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WATER SECURITY *in* PERI-URBAN SOUTH ASIA

Adapting to climate change and urbanization

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UNIVERSITY PRESS

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Published in India by
Oxford University Press
YMCA Library Building, 1 Jai Singh Road, New Delhi 110 001, India

First published by Oxford University Press India in 2016

ISBN-13: 978-0-19-946416-6
ISBN-10: 0-19-946416-2

Typeset in Adobe Garamond Pro 11/13
by Tranistics Data Technologies, Kolkata 700091
Printed in India by Rakmo Press, New Delhi 110 020

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Urban Growth and Regional Hydrology

Historical Evolution and Spatial Growth

Khulna is the third largest metropolitan city in terms of population (BBS 2011) and one of the five biggest river ports in Bangladesh, having a population of about 1.4 million (in 2011) within its administrative boundary of approximately 46 square kilometres. It is the central urban corridor of the south-west coastal region of Bangladesh because of its location and linkages with the regional towns and growth centres. Khulna is regionally and economically important for its proximity to the second sea-port of the country at Mongla. Population growth and socio-economic development in the south-west region are leading to new economic activities, industries, and human settlements in Khulna city and its surrounding areas, and changing their land-use patterns and local resources. Particularly, export processing activities based on shrimp farming are strengthening the economy of Khulna (Aqua-Sheltech Consortium 2002).

Khulna was set up as a *thana* (second lowest tier of administration in Bangladesh) in 1836, and later upgraded to a sub-division in 1842 and to a district in 1882. About half of this new district was part of the Sundarbans—the world's largest mangrove ecosystem. Khulna was declared a municipality in 1884, and was linked with the regional railway network in 1885. Finally in 1984, it was promoted as a city corporation. During the British rule (1700–1947), Khulna was a market town and the seat of regional administration, which attracted people from the surrounding areas to settle in the city. Historical demographic characteristics indicate that the population growth in Khulna has been fast (3.8 per cent per year) on an average, mainly due to rural–urban migration. The growth was particularly rapid during the post-partition (1947) and post-liberation (1971) periods. Population in the present metropolitan area was only 128 thousand in 1961, which increased to 468 thousand in 1974, 921 thousand in 1991, and 1.18 million in 1998. Although the population in Khulna was projected to increase to 1.57 million in 2015 and 1.65 million in 2020 (Aqua-Sheltech Consortium 2002), the most recent census (BBS 2011) indicates a decrease in population. This decrease might have occurred due to the increasing salinity and natural disasters in the region, and the closure of jute-based industries in the Daulatpur and Khalispur areas, where a large number of migrant labourers and their families used to stay.

Industrialization took off in Khulna in the 1950s and 1960s (Murtaza 2001). Industrial and commercial activities, particularly jute processing and trading, were accelerated after establishment of a river port at Chalna, located about 32 kilometres away. The city experienced economic stagnation in the late 1970s and 1980s due to public-sector investment policies and international market conditions, with an adverse impact on employment and the labour market. The economy started to regain momentum in the 1990s with shrimp farming, processing, and trading activities, and the establishment of a medical college, a university, and a technical institute, later upgraded to an engineering university (Aqua-Sheltech Consortium 2002).

In the light of the prioritized national development objectives of poverty alleviation, productive employment generation, human resource development, and infrastructure development, Khulna offers important contributions to the national economy. Although jute, steel, and newsprint industries have been declining, shrimp processing, cement, and fertilizer industries are growing at the outskirts of the city. Spatial growth of Khulna is largely guided by the local topography. The city originated at the southern end of a natural levee along the western side of the Rupsha-Bhairab River, and extended along the levee almost linearly in the north-west direction (Figure 1.1). Floodplains, back swamps, and tidal marshes unsuitable for human settlements exist beyond the levee, about 4 kilometres from the river. This growth pattern was further shaped by the construction of the Khulna-Jessore highway and the enhanced economic activities along the Khulna-Jessore corridor (Aqua-Sheltech Consortium 2002).

Despite the spatial growth and revamped economy, urbanization in the Khulna area has taken place at the cost of conversion of low lands and loss of waterbodies. The present urbanization and growth trends of Khulna indicate that the areas covered by waterbodies, low lands, and fallow lands are decreasing, whereas the built-up areas are increasing. It is projected that in 2019 the waterbodies and low lands in the present city area will reduce to 3 per cent and 29 per cent respectively and the built-up areas will expand to 33 per cent (Ahmed 2011).

The Master Plan of 1961 for Khulna city delineated an area of 181 square kilometres as the planning boundary, anticipating a high population growth with a moderate gross density of about 17,300 persons per square kilometre. However, after four to five decades, the average density has reached a much higher level in the Khulna City Corporation (KCC) and its adjoining areas, which resulted in a rapid growth of the city (see Figure 1.1). The present Master Plan (2001) covers a much larger area of 232 square kilometres, which is approximately half of the Structure Plan area of 451 square kilometres. The Detailed Area Plan of the present Master Plan envisages several development projects focusing on housing development and slum rehabilitation, which are likely to result in large-scale land conversion in the present peri-urban areas. This will eventually reduce

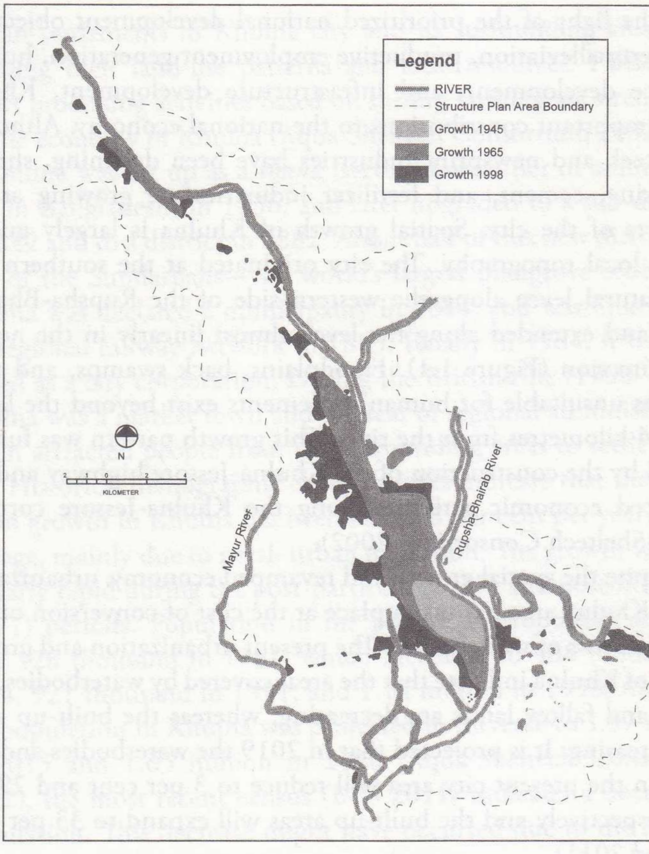

Figure 1.1 Spatial Growth of Built-Up Areas in Khulna City
Source: Based on maps by Aqua-Sheltech Consortium (2002).

surface water storage and groundwater recharge to deteriorate water insecurity in the area.

Lateral growth of Khulna city is likely to extend beyond the Rupsha-Bhairab River in the east and the Mayur River in the west. These two rivers are hydraulically linked through an intricate network of canals and waterbodies (Figure 1.1). Both rivers play important roles in trade, commerce, industries, livelihoods, and ecosystem sustenance in the urban and peri-urban areas. The Rupsha-Bhairab River is the main river link for transporting goods and providing services to the people and industries situated in the Jessore–Khulna urban corridor. The Mayur River also has economic, hydrological, and ecological significance in linking the Khulna area regionally.

The Mayur River

The Mayur River originates from Beel Pabla and Beel Dakatia, and drains into the Rupsha-Bhairab River near Alutala. The main branch of the river, having six tributaries and two distributaries, is about 11.7 kilometres long, and receives water from a drainage area of about 53 square kilometres. The average width of its main channel varies from 12 to 80 metres. Satellite images show that the course of the river has been shifting and as a result, its geo-morphological characteristics are changing over time. The present sinuosity (1.37) of the river indicates that it is no longer geo-morphologically active, and may become an abandoned channel in future. In addition to these natural trends, the dumping of solid wastes in the river and the construction of two regulators on it have reduced its carrying capacity and obstructed its natural tidal flow, which in turn have altered the hydro-morphology of the river.

