a negative impact on the environment. (n=62)	62	Percentage (%)
1. Strongly agree	22	35
2. Somewhat agree	27	44
3. Disagree	13	21



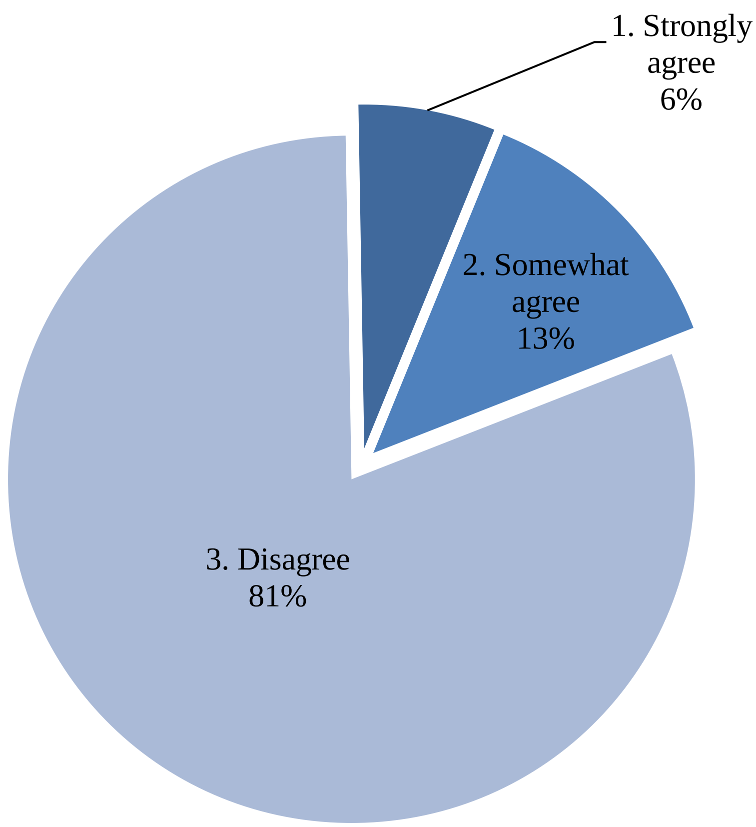
Tap water is cleaner and safer than bottled water because it must meet stricter safety regulations. (n=62)	62	Percentage (%)
1. Strongly agree	12	19
2. Somewhat agree	20	32
3. Disagree	30	49



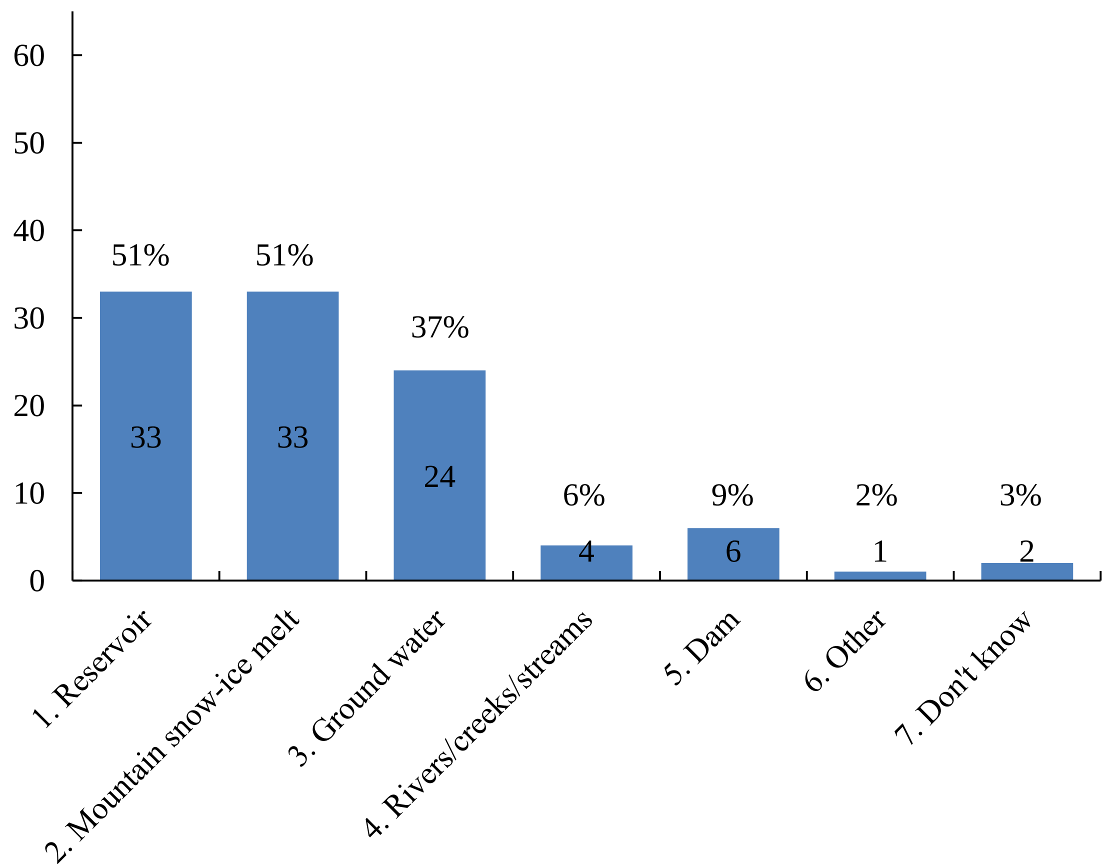
I like the taste of bottled water better than tap water. (n=61)	61	Percentage (%)
1. Strongly agree	10	16
2. Somewhat agree	22	36
3. Disagree	29	48



Tap water is fine for adults, but it's better to give children bottled water. (n=62)	62	Percentage (%)
1. Strongly agree	4	6
2. Somewhat agree	8	13
3. Disagree	50	81