The river is shared by the urban and peri-urban residents for various uses. Although it provides important ecosystem services and functions to the urban and peri-urban residents of Khulna, it has been facing severe threats due to unplanned and unregulated urbanization. Future projections indicate that it would be further affected by salinity intrusion and sea-level rise due to climate change. These compounding effects of climate change and urbanization will reduce water availability in the river and aggravate the water insecurity in the area.

Exogenous Stressors of Water Insecurity

Water insecurity in the Khulna area is largely constituted by a number of stressors related to urbanization, climate change, and regional and upstream interventions in the hydrological systems. Some stressors such as wastewater pollution and solid waste disposal originate locally due to urbanization, while others such as salinity intrusion and reduced upstream freshwater flow are the results of climate change or interventions in the flow regime.

Salinity and Water Pollution

Drinking water supply in Khulna city and its surrounding areas mainly depends on groundwater. However, the groundwater contains a relatively high level of salinity, which often makes the water unpleasant or unsuitable for drinking and domestic uses. Our analysis of the observed salinity levels in the groundwater represented by total dissolved solids (TDS) indicates that its salinity is generally higher during the dry season. Excessive groundwater withdrawal is partly blamed for increased salinity intrusion into the local aquifers. The hand tube wells (HTWs) installed in the upper aquifer become dry during the summer season (March–May). The presence of iron and arsenic in the upper aquifer groundwater in excess of drinking water standards is another constraint in its use. The Khulna Water Supply and Sewerage Authority (KWASA) can supply piped water to only 30 per cent of the urban population. The rest of the urban and peri-urban population depends on shallow HTWs, deep tube wells (DTWs), and surface-waterbodies such as ponds, *khals* (canals), and rivers.

The Mayur River is a vital source of water for agriculture, fisheries, and domestic and subsistence uses. This river is the main drainage channel for the eastern part of a coastal polder (no. 28/2). It also plays an important role in groundwater recharge. The Mayur was a vigorous river about thirty years ago. Trawlers and gigantic country boats used to ply the river with passengers and goods. However, over the years, it has lost its natural flow regime and transportation route due to a number of human interventions. The disposal of solid wastes and the discharge of wastewater from the urban areas have severely degraded the carrying and assimilation capacities of the river. The discharge of the untreated wastewater from the city through about twenty outfalls and the dumping of solid wastes from nearby slaughter houses, markets, bus-terminals, hospitals, clinics, automobile factories, and industrial units are filling up the river and increasing its pollutant loads. A large slaughterhouse is located on its bank at the Gallamary bus station from which the wastewater is directly discharged into the river without any treatment. Besides, the construction of another slaughterhouse by the KCC on the river bank is underway. Further, encroachment of the river is severely reducing its width in many places. The natural tidal flow is also lost due to the flow regulation through two regulators on the river, constructed during 1982–3 by the Bangladesh Water Development Board (BWDB). The regulators are not operated properly and sometimes their operation is controlled by the local muscle-powers and elites for their fishing activities. The condition of the river has so deteriorated that it now looks like a wastewater channel at many points including Rayermahal, Gallamary, and Shashanghat. At Gallamary point, the river depth is hardly above 0.3 metres.

The water in the Mayur River is too polluted to support aquatic life and livelihoods round the year. Our analysis of water quality indicates that the dissolved oxygen (DO), biochemical oxygen demand (BOD), TDS, and salinity levels along almost the entire length of the river do not meet the recommended standards for the drinking and irrigation water quality guidelines set by the Department of Environment (DoE) of Bangladesh and the World Health Organization (WHO). During the dry season, the pollution of the river rises drastically with the fall of its water level, which completely depletes the fisheries and other aquatic resources, resulting in significant impacts on the livelihoods of the peri-urban poor.

The growing land-developing businesses in Khulna are also responsible for filling up of the open waterbodies in the peri-urban areas. Competition among different user groups in the urban and peri-urban areas for the scarce water resources increases as urbanization increases the domestic and industrial water demands and reduces the surface and groundwater resources. This competition has created complex water-use conflicts among the urban and peri-urban residents. Our observation indicates that the nature and dynamics of these conflicts are governed by various social, economic, and political factors, and are visible in three major ways. First, urban wastewater flow limits freshwater availability in both urban and peri-urban areas, and creates water use conflicts between the urban and peri-urban residents as well as among the urban residents themselves. Wastewater flow from a few industries in the peri-urban areas adds to river pollution. Second, urban water supply is planned to be augmented by transferring groundwater from peri-urban areas. This water transfer plan, presently postponed, was protested against by the peri-urban residents because it would severely deplete their local groundwater. Third, culture fisheries, practised in the peri-urban stretches of the Mayur River and adjoining areas, require saline water whereas agriculture requires freshwater. Urban elites, who own most of the fish farms, influence the control of saline water flow through the downstream regulator at Alutala, limiting freshwater availability for peri-urban agriculture.

Climate Change and Regional Interventions

Khulna is located in the tropical climate zone and has a tropical monsoon climate. It has been identified as one of the 15 most climate change vulnerable cities in the world (IIED 2009). Cyclone, storm surge induced flooding, riverine coastal flooding, waterlogging, salinity intrusion, and coastal erosion are the main hydro-climatic hazards in the area. The cyclones Sidr in 2007 and Aila in 2009, two extreme events that are believed to have originated within a short period of time due to climatic changes, caused widespread damage to property and livelihoods. Commissioning of the Farakka Barrage on the Ganges River in India in 1975 has reduced the freshwater inflow to the region through the Gorai River system. Further, construction of the coastal embankments and polders has gradually reduced the floodplain storage areas for the tidal waters flowing from the Bay of Bengal.

The global sea level is projected to increase by 35 centimetres (23–47 centimetres) at the end of this century (2090–9) from the base level (1980–99) in the A1B emission scenario of the Intergovernmental Panel on Climate Change (IPCC) (2007). However, the distribution will not be uniform due to ocean density and circulation changes. The rise along the Bangladesh coast could be 0–5 centimetres more than the global average. Spatial coverage and temporal duration of salinity in the coastal areas of Bangladesh would also increase due to this sea level rise. The isohaline (points representing equal magnitude of salinity) of 5 parts per thousand (ppt) could move about 9 kilometres farther inland during the dry season due to a sea level rise of 32 centimetres (Rahman et al. 2007). The inundated area could also increase by about 11 per cent due to 88 centimetres rise in sea level. Other estimates indicate that the average sea level rise along the Bangladesh coast would be 10 centimetres (5–14 centimetres) by 2020, inundating 2,500 square kilometres or

2 per cent of Bangladesh. This would increase to 25 centimetres (11–34 centimetres) in 2050, inundating 6,000 square kilometres or 4 per cent of the country. By the end of the century, the sea level rise would be 1 metre, inundating 18 per cent of the land area (Nelson 2003).

The urban and peri-urban areas in Khulna are relatively flat—on an average only 2.5 metres above the mean sea level (msl)—and poorly drained, and experience frequent cyclones. In future, the poor and vulnerable people in Khulna will face the effects of climate change in three major ways: (i) sudden onset events such as floods and cyclones, (ii) slow onset processes such as coastal erosion and salinity intrusion, and (iii) cascade effects such as aggravation of existing problems by straining overstretched public services (Roy et al. 2013). Huq et al. (1995) examine the effects of a 1-metre rise scenario and identify Khulna district as one of the three most vulnerable districts in Bangladesh, with about 80 per cent of the area prone to inundation affecting 3 million people. Aggravated flooding, salinity intrusion, and storm surges are identified as other consequences of the sea level rise. Hanson et al. (2011) rank Khulna 13th among the 20 most vulnerable port cities on the basis of a combined consideration of climatic and socio-economic changes. This ranking also projects the risk of population exposed to coastal flooding due to sea level rise and storm surge in 2070, and finds Khulna at the 6th place, seeing more than 700 per cent increase in exposure. In terms of damage as a percentage of overall gross domestic product (GDP), Hallegatte et al. (2013) rank Khulna 8th among the 10 most vulnerable coastal cities.