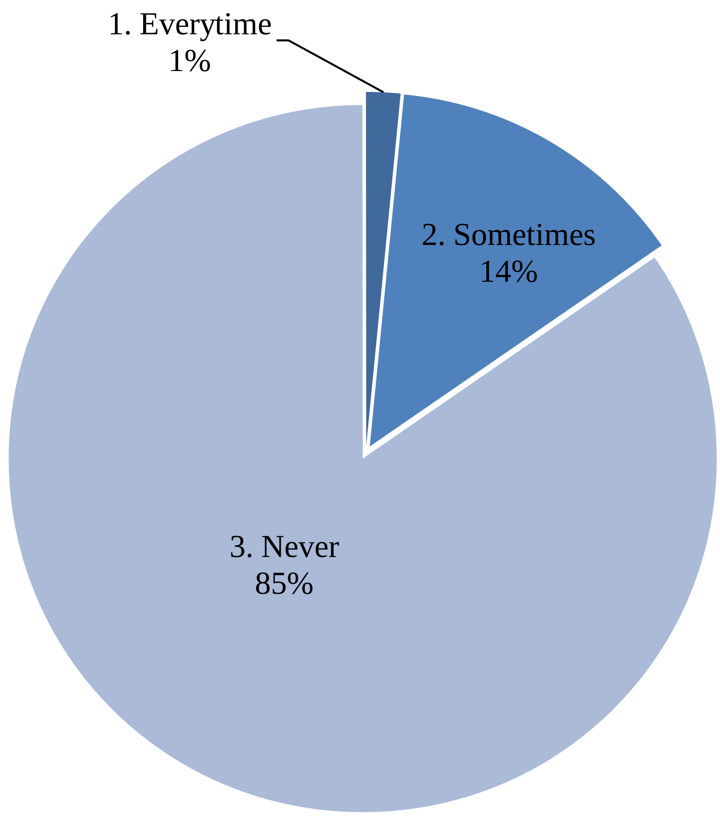


Q18: To the best of your knowledge, where do households in the city get their tap water? (That is, what is the source of tap water that you are consuming?) (Check all that apply, n=65)	65	Percentage (%)
1. Reservoir	33	51
2. Mountain snow-ice melt	33	51
3. Ground water	24	37
4. Rivers/creeks/streams	4	6
5. Dam	6	9
6. Other	1	2
7. Don't know	2	3



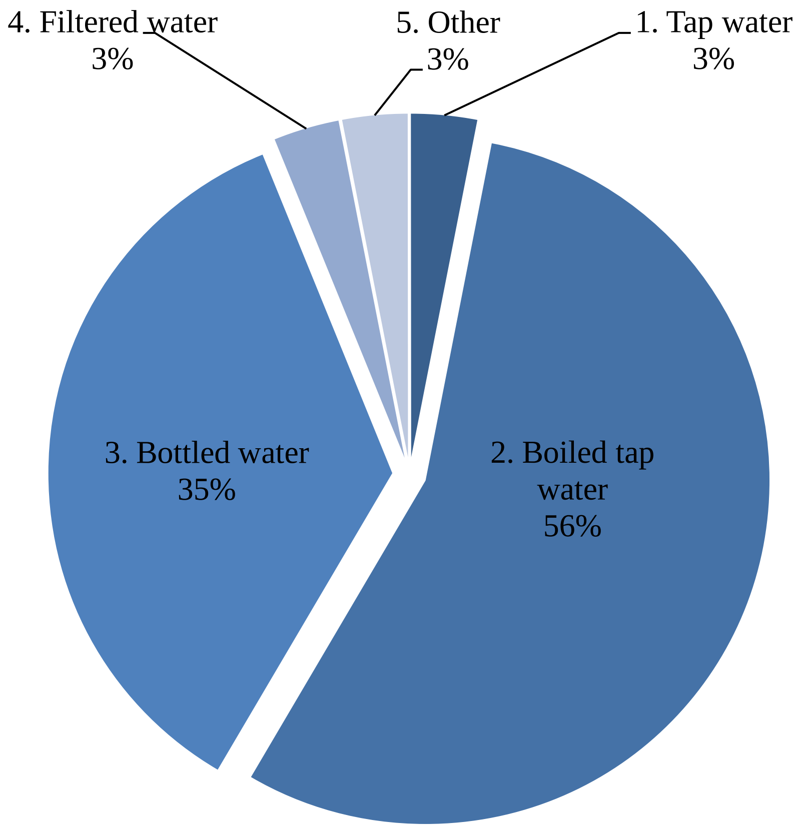
Most of the households are aware of the water sources of their drinking water, which are mainly mountain snow-ice melt/reservoirs and groundwater.

Q19: How often do you ask for tap water at a restaurant, bar or hotel? (n=65)	65	Percentage (%)
1. Every time	1	2
2. Sometimes	9	14
3. Never	55	85



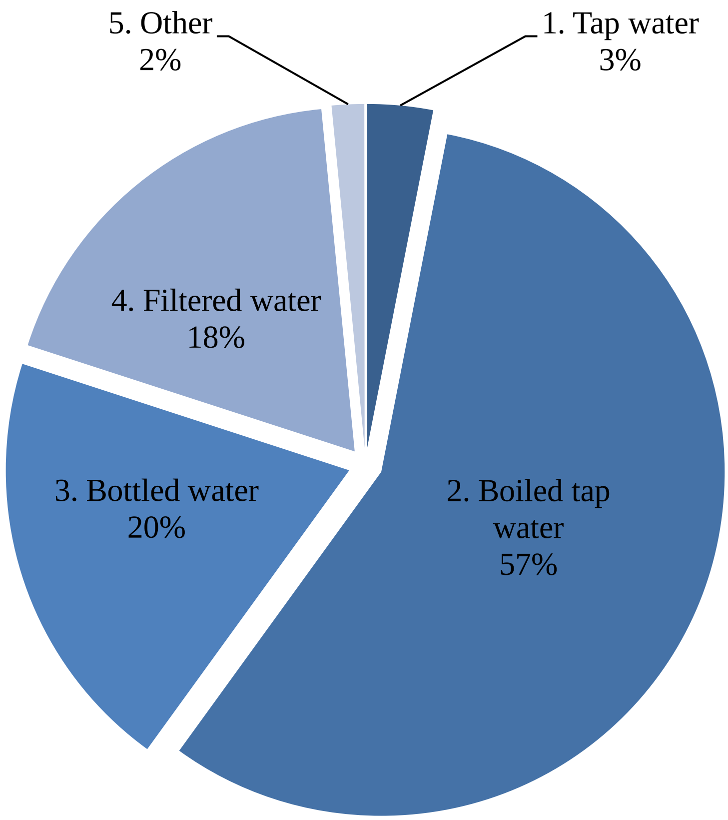
85% of the households do not ask for fresh tap water at a restaurant, bar or hotel. In Kumul (and the rest of China), a restaurant/bar/hotel serves hot (boiled) water or tea.

Q20: What is your main water source available in your workplace for drinking? (n=65)	65	Percentage (%)
1. Tap water	2	3
2. Boiled tap water	36	56
3. Bottled water	23	35
4. Filtered water	2	3
5. Other	2	3



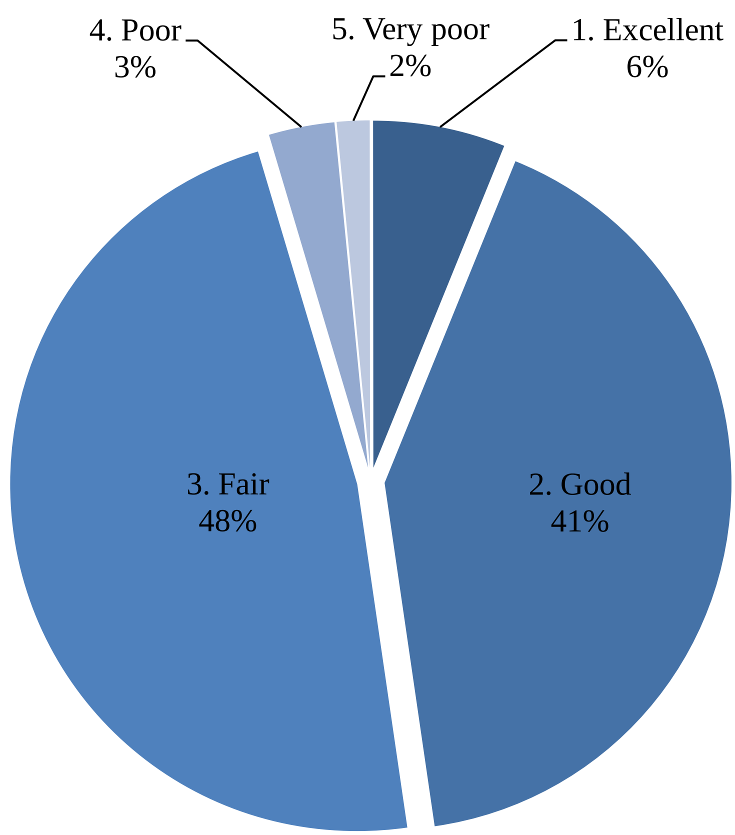
At most of the local workplaces, the main water sources available for drinking are Boiled Water and Bottled Water.

Q21: What source of water would you prefer to be available at your workplace? (n=65)	65	Percentage (%)
1. Tap water	2	3
2. Boiled tap water	37	57
3. Bottled water	13	20
4. Filtered water	12	18
5. Other	1	2



57% of locals would prefer boiled tap water be available at their workplaces. The majority of households prefer tap water but boiled.

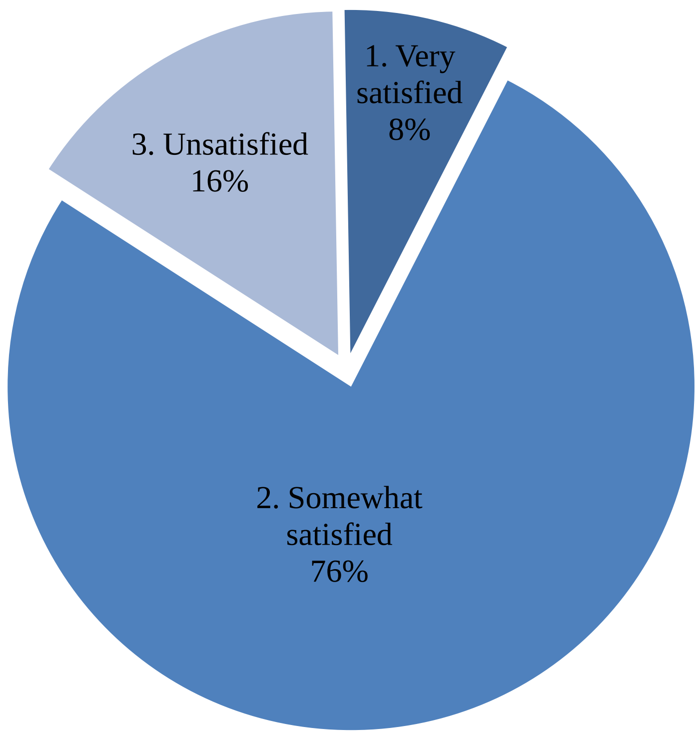
Q22: How would you rate the overall quality of the City of Kumul’s tap water? Would you say…? (n=65)	65	Percentage (%)
1. Excellent	4	6
2. Good	27	42
3. Fair	31	48
4. Poor	2	3
5. Very poor	1	2