Apart from forced migration, the secondary effects of the sea level rise would include adverse impact on socio-cultural conditions, land productivity, livelihood, nutrition, and health (Nelson 2003). Even if the climate remains unchanged and the population grows at 1.4 per cent per annum, the population at risk will be 6.8 and 12.7 million in 2025 and 2050 respectively (BBS 2005). At this growth rate, 11.1 million people will be at risk for an average climatic condition in 2050 (Karim and Mimura 2008). These anticipated effects of climate change compounded by the reduction in the upstream flow during the dry season and the interventions in the regional floodplain with embankments and polders are likely to have significant impact on the water resources in the Khulna area.

The variation of water level in the Rupsha-Bhairab River has direct implications for the surface water availability and drainage in the Khulna area. Our analysis of tidal water levels of the river at Khulna for a period of 74 years (1937–2010) indicates that the annual maximum high tidal water levels are increasing at a rate of 18 millimetres per year and the annual minimum low tidal water levels are decreasing at a rate of 8 millimetres per year (see Figure 1.2). Both these trends are statistically significant at a confidence level of 99 per cent. This increasing trend in the tidal range is an indication of tidal

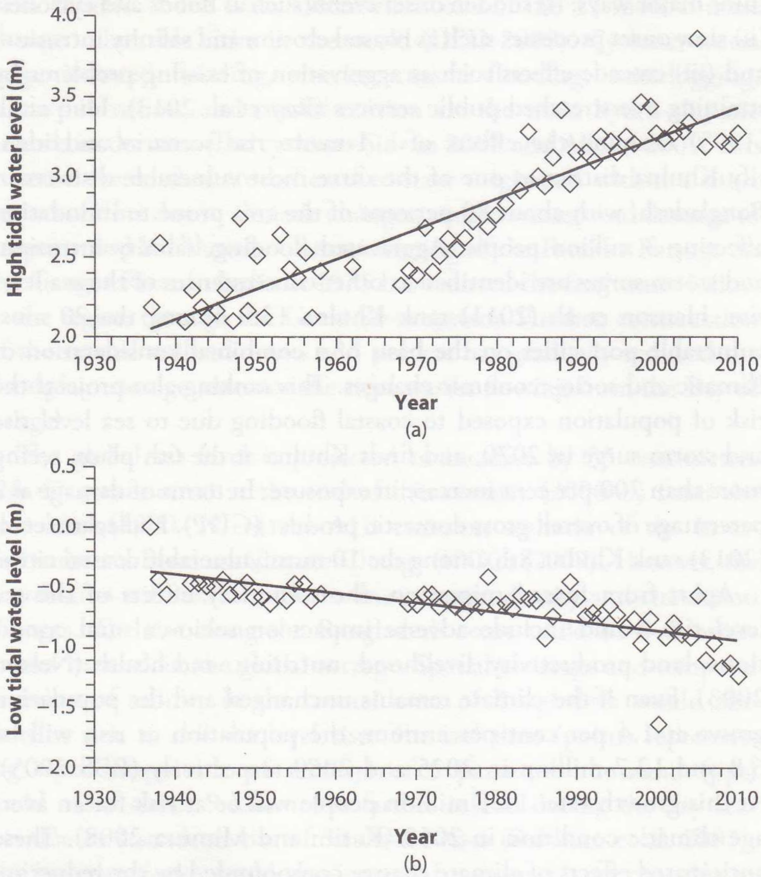

Figure 1.2 Trends in Annual Extreme Tidal Water Levels in the Rupsha-Bhairab River at Khulna: (a) Maximum High Tide and (b) Minimum Low Tide
Source: Authors' analysis.

amplification, most likely caused by the cumulative effects of polderization and river sedimentation. As the BWDB measuring station at Khulna is located at a distance of 125 kilometres inland from the coast, the data for the Bangladesh Inland Water Transport Authority (BIWTA) station at Hiron Point, which is only 11 kilometres inland from the coastline, were also analysed for a period of 33 years (1977–2010) to see the trend in tidal water levels at the coast. The trend in the annual maximum water level is found to be increasing at a rate of 7 millimetres per annum and that in the minimum water level to be decreasing at 4 millimetres per annum. The increasing trend is significant at 80 per cent level of confidence and the decreasing trend at 90 per cent level of confidence. This indicates that the tidal amplification is relatively larger at an inland location, which possibly also includes the effects of sea level rise.

The possible reasons for the decreasing trends in the annual minimum water levels at both Khulna and Hiron Point could be the reduction in the freshwater flow from the upstream areas, or the reduction in the storage areas of the saline tidal water, or both. The increasing trends in the annual maximum water levels could result either from silting up of the rivers, reduction in the flood tide propagation areas, or a rise in the sea level, or a combination of these factors.

However, if sea level rise had any effect on the observed trends, the effect had been much lower than that of anthropogenic interventions as the high and low tidal levels have significant opposite trends. The rising trend in the high tidal water level can be explained by a sea level rise phenomenon but not the falling trend in the low tidal water level. About 40 polders with 1,566 kilometres of embankments and 282 drainage sluices, encompassing an area of 411 thousand hectares, were constructed in the Khulna-Jessore region under the coastal embankment project during the 1960s and 1970s with the financial assistance from the United States Agency for International Development (USAID). The time series data on flood control, drainage, and irrigation coverage reveals that the coverage has increased to 477,116 hectares in 1993 from 0 in 1956 in the Khulna district. The embankments constructed denied the entry of the tidal waters into the polders. As a result, the heavy loads of silt carried by the tides settled on the river beds, which gradually rose above the levels of the lands within the polders and closed the exits of the sluices.

Simultaneously, subsidence continued within the polders without having compensating silt deposits. These led to severe drainage congestion in the coastal areas, particularly in polders 24, 27, and 28, during the 1990s. These coastal polders and the Farakka Barrage had contributed to the gradual siltation of the coastal rivers and are the principal factors contributing to the tidal water level extremes. A comparison of the multi-year bathymetries of the Rupsha-Bhairab River supports these arguments.

Upstream Interventions

The Gorai River is the principal distributary of the Ganges River on its right bank, inside Bangladesh. Its flow is the major source of freshwater for southwest Bangladesh during the dry season to check saline water intrusion from the Bay of Bengal, to prevent siltation in the regional rivers, to maintain navigational depth, to sustain the mangrove ecosystem of the Sundarbans and to provide irrigation water for agriculture. However, due to diversion of the water from the Ganges River with a barrage at Farakka inside India since 1975, the dry season flow of the Gorai River has reduced significantly. For instance, the long-term variation in annual minimum flow indicates that such flow reduced to almost nil immediately after commissioning of the barrage in 1976. Yet it was not until 1981 that the effect of the withdrawal became very prominent. The average lowest flow was about 110 cubic metres per second (m^3/s) till 1980 and it came down to only about 10 m^3/s during the period 1981–98. The off-take of the Gorai was silted up due to the reduction in inflow from the Ganges. Towards the end of 1996, Bangladesh and India signed a treaty to share the Ganges flow. The treaty became effective in January 1997 and established the circumstances for restoration of the Gorai flow. A 20-kilometre reach of the river from its off-take was dredged after the monsoon season of 1998 and maintenance dredging was continued for another two years. The three-year dredging removed about 18.5 million cubic metres of sediment from the river (Groot and Groen 2001). This resulted in an increase of the annual minimum flow to about 45 m^3/s during the years 1999–2008. In the end, the dredging of the river could restore only about 42 per cent of the natural minimum flow and that was even on a temporary basis.

The minimum flow in the last three years became almost nil. The disruption to the natural flow regime of the Ganges in the upstream with the Farakka Barrage has caused significant adverse effect on the flow regime and morphology of the Gorai.