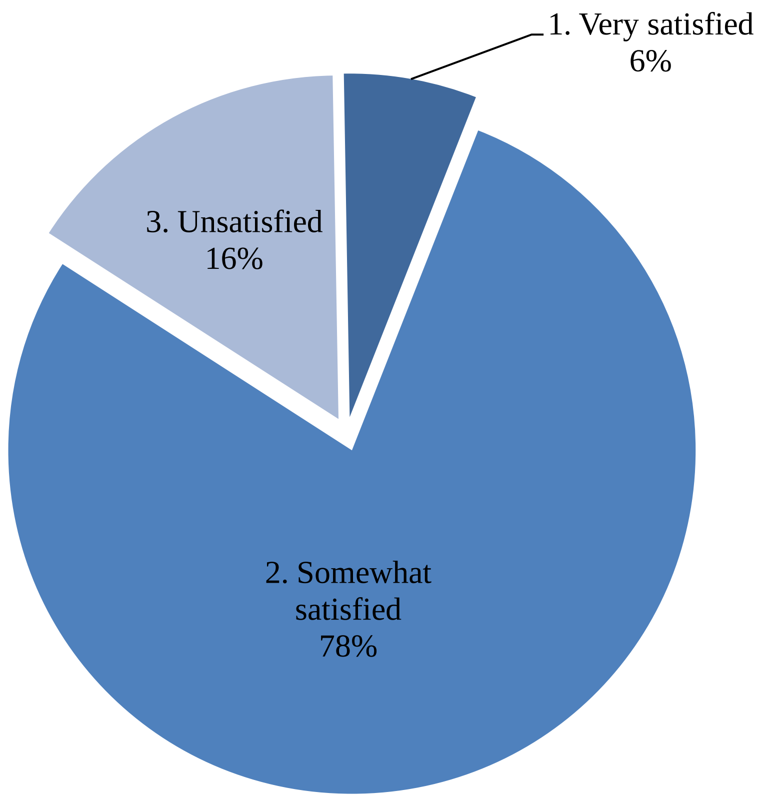
48% of the households rated the overall quality of Kumul’s tap water as Fair, 42% as Good, 6% as Excellent, and 1% as Very Poor.

Q23: How satisfied are you with each of the following aspects of the City of Kumul’s tap water? Very satisfied/Somewhat satisfied/Unsatisfied

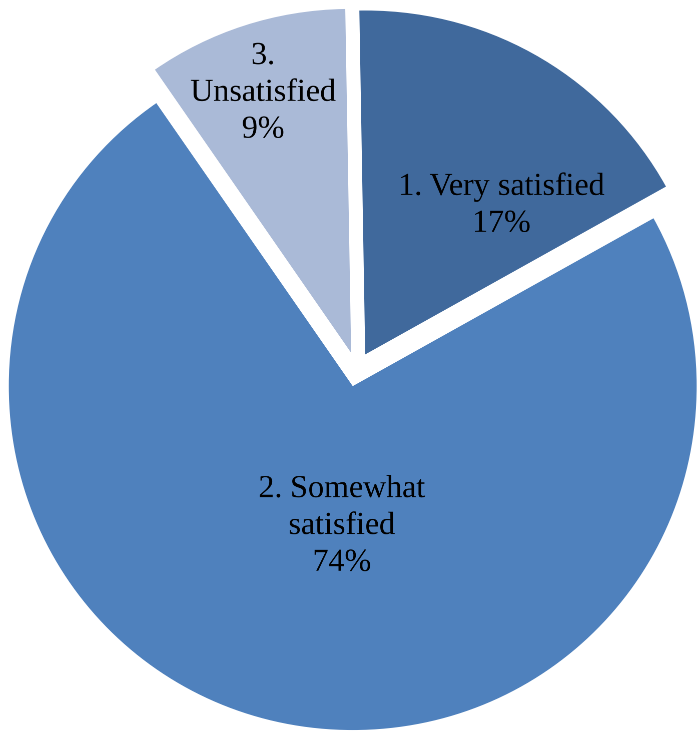
Clarity (n=64)	64	Percentage (%)
1. Very satisfied	5	8
2. Somewhat satisfied	49	76
3. Unsatisfied	10	16



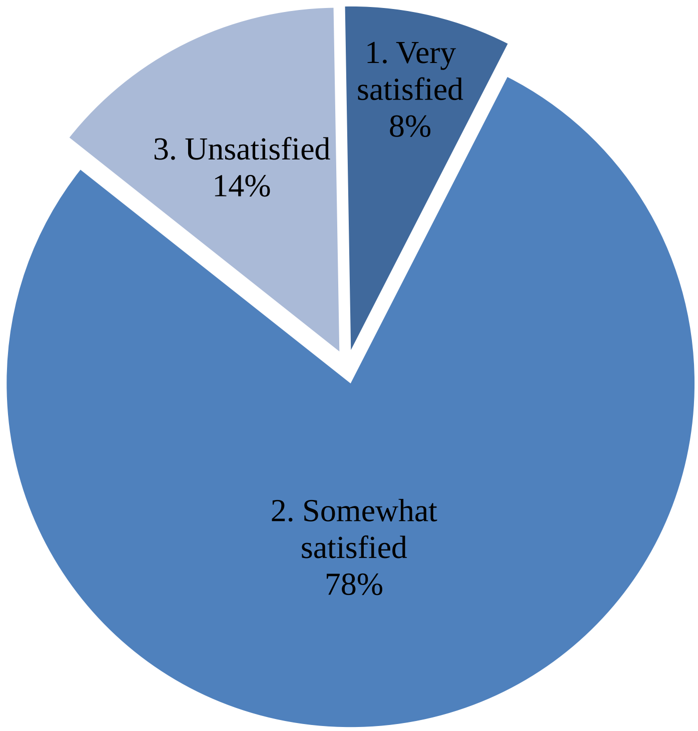
Safety (n=64)	64	Percentage (%)
1. Very satisfied	4	6
2. Somewhat satisfied	50	78
3. Unsatisfied	10	16



Smell (n=64)	64	Percentage (%)
1. Very satisfied	11	17
2. Somewhat satisfied	47	74
3. Unsatisfied	6	9

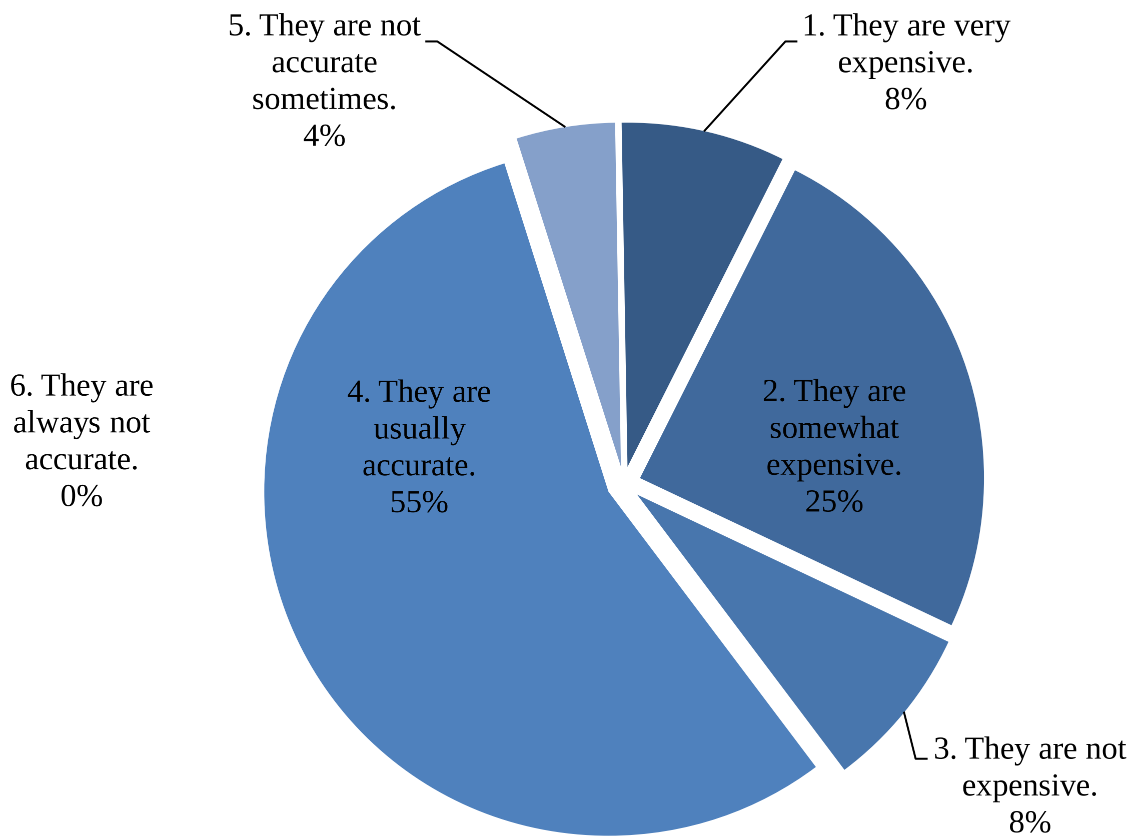


Taste (n=64)	64	Percentage (%)
1. Very satisfied	5	8
2. Somewhat satisfied	50	78
3. Unsatisfied	9	14



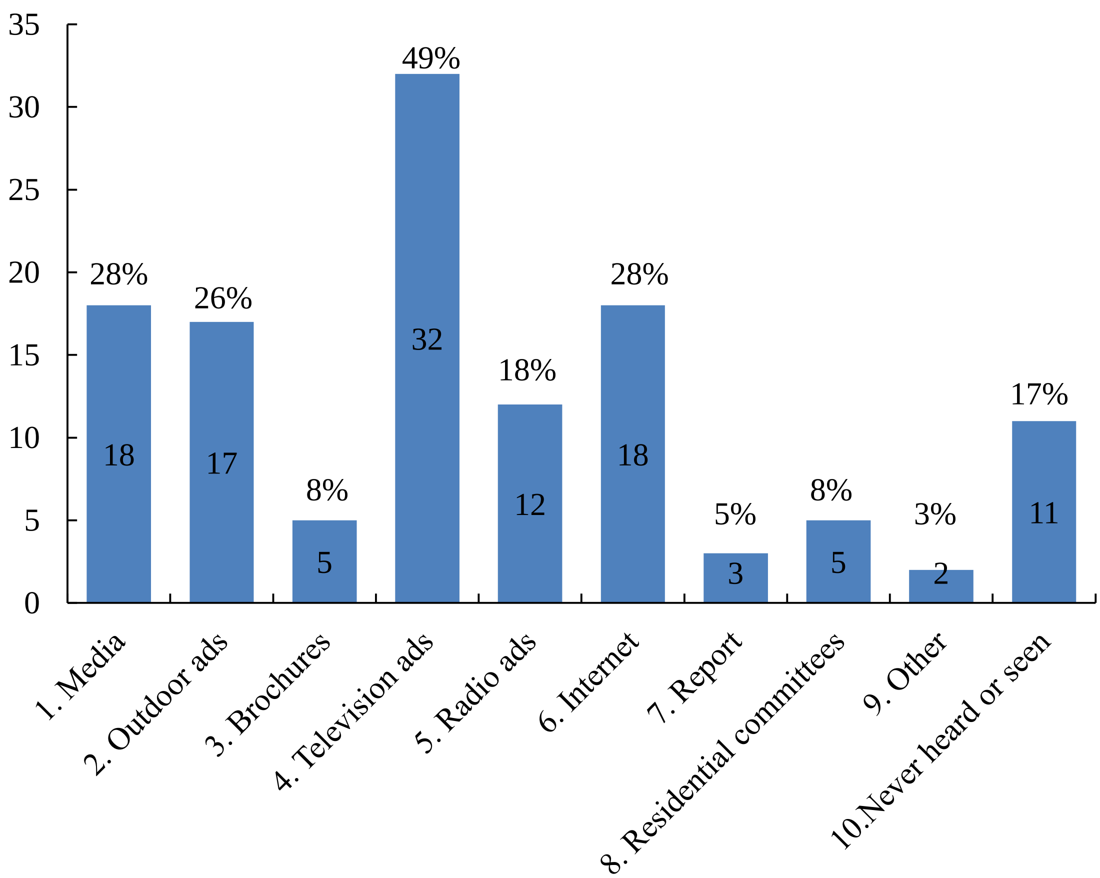
A. 3 Water Service-related Questions:

Q25: What do you think about the water bills that you receive? (n=65)	65	Percentage (%)
1. They are very expensive.	5	8
2. They are somewhat expensive.	16	25
3. They are not expensive.	5	8
4. They are usually accurate.	36	55
5. They are not accurate sometimes.	1	2
6. They are always not accurate.	0	0