The Rupsha-Bhairab River still has a connection to the Gorai River and receives freshwater supplies. The Gorai River flow pushes away the saline water front in the Rupsha-Bhairab near Khulna (Mirza 1998). The analysis of the river water salinity near Khulna using a data set of 34 years (1975–2008) shows a higher salinity during the high (flood) tide compared to that during the low (ebb) tide. There is a negative correlation between the Gorai River flow and electrical conductivity (EC) in both the tidal cycles. The correlations are statistically significant at 95 per cent confidence level during the months of February to May. The highest correlation coefficient in the high tidal cycle was found to be -0.68 in March and that in the low tidal cycle was -0.64 in April, both the correlations being statistically significant at 99 per cent level of confidence. In sum, when the Gorai River flow was high, the river water salinity in Khulna was low. This inference is also supported by the difference of EC values between the pre- and post-dredging situations of the Gorai. The EC values became lower due to the dredging of the river after the monsoon season of 1998.

Peri-urban Characteristics

The predominant characteristics of the peri-urban areas in Khulna are heterogeneity in land use, mixed institutional arrangement, diversity in livelihood options including dependence on urban resources, urban–peri-urban hydrological linkages, urban–peri-urban water use nexus, and vulnerability to water stress. These characteristics were identified through participatory rural appraisal (PRA) on the basis of the issues raised by primary and secondary stakeholders, and the information gathered from literature review. Three peri-urban sites, Chhoto Boyra, Labonchara, and Alutala (see Figure 1.3), were selected to study more closely the social and demographic profiles, institutions and governance, vulnerabilities, and impacts of urbanization and climate change. Tables 1.1 to 1.3 present a summary of basic information on these sites. Most of the existing civic facilities

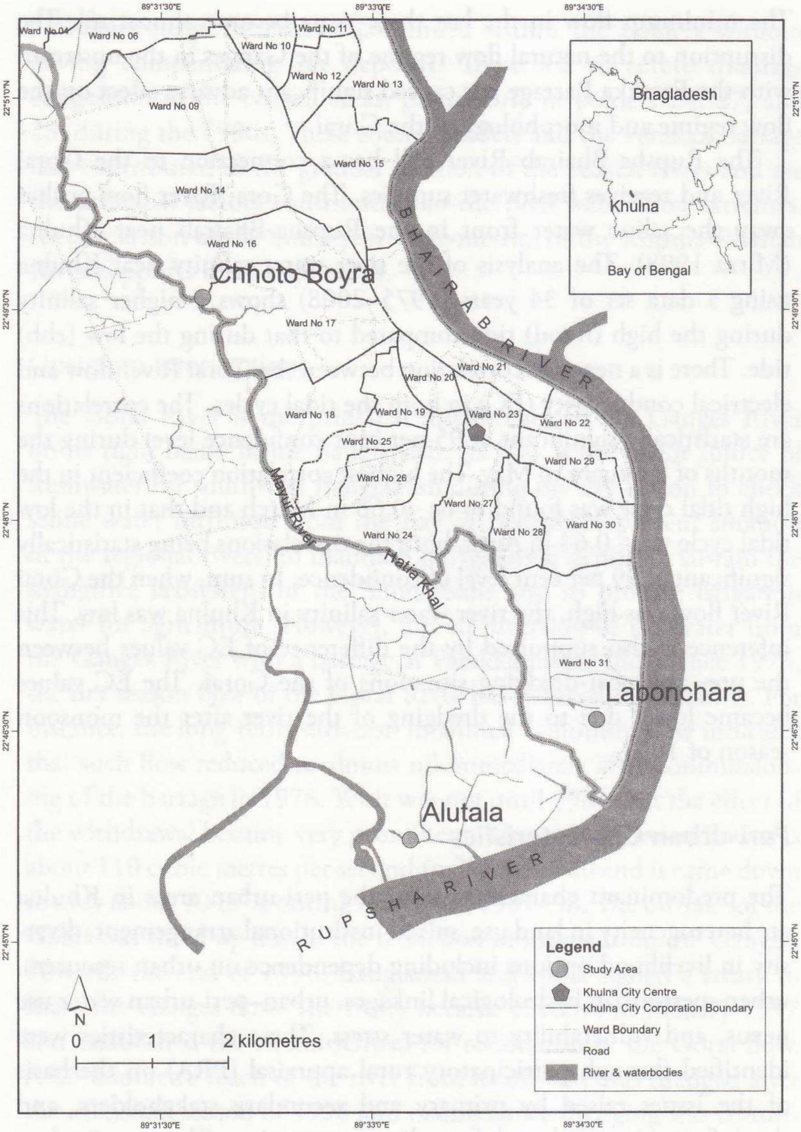

Figure 1.3 Location of Research Sites in Khulna
Source: Authors.

Table 1.1 Summary of Basic Information of Research Locations

	Chhoto Boyra	Labonchara	Alutala
Population	About 5,000	About 3,000	About 3,000
Households	About 1,000	About 500	About 500
Literacy rate	>70%	>80%	>50%
Occupation	Service: 80%, Agriculture: 5% and Informal business/job: 5%	Service: 20%, Daily labour: 50%, Business: 30%	Agriculture: 95%, Others: 5%
Land use	Settlements: 95%, Agriculture: 5%	Settlements 95%, Agriculture 5%	Agriculture dominant
Water sources	Drinking and domestic: 100% DTW, Agriculture: 100% surface water or rainwater, Livestock: 100% DTW	Drinking and domestic: 100% DTW, Irrigation: canal water	Drinking and domestic: 100% DTW, Irrigation: surface water by low lift pump (LLP)
Water supply coverage	KCC pipe connection: very little (10–20%) and the supply is not reliable. Local people use community/private DTWs	No KCC coverage	No KCC coverage (100% through private or community DTW)
Drainage facility	Inadequate	None	None (not essential)
Solid waste management facility	Inadequate	Institution absent	Institution absent
Sanitation coverage	Sanitary/Pucca: 95%, Semi-pacca: 5%	Sanitary/Pacca: 50%, Semi-pacca: 50%	Electricity coverage: None, solar panels widely used Cooking: Biomass fuel 100%

(*Cont'd*)

Table 1.1 *(Cont'd)*

	Chhoto Boyra	Labonchara	Alutala
Energy source	Electricity coverage: 100% Cooking: biomass fuel 95% liquefied petroleum gas 5%	Electricity coverage: 100% Cooking: Biomass fuel 100%	Saline water
Major water issues	Pollution and degradation of the Mayur River, waterlogging	Waterlogging and water-borne diseases	Government family planning services, Microcredit organizations, Cyclone shelter cum primary school
Major institutions	Forest office, Fisheries office, Medical college, Nursing college, Women's college, Boys' college, Education institute, Community organization	Rapid Action Battalions' head quarter, Naval office, Police camp, Jute mills, Ice mills, Automated rice mills, Fish processing industry, Bon mills, Fish meal mills, Paper-board mills	Under local government (Jalma Union under Botiaghata Upazilla)
Administrative system	Under Ward No. 16 of KCC, and Botiaghata Upazilla (west side of the Mayur River)	Under Ward No. 31 of KCC	

Source: Field survey, 2011–12.

in Alutala, situated outside the jurisdiction of the KCC, are in poor condition. The people in Alutala, in general, are suffering from a deteriorated road network, inadequate water supply, lack of educational facilities, and absence of electricity coverage. On the other hand, the absence of solid waste management and of drainage and sewerage facilities is one of the major problems in Chhoto Boyra.

More detailed baseline data collected through a household survey at these peri-urban sites were analysed to understand a wide range of issues including demography, socio-economic conditions, water-related vulnerabilities, urbanization impacts, and climate change implications. The methodology of the household survey can be found in the Introduction. The age of male respondents ranged from 18 to 85 years and of female respondents from 18 to 70 years with mean ages of 42 and 36 years respectively. About 18 per cent male and 16 per cent female respondents were illiterate. The main occupations of the male respondents were based on business, agriculture, service, and labour. The female respondents were mostly housewives. The proportion of migrants was about 37 per cent of both male and female respondents. The causes of migration varied between them. For the men, the major reasons for migration include opportunities to own land or a house, and opportunities for better urban facilities and employment or livelihood. For the women, opportunities to own land or a house and the low cost of living in the peri-urban areas are among the major reasons for migration. Most surveyed households are nuclear with an average size of 3.5, which is similar across the sites. About two-thirds of the total population comprise non-earning members due to age consideration, disabilities, and so on. They are dependent on the earning members of their families. The percentages of working age and earning people at Chhoto Boyra are significantly higher than those of the other two sites. The occupational pattern of household members varies across the sites. For instance, agriculture-based occupations are mostly concentrated in Alutala, which is predominantly rural. On the other hand, local labour, private service, and small businesses are the major occupations in Labonchara. In Chhoto Boyra, major occupations are service and (mostly small) businesses. Occupations such as housewife and student are more or less similar across the sites.

A poverty assessment based on average monthly household income indicates a significant difference in income among the sites. In Alutala, Labonchara, and Chhoto Boyra it is Bangladeshi taka (BDT) 5,350, 7,567, and 15,338 respectively, whereas the overall average is BDT 9,036. At these three sites, about 45 per cent of the households are living below the United States dollar (USD) 2 purchasing power parity (PPP) poverty line. The poverty situation is severe in Alutala where about 75 per cent of the households (84 per cent of the population) are living below the poverty line. Although a similar poverty situation is seen in Labonchara and Chhoto Boyra, the income difference between these sites indicates a prevalence of extreme poverty in Chhoto Boyra.

The amount of land owned by the households in Chhoto Boyra is significantly lower than that in Labonchara and Alutala, while ownership of agricultural land is significantly concentrated in Alutala. The households in Alutala own a higher amount of agricultural land than those at the other two sites. However, the amount is so little that most of the households depend on agriculture lease of land for cultivation. Apart from rainwater, a nearby stream/river (42 per cent of total), and groundwater (8 per cent of total) are the main sources for irrigation.

Construct of Vulnerability: Differential Exposure and Capacity

Peri-urban communities in Khulna are vulnerable to water insecurity because of their exposure to different stressors of climate change and urbanization, which have direct or indirect implications for water security, and the lack in their capacity to mitigate the impacts. The water insecurity implications are generally derived in terms of livelihoods, health, and quality of life. Vulnerability arises from the lack of access to different forms of capital that are mobilized in the pursuit of livelihoods, and the inability of the communities to mobilize institutions to face these adverse conditions. Vulnerability of the peri-urban communities in Khulna varies across the sites as well as gender and different groups within the communities. In the following discussion, we focus on the factors that shape the differential vulnerabilities of water users in Khulna.

Urbanization is sustained mainly by the acquisition and conversion of agricultural land and waterbodies in the peri-urban areas. As the ownership and use of the land change, the process of land conversion as well as tenancy adversely affects the availability of water, the access to it, and its quality in these areas. These ultimately lead to stresses on the lives and livelihoods of the peri-urban communities. In peri-urban Khulna, urbanization has altered land entitlements, and water access and rights. At the same time, contestation for peri-urban resources has created conflicts and undermined community resilience. This is evident from the consequences of urban land development projects buying peri-urban lands in Chhoto Boyra, or urban elites taking control over peri-urban water resources in Alutala. Urbanization has also altered the peri-urban biophysical systems and processes. Urban wastewater and solid wastes have degraded the common waterbodies such as the Mayur River and the local environment. Climate change impacts have aggravated the existing urbanization impacts such as temperature rise and groundwater decline from excessive withdrawal and reduced recharge.

Mass migration from areas hardest hit by frequent disasters is also a dominant demographic element of construction of peri-urban communities, which is always likely to increase, and at worst, may bring about further social instability in both sending and receiving areas (Raleigh et al. 2008). Environmental migration shapes and reshapes processes of peri-urban Khulna. As a large number of migrants settle in peri-urban areas, contestation for the limited resource base and livelihood opportunities create additional stresses on different capitals. Despite these adverse conditions, we found that the original residents in Khulna in general support in-migrants with shelters and daily necessities. Migrants, who are able to establish networks and social contacts, are benefitting from this integration into Khulna's informal economy. However, environmental migrants still remain socially and economically disadvantaged, lacking in skills and facing wage underemployment. While men can find casual daily-labour work, women find it much harder to be economically active with respect to income generation (Roy et al. 2013).

Relatively high levels of physical vulnerability or exposure are evident in low-income settlements of Khulna, which varies in nature and extent both within and across the settlements. Our analysis of climatic data suggests that these vulnerabilities will aggravate in future. Roy et al. (2013) found five dominant forms of physical vulnerabilities in this area. First, close proximity of Khulna to the coast poses a high risk of groundwater salinity. The risk is higher in low-income settlements where people commonly depend on groundwater from shallow tube wells at an elevated risk of passive sodium intake. Second, peri-urban settlements are situated at low elevations, which expose them to a high risk of inundation and waterlogging. Poorly designed and maintained drainage systems along with indiscriminate disposal of solid waste in the drains add to frequent and prolonged waterlogging. Third, poor sanitation and unhealthy environment in low-income settlements, and inadequate and poorly constructed community latrines have resulted in long waiting times. Consequently, many households have constructed 'hanging latrines' over canals and ponds, which discharge raw sewage directly into the waterbodies. Fourth, poorly constructed dwellings have low resistance to cyclones and minimal insulation against heat or cold, and most of them cannot provide protection against heavy rainfall. Fifth, narrow lanes and highly concentrated settlements often result in conflicts among neighbours, and poor provision of ventilation and light. Narrow lanes are also unsuitable for emergency evacuation and rescue operations. In the following discussion, we highlight these variations in vulnerability across and within the sites, and how these are constituted at different levels of exposure and capacity, focusing on three major areas around which the vulnerabilities are evident.

Drinking Water Supply

Peri-urban communities in Khulna are primarily vulnerable to the unavailability of freshwater for drinking and domestic uses. Since most of the surface water and groundwater sources are polluted or saline, they have to look for distant sources to collect water. The degree of this burden of water collection varies across economic classes and among men, women, and children. In the urban areas, the drinking water supply system is entirely based on a groundwater resource. The KWASA serves only 30 per cent of the urban population through a piped distribution system, the rest of the population depends on personal or community-based HTWs.

Among the peri-urban areas, Alutala has public tube wells installed by government organizations as the only primary source of water for drinking and cooking. In Labonchara, people collect water from public tube wells as well as private hand pumps for drinking and cooking. In Chhoto Boyra, the major source of water for domestic consumption is private hand pumps. The primary sources of water for bathing and washing are similar to those for drinking and cooking in Labonchara and Chhoto Boyra. However, in Alutala, people collect water from nearby ponds, canals, and the river for washing and bathing. In general, groundwater is the major source of water for domestic uses, whereas surface water from the river, canals, and ponds are the major sources for agriculture, fisheries, and subsistence uses, particularly in Alutala and Labonchara.

Although the drinking water supply is groundwater-based, the shallow aquifer of the region contains relatively high EC and sodium-ion concentration. Accordingly, the water quality of the shallow aquifer is quite unsatisfactory and does not meet the guideline values for drinking water recommended by the DoE of Bangladesh and the WHO. However, the quality of the groundwater of the deep aquifer does meet these standards. The quality of water from the public tube wells also varies across the sites. The quality is relatively better at Alutala than at Chhoto Boyra and Labonchara. Scarcity of drinking water is becoming more severe in the peri-urban areas due to the encroachment of waterbodies and the increasing salinity in surface and groundwater.

Calculation of a household-water stress indicator for drinking and cooking, based on the distance, number of daily trips, and time spent in fetching water from the primary water sources, indicates that water stress in Alutala, where most households live below the poverty line, is significantly higher than in Labonchara and Chhoto Boyra. The average distance to public tube wells, the only primary source of water for drinking and cooking, is relatively high in Alutala. The correlation between total household income and water stress is found to be negative and statistically significant, indicating that households with a lower income tend to be faced with a higher water stress. This would mean that the economic condition of a household is found to be a primary factor in driving water stress in the peri-urban areas of Khulna. The female members of a household are mainly responsible for fetching water for domestic uses, irrespective of the peri-urban site. As such, they face a higher stress in fetching water than their male counterparts. In addition, female household members in Alutala or Chhoto Boyra are facing a significantly higher water stress than in Labonchara, due to the larger distance to the source of water and the poor economic condition of households in the former case.