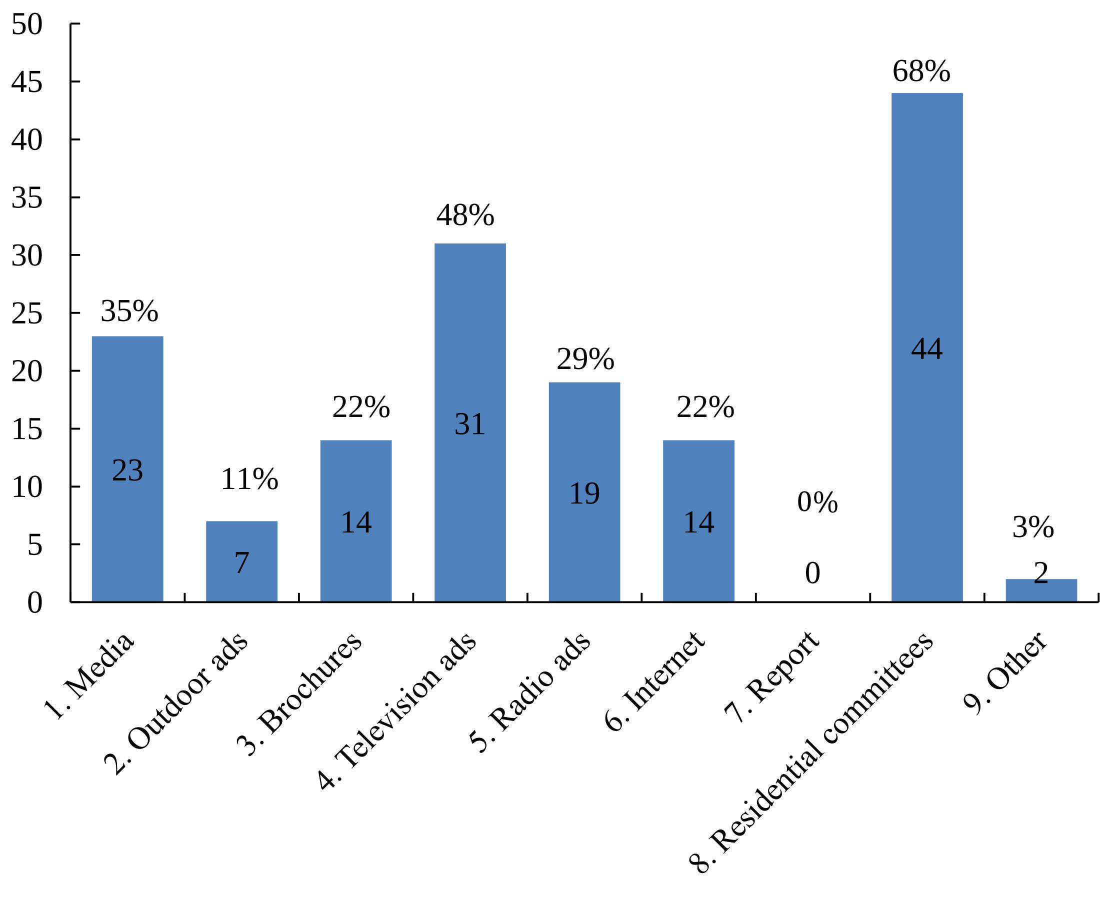


Water bills are usually accurate. Majority (55%) receive accurate bill while 25% thought that the bills were somewhat expensive.

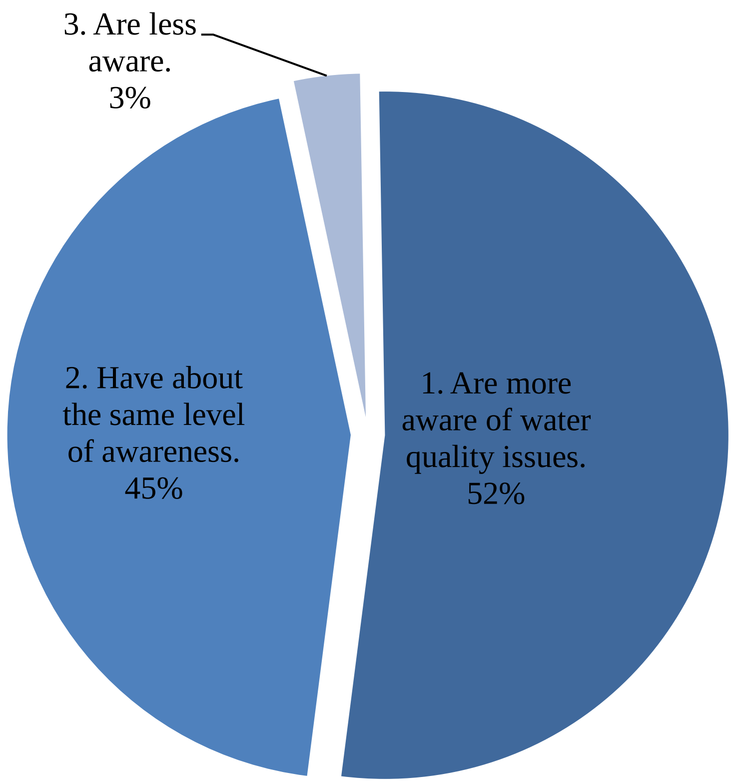
Q26: If there are any messages on water quality, where do you generally see or hear them? (Check all that apply, n=65)	65	Percentage (%)
1. Media such as newspaper, magazines etc.	18	28
2. Outdoor ads, billboards	17	26
3. Brochures	5	8
4. Television ads	32	49
5. Radio ads	12	18
6. Internet	18	28
7. Annual Water Quality Report published by water-related institutes	3	5
8. Residential committees or property management companies	5	8
9. Other	2	3
10. Never heard or seen any	11	17



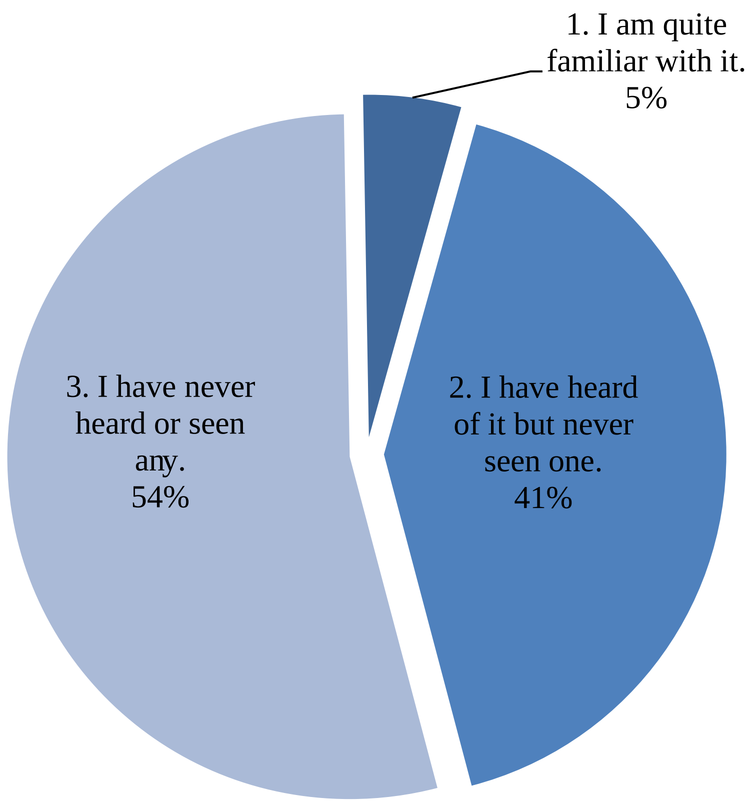
Q27: What is the best way for related water institutes to communicate with you about the city's drinking water information? (Check all that apply, n=65)	65	Percentage (%)
1. Media such as newspaper, magazines etc.	23	35
2. Outdoor ads, billboards	7	11
3. Brochures	14	22
4. Television ads	31	48
5. Radio ads	19	29
6. Internet	14	22
7. Annual Water Quality Report published by water-related institutes	0	0
8. Residential committees or property management companies	44	68
9. Other	2	3



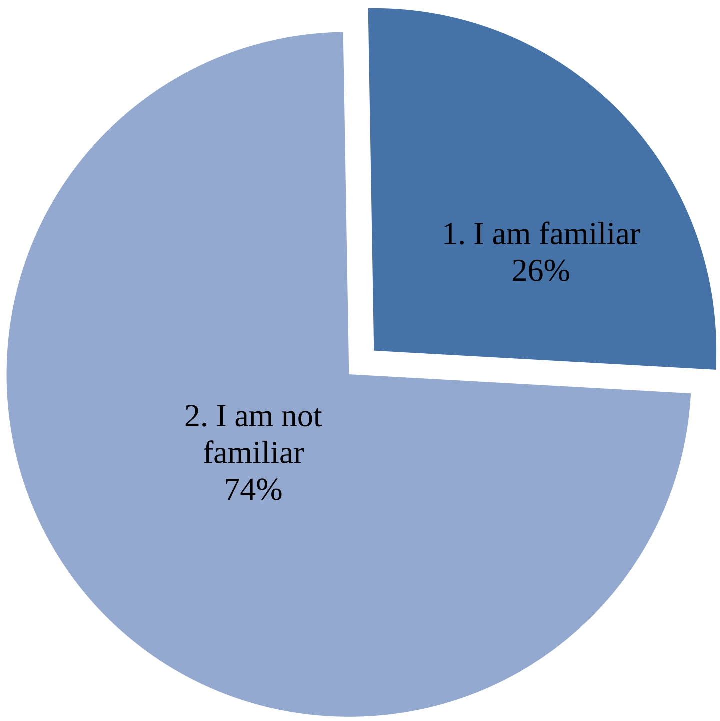
Q28: Compared to one year ago, would you say that you … (n=65)	65	Percentage (%)
1. are more aware of water quality issues.	34	52
2. have about the same level of awareness.	29	45
3. are less aware.	2	3



Q29: How are you familiar with the City's Annual Water Quality Report? (n=65)	65	Percentage (%)
1. I am quite familiar with it.	3	5
2. I have heard of it but never seen one.	27	42
3. I have never heard or seen any.	35	54



Q32: Are you familiar with the new technologies available for the selection of water saving devices that reduce your energy bills and save water, e.g. water saving shower heads, toilets or faucets? (n=65)	65	Percentage (%)
1. I am familiar.	17	26
2. I am not familiar.	48	74



APPENDIX E RELEVANT LAWS AND REGULATIONS

E.1 Laws

Environmental Protection Law (1989)

Water Pollution Protection and Control Law (1984, revised 1996)

The Water Law (1988, 2002)

E.2 Regulations

Environmental Quality Standards for Surface Water [GB3838-2002]

Based on surface water features and water environment protection targets, followed by function level into five categories:
—Grade Ⅰ: principal source of water for the State Nature Reserve;
—Grade Ⅱ: principal for centralized drinking water source protection area of surface, rare aquatic habitat, fish and shrimp production field, the larvae feeding grounds, etc.;
—Grade Ⅲ: principal for centralized drinking surface water source two protected areas, fish and shrimp wintering grounds, migration routes, aquaculture area and the swimming area of fisheries waters;
—Grade Ⅳ: principal areas for general industrial use and entertainment of human non-direct contact with water areas;
—Grade Ⅴ: principal areas for agricultural use and general landscape requirements waters.

Environmental Quality Standards of Surface Water (GB3838-2002) Unit: mg/L (excluding pH)						
Ref.	Parameter	Grade Ⅰ	Grade Ⅱ	Grade Ⅲ	Grade Ⅳ	Grade Ⅴ
1	pH	6 to 9	6 to 9	6 to 9	6 to 9	6 to 9
2	DO ≥	7.5 (or 90% sat)	6	5	3	2
3	COD_{Mn} ≤	2	4	6	10	15
4	COD_{Cr} ≤	15	15	20	30	40
5	BOD_5 ≤	3	3	4	6	10
6	N-NH_3 ≤	0.015	0.5	1.0	1.5	2.0
7	Total Phosphorus (P) ≤	0.02 (0.01)*	0.1 (0.025)*	0.2 (0.05)*	0.3 (0.1)*	0.4 (0.2)*
8	Total Nitrogen (N) ≤	0.2	0.5	1.0	1.5	2.0
9	Copper (Cu) ≤	0.01	1.0	1.0	1.0	1.0
10	Zinc (Zn) ≤	0.05	1.0	1.0	2.0	2.0
11	Fluoride (F) ≤	1.0	1.0	1.0	1.5	1.5
12	Selenium (Se) ≤	0.01	0.01	0.01	0.02	0.02
13	Arsenic (As) ≤	0.05	0.05	0.05	0.1	0.1
14	Mercury (Hg) ≤	0.00005	0.00005	0.0001	0.001	0.001
15	Cadmium (Cd) ≤	0.001	0.005	0.005	0.005	0.01
16	Chromium (Cr^{6+}) ≤	0.01	0.05	0.05	0.05	0.1