Water Pollution

Surface water pollution is a major reason behind water insecurity in the Khulna area. Peri-urban communities, particularly those dependent on the Mayur River and other polluted water sources are extremely vulnerable to degrading water quality. Although urbanization brought new opportunities, through socio-economic development, for some people who had lived in the peri-urban areas, urban abuses and unplanned development activities have downgraded the existing water resources through pollution, physical encroachment, and quality deterioration. The peri-urban residents often mention that the urban wastewater and solid waste are the two major causes of water pollution in the natural channels and rivers. Indeed, unwise discharges of wastes and wastewater from the city areas are polluting the surface waterbodies in the city and its surroundings. At present, about 240–60 tons of solid wastes are generated daily within the KCC area, which is disposed of in the unplanned landfills and low-lying areas around the city, causing severe environmental and health problems in the peri-urban areas.

Wastewater generated in the city is discharged into the Mayur River, an open waterbody shared by the peri-urban residents, through 22 open drains. The pollution of the river's water limits the livelihood opportunities based on agriculture and aquaculture that previously existed in the peri-urban areas. The aquatic environment is severely degraded in Chhoto Boyra, where a major outfall discharges urban wastewater into the Mayur River. Salinity, iron, and arsenic at Chhoto Boyra, salinity and arsenic at Labonchara, and salinity, arsenic, and iron at Alutala are the major quality concerns in using the water. Waterlogging, a major problem in both Labonchara and Chhoto Boyra in the event of heavy and continuous rainfalls, also causes pollution of local surface waterbodies. Other major sources of water

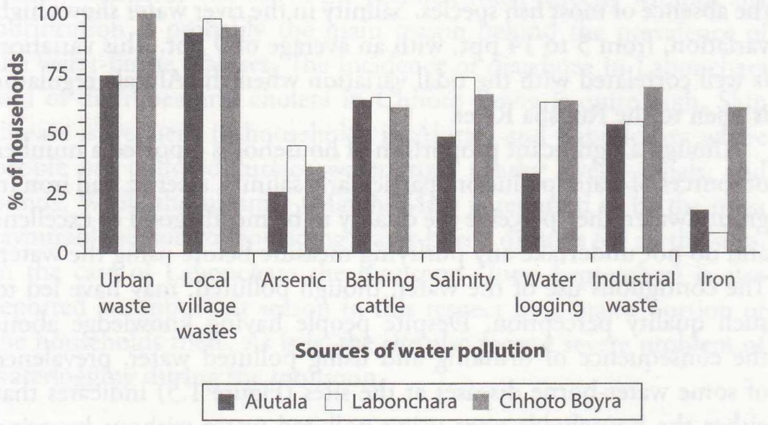

Figure 1.4 Sources of Water Pollution in the Peri-urban Sites
Source: Computed from household survey data, 2011–12.

pollution include industrial wastes and bathing of cattle (Figure 1.4). In addition, salinity intrusion and arsenic contamination in groundwater are also reducing water access and security in the region.

The pollutant load in the Mayur River is largely contributed by urban wastewater and solid waste. Our assessment of the physico-chemical characteristics of the wastewater flowing into the river from the KCC area, through collection of wastewater samples from 10 spots on the drainage network at monthly intervals, and analysis of 15 water quality parameters, revealed that the pH (power of hydrogen) values were within the permissible limit for re-use in agriculture. The DO levels were found to be below the permissible level recommended for irrigation. The EC and TDS values exceeded the irrigation water quality limits at a few spots. Some anion and cation concentrations were higher than the irrigation water quality limits. In sum, the wastewater is not totally safe for re-use in agriculture, and may pose threats for health, sanitation, and the environment.

Our analysis of the hydrochemistry of the Mayur River indicates that the river is overwhelmed with pollution, and the localized pollution is increasing rapidly due to stagnation and drainage congestion. Dissolved oxygen in the river water ranges from 0.9 to 4.8 milligrams per litre (mg/L), whereas at least 5 mg/L is essential to maintain healthy aquatic life, and a DO level less than 3 mg/L is indicative of the absence of most fish species. Salinity in the river water shows high variation, from 5 to 14 ppt, with an average of 9 ppt. This variation is well correlated with the tidal variation when the Alutala regulator is open to the Rupsha River.

Though a significant proportion of households reported a number of sources of water pollution, particularly salinity, arsenic, and iron in groundwater, they perceive the quality to be mostly good or excellent and do not undertake any purifying measure before using the water. The contiguous use of the water, though polluted, may have led to such quality perception. Despite people having knowledge about the consequence of drinking and using polluted water, prevalence of some water-borne diseases at the sites (Figure 1.5) indicates that either the households were using polluted water without knowing that the water was polluted, or they were forced to use the water since they did not have access to an alternative source. Although the perceived quality of water is satisfactory, our study on the quality of groundwater—the major source of drinking water supply in the project sites—revealed that the quality was quite unsatisfactory and failed the standard guideline values for drinking water of the DoE, Bangladesh, and WHO. Sodium, potassium, and EC levels, particularly in shallow aquifer, mostly exceeded the drinking water

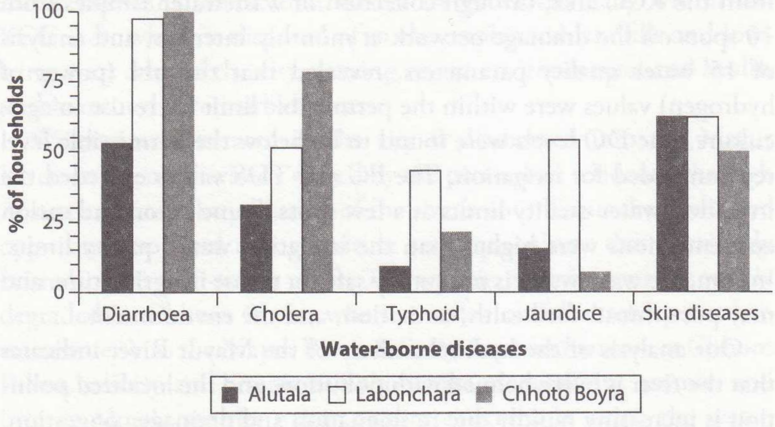

Figure 1.5 Incidence of Water-borne Diseases in the Peri-urban Sites
Source: Computed from household survey data, 2011–12.

quality standard. The use of the polluted water directly without any purification is probably the main reason behind the prevalence of the water-borne diseases. The incidence of diarrhoea in Labonchara and of diarrhoea and cholera in Chhoto Boyra is quite high. Skin disease is frequent in households in Alutala and Labonchara where people use polluted surface water from nearby rivers, canals, and ponds. While the summer (March–May) is reported to be the most favourable season for spreading water-borne diseases for all the sites, in the case of Labonchara the monsoon (June–September) is also reported an important season in this respect by a major portion of the households there. As it is, the site also faces a severe problem of waterlogging during the monsoon.

Differential Urbanization Impacts

Perception of urbanization rate varies across as well as within the sites. In Alutala, the urbanization rate is perceived to be slow to medium while that in Labonchara is medium. On the other hand, the urbanization rate in Chhoto Boyra is perceived as medium to fast. There is not much difference in the perception of the urbanization rate between the male and female respondents of a site. Moreover, the perceptions of the impacts of urbanization on various aspects are found to be similar between men and women within a site. However, some variations in perception are found across sites. In general, urbanization is recognized as a deteriorating factor for water quality and land use.

Urbanization in Alutala is largely seen as a positive factor having potential beneficial impacts on income, civic facilities, and quality of life, whereas in Chhoto Boyra it is seen to have adverse impacts on these aspects. Most of the civic facilities in Alutala, which is outside the jurisdiction of the KCC, are either in poor or very poor condition. People in Alutala, in general, suffer from a deteriorated road network, inadequate water supply, lack of education facilities, and absence of electricity coverage. On the other hand, lack of a solid-waste management system, as much as drainage and sewerage facilities, are among the major problems in Chhoto Boyra. Overall, there are significant negative correlations between a perceived urbanization rate and civic facilities (-0.18), standard of life (-0.15), and kinship (–0.16), indicating that increasing urbanization has negative impacts. Although not significantly, employment opportunity is found to be positively correlated with perceived urbanization. A major impact of the urbanization has been on the water resources in these peri-urban sites (see Figure 1.6). Water pollution and increasing water demand are the major problems caused by urbanization. These sites are also facing encroachment of waterbodies including the Mayur River, which is relatively severe in Chhoto Boyra and Labonchara.