17	Total lead (Pb) ≤	0.01	0.01	0.05	0.05	0.1
18	Total cyanide (CN^-) ≤	0.005	0.05	0.2	0.2	0.2
19	Volatile phenol ≤	0.002	0.002	0.005	0.01	0.1
20	Oil ≤	0.05	0.05	0.05	0.5	1.0
21	Anionic detergent ≤	0.2	0.2	0.2	0.3	0.3
22	Sulphide ≤	0.05	0.1	0.2	0.5	1.0
23	Coli forms (#/L) ≤	200	2000	10,000	20,000	40,000

Standards for Drinking Water Quality [GB 5749-2006]

Scope: This national standard specifies the sanitary requirements for drinking water quality, drinking water source quality, central water supply organization, secondary water supply and health- and safety-related products, together with the water quality monitoring methods and water examination methods. It is applicable to all kinds of central drinking water supply and non-central drinking water supply in both urban and rural regions.
The standards replaced the Standard of GB 5749-85 "Sanitary Standards of Drinking Water". The main changes were increases in the number of parameters from 35 items of the Standard of GB 5749-85 to 106 items, adding 71 items and revising 8 items, including,

- the number of microorganism indices increases from 2 items to 6 items;
- the number of drinking water disinfectants increases from 1 item to 4 items;
- the number of inorganic chemicals in the toxicological indices increases from 10 items to 21 items;
- the number of organic chemicals in the toxicological indices increases from 5 items to 53 items;
- the number of sensory character and general physical-chemical indices increases from 15 items to 20 items; and the standard for turbidity is revised.

Regular Parameters			
Item	Limit	Item	Limit
1. Microorganism indices		3. Sensory character and general chemical indices	
Total Coliform Bacteria (MPN/100mL or CFU/100mL)	Shall not be detected	Color (Pt-Co Color Unit)	15
Thermotolerant Coliform Bacteria (MPN/100mL or CFU/100mL)	Shall not be detected	Turbidity (NTU-Nephelometric Turbidity Units)	1 or 3
Escherichia Coli (MPN/100mL or CFU/100mL)	Shall not be detected	Odor and Taste	No strange odor and peculiar taste
Total number of bacteria colony (CFU/mL)	Shall not be detected	Visible matter	None
2. Toxicological indices		pH (pH unit)	No less than 6.5 and no greater than 8.5
Arsenic (mg/L)	0.01	Aluminum (mg/L)	0.2
Cadmium (mg/L)	0.005	Iron (mg/L)	0.3
Chromium (six. mg/L)	0.05	Manganese (mg/L)	0.1
Lead (mg/L)	0.01	Copper (mg/L)	1.0
Mercury (mg/L)	0.001	Zinc (mg/L)	1.0

Selenium (mg/L)	0.01	Chloride (mg/L)	250
Cyanide (mg/L)	0.05	Sulfate (mg/L)	250
Fluoride (mg/L)	1.0	Total Dissolved Solid (mg/L)	1000
Nitrate (measured as N, mg/L)	10 or 20 (groundwater limited)	Total Hardness (measured as $CaCO_3$, mg/L)	450
Chloroform (mg/L)	0.06	Oxygen Demand (COD_{Mn} Method, measured as O_2, mg/L)	3 or 5 when oxygen demand of raw water is greater
Carbon Tetrachloride (mg/L)	0.002	Volatile phenol (measured as phenol, mg/L)	0.002
Bromate (When use Ozone, mg/L)	0.01	Anion Synthetical Detergent (mg/L)	0.3
Formaldehyde (When use Ozone, mg/L)	0.9	4. Radioactive Indices	Value for guidance
Chlorite (When use Chlorine Dioxide as disinfectant, mg/L)	0.7	Total α Radioactivity (Bq/L)	0.5
Chlorate (When use compounded Chlorine Dioxide as disinfectant, mg/L)	0.7	Total β Radioactivity (Bq/L)	1

- MPN means most possible number; CFU means colony forming unit. Escherichia Coli and Thermotolerant Coliform Bacteria shall be further tested when total Coliform Bacteria is detected in water sample. It is not necessary to test Escherichia Coli and Thermotolerant Coliform Bacteria when total Coliform Bacteria is not detected in water sample.
- Higher Turbidity standard used when conditions of water source and purification technologies are limited.

APPENDIX F QUALITY TESTING

Determination process of five indices tested daily in Kumul:

Total bacterial colony count

Nutrient agar was used to test the total bacterial colony count. Treated water from No.3 Water Purification Plant was sampled from the generator room of No.2 Water Purification Plant. First, the water sample needed to be sterilized. At the same time, nutrient agar was heated, lysed, and boiled on an electric furnace, then was cooled down to 45°C. Once all the preparation was done, the following process was done in the sterile room. One mL of water sample was added to a culture dish. Then nutrient agar was added until the face of the dish was covered by nutrient agar. The bacterial colony was counted after the dish had been kept in an incubator for 48h. For domestic consumption, the standard was no more than 100 counts in the water. For bottled water (purified water), the standard was no more than 20 bacterial colony counts.

Turbidity

Scattering turbidimeter was used to test the turbidity of water. Water from three sampling points (source water from the tank in the water allocating station and water from mechanical mixing tanks in No.1 and 2 WPPs) needed to be tested every two hours every day. The turbidity should not exceed 3 NTU.

pH

pH was measured weekly. An acidimeter was used to test the pH of water. The pH of Kumul's drinking water ranged between 7.9 and 8.0. The national standard is 6.5~8.5.

Total coliform group

This item was not being tested if the total bacterial colony count was within the standard value. Total coliform group was only tested when total bacterial colony count exceeded 100.

Residual chlorine

Residual chlorine was tested, using a Residual Chlorine Colorimeter through visual colorimetric method, immediately after a sample was taken at the site.%