Membership of a social network or government organization and connection to political leadership are usually seen as contributing factors to community resilience. No member of the peri-urban households interviewed was found to be a member of the local government at the time of the survey. Some households do have some contact with local, influential persons. The households in Labonchara are more in contact with influential persons than in Alutala and Chhoto Boyra.

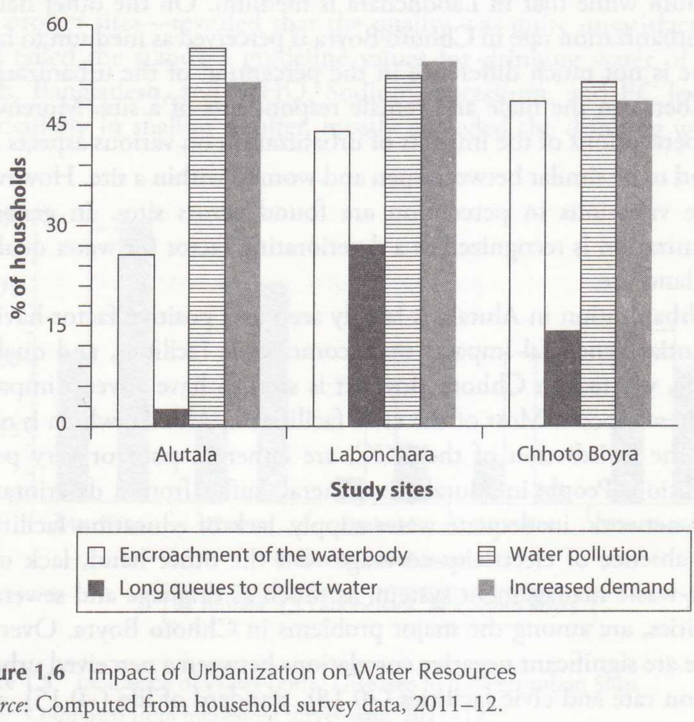

Figure 1.6 Impact of Urbanization on Water Resources
Source: Computed from household survey data, 2011–12.

Though most households have friends in the city, not all of those with friends there can depend on those friends during a crisis. Particularly the households living in Chhoto Boyra are less likely to depend on their city friends at a time of emergency. Virtually no household is affiliated with any organization that could assist them when needed.

Climate Change Implications: Interpretation of Hydro-meteorological Data and People's Perception

Climate change is commonly represented by changes in the climatic data observed at meteorological stations. Impacts of these changes on different elements of biophysical systems are inferred from an analysis of long-term trends and the variability in these climatic variables, while statistical parameters of the analysed data-sets give an indication of the significance or reliability of the trends and variability. These impacts can be further interpreted in the local peri-urban contexts to assess their environmental, social, economic, health, and daily-living implications that relate to water insecurity. However, these observed climatic changes and their physical interpretations may differ from the perceived changes and lived experiences of the peri-urban communities. These differences occur because people do not perceive climatic changes separately but only as causes of changes in their lives and livelihoods. These perceptions may be influenced by the degree of their vulnerabilities and other changes such as urbanization.

In this section we first analyse the observed changes in basic climatic variables, then take an account of the perception of peri-urban communities of these changes. Finally, we compare and interpret these observed and perceived changes to derive probable implications for the peri-urban communities.

Temperature

Analysis of historical climatic data (1948–2010) indicates that the temperature in the area is increasing at a significant rate, particularly in recent years. The mean maximum and minimum temperatures at both seasonal and monthly time scales show increasing trends. The average maximum temperatures in the pre-monsoon and monsoon seasons, and the average minimum temperatures in the pre-monsoon, post-monsoon (October–November), and winter (December–February) seasons are increasing at faster rates in recent times than anticipated either from long-term observed trends reported in SMRC (SAARC Meteorological Research Centre) (2003), or climate-model projections reported in Warrick et al. (1996), Ahmed and Alam (1999), and World Bank (2000). The highest increasing trend in the mean maximum temperature is seen during the monsoon (0.037 degree Celsius [°C] per year) while that in the mean minimum temperature is seen in the winter (0.047°C per year).

At a monthly scale, both mean maximum and minimum temperatures have increasing trends in all months except for the maximum temperature in January. The highest trend in the mean maximum temperature (0.059°C per year) is seen in May (see Figure 1.7), which is the warmest month after April and that in the mean minimum temperature is seen in February (0.067°C per year), which is the last month of the winter season. In fact, the last month of the post-monsoon season (November) and the first month of the winter season (December) also show strong increasing trends in the night-time mean minimum temperature. This may indicate that the winter season is shrinking in duration in Khulna. The annual minimum temperature has an increasing trend whereas the annual maximum temperature has no overall trend. The number of extremely hot days and cold nights per annum and the longest duration of such days and nights have trends similar to the trends in the annual maximum and

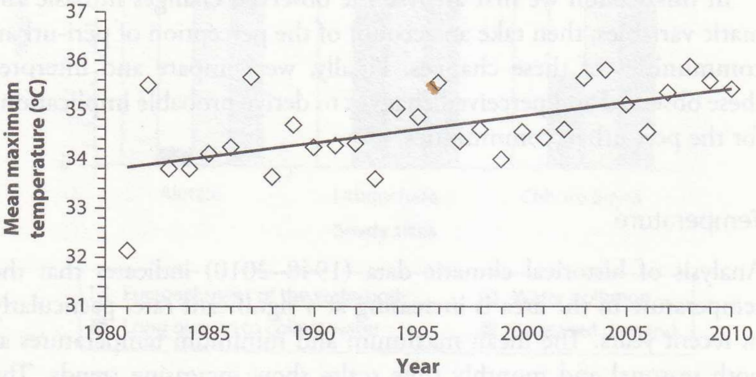

Figure 1.7 Trend in Mean Maximum Temperature in May in Khulna
Source: Authors' analysis.

minimum temperatures. The mean monthly diurnal temperature range has a non-significant decreasing trend in the long-term data and a significant decreasing trend (99 per cent level) in the recent data during the months of December to April. The heat index, which is a measure of perceived temperature in human body (Steadman 1984, Rothfusz 1990, Delworth et al. 1999), shows an increasing trend.

Rainfall

The rainfall across several decades (1948–2010) has increasing trends of 8 millimetres, 31 millimetres, 9 millimetres, and 6 millimetres per decade during the winter, monsoon, post-monsoon and pre-monsoon seasons respectively. The trends are significant only for the winter and monsoon seasons at 95 per cent and 80 per cent levels of confidence respectively. Shahid (2010) found similar trends in seasonal rainfalls for Khulna using a non-parametric technique with a shorter data-set (1958–2007). Among the monsoonal months, June has a non-significant negative trend of 6 millimetres a decade, July a non-significant positive trend of 5 millimetres a decade, August a positive trend of 14 millimetres a decade being significant at 80 per cent level of confidence, and September has a positive trend of 18 millimetres a decade being significant at 90 per cent level of confidence. Apparently, there are some evidences that the monsoon is strengthening towards the end of the season.

The annual total rainfall is found to be increasing at 53 millimetres a decade which is significant at 95 per cent level of confidence. The number of rainy days in a year is found to be increasing at 0.8 days per annum, which is significant at 99 per cent level of confidence (Figure 1.8). The numbers of rainy days during the wet (June–October) and dry (November–May) seasons also show increasing trends of 0.6 days and 0.2 days a year, respectively. Both these trends are found to be significant at 99 per cent level of confidence. The maximum number of consecutive rainy days in a year is found to be increasing at 99 per cent level of confidence. The maximum number of consecutive non-rainy days in a year is found to be decreasing at 99 per cent level of confidence. The maximum rainfalls in one day, in three consecutive days, and in seven consecutive days, though increasing, are not statistically significant. Also, the

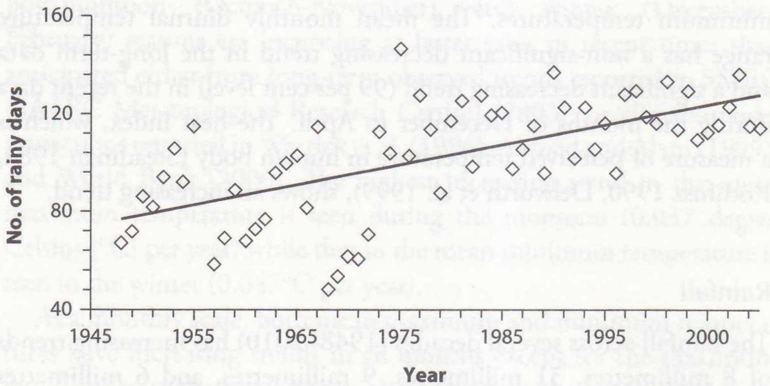

Figure 1.8 Trend in the Number of Rainy Days in a Year in Khulna
Source: Authors' analysis.

number of days with a rainfall of more than 50 millimetres and 100 millimetres, though showing increasing trends, is not statistically significant.

Sunshine Duration

The mean seasonal sunshine duration (1984–2010) is decreasing at the rates of 7.8 per cent, 4.9 per cent and 1.6 per cent per decade in the winter, post-monsoon, and pre-monsoon seasons respectively. The winter and post-monsoon trends are statistically significant at 99 per cent and 95 per cent level of confidence respectively. The monsoon season, in contrast, has a non-significant increasing trend of 4.0 per cent per decade. At a monthly scale, the sunshine duration has a decreasing trend for all the months, except for June, July, and August. The trends in December and January of the winter season are statistically significant at 99 per cent and 95 per cent level of confidence, respectively. The trend in October of the post-monsoon season is significant at 95 per cent level of confidence. The trends in the other months are not significant at 90 per cent level of confidence.

The trend in sunshine duration found in this study is more or less consistent with the findings of Climate Change Cell (2009), Mondal et al. (2009), Zaman and Mondal (2011), and Institute of Water and Flood Management (IWFM) (2012) for Bangladesh. Consistent with the changes in sunshine duration, the mean seasonal humidity (1948–2010) has an increasing trend of 2.3 per cent, 1.3 per cent, and 0.3 per cent per decade in the winter, post-monsoon and pre-monsoon seasons respectively. In contrast, the monsoon season has a decreasing trend of 0.4 per cent per decade. The trends in the winter and post-monsoon seasons are significant at a level of confidence of 99 per cent. The decreasing trend in the monsoon season is significant at a lower level of confidence (90 per cent). The trend of the pre-monsoon season is not significant. At a monthly scale, the highest rate of increase is found in the month of January in the middle of the winter and then the rate gradually falls till the month of June, the beginning of the monsoon, and thereafter the rate increases gradually till January.

Humidity and Evapotranspiration

Our analysis of long-term humidity at Khulna indicates that the months of May–August have decreasing trends. The trend in relative humidity found in our study is more or less consistent with the findings of Mondal et al. (2009), Nasrin and Mondal (2011), and IWFM (2012) for Bangladesh. Since long-term detailed evaporation data for Khulna were unavailable, trends found in other studies conducted in similar regional cities were considered. Evaporation at Jessore, a regional city, is found to have decreased in all the 10-day periods in a year during the post-1980 period compared to the pre-1980 period. The long-term reference crop evapotranspiration (ET_0) in the Khulna area has, on an average, a decreasing trend of 0.02 millimetres/day per year in the dry season (Nasrin and Mondal 2011). That means, the decreasing sunshine and increasing humidity, which lessens ET_0, have a larger effect on ET_0 than the increasing temperature, which increases ET_0. This is contrary to the general belief that, due to climate change, crop evapotranspiration and hence the irrigation requirement would increase.

People's Perception

The household survey revealed that there is variation in the local perception of climate change across the three peri-urban sites

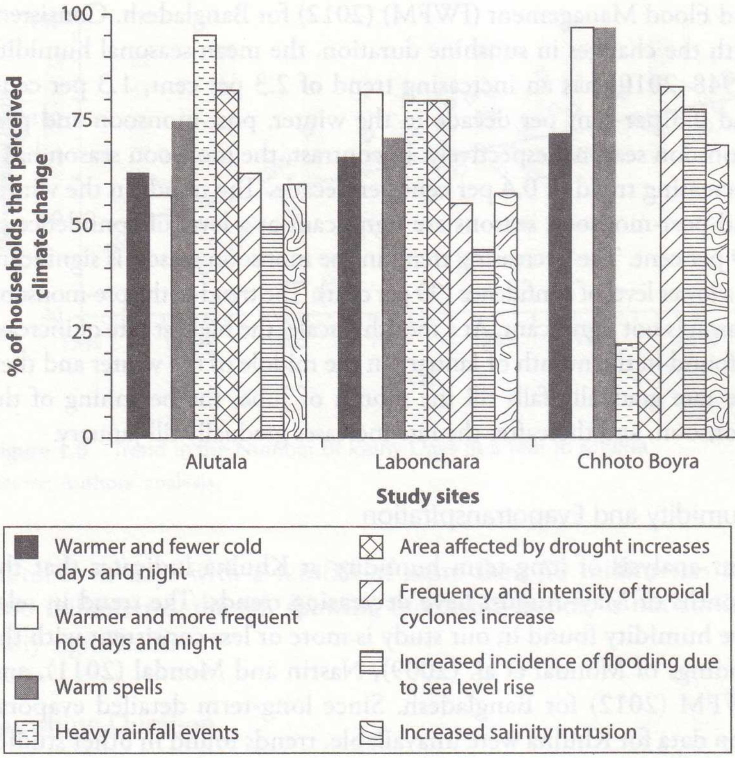

Figure 1.9 Perception of Climate Change at the Study Sites
Source: Computed from household survey data, 2011–12.

(see Figure 1.9). Temperature-related manifestations (warmer and frequent hot days, warm spells, and so on) of climate change are, to some extent, perceived more by the female respondents than the males. Other manifestations, such as drought, cyclone, flood, and salinity intrusion, are perceived more by the male respondents. Such differences in perception may be due to the fact that the men are more exposed to the external environment than the women, whose activities are mostly confined to their homestead territories.

Perceptions of these manifestations are also linked to the perceived urbanization rate of the respondents (Figure 1.10), and are found to be statistically significant. This indicates that those who believe that urbanization rates are high in their localities

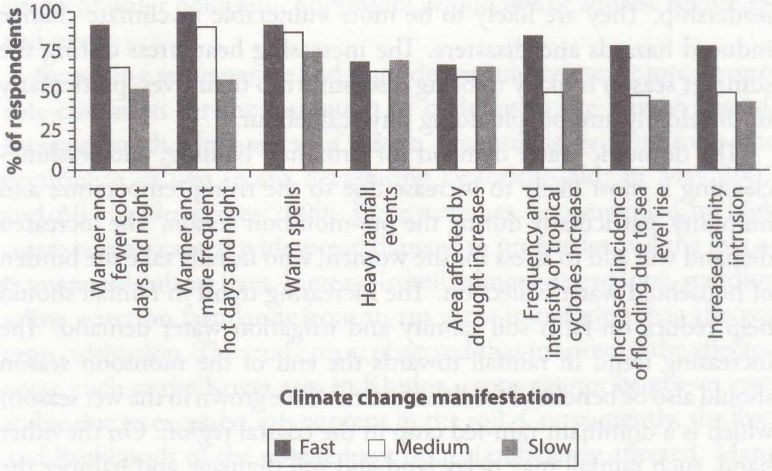

Figure 1.10 Perception of Climate Change at Three Perceived Urbanization Rates

Source: Computed from household survey data, 2011–12.

also tend to perceive that climate change manifestations are more strongly felt.

About half of the interviewees informed that no initiative was taken in their localities to address climate change vulnerabilities. The remaining respondents did not even know about any possible initiative. This indicates that climate-change vulnerability reduction initiatives of any form, including awareness raising, capacity building, risk reduction, and adaptation measures, have not yet reached these communities living in the peri-urban areas of Khulna, though they are among the most vulnerable to climate change.

Implications for Peri-urban Communities

Current trends and the range of climatic variables are perceived to have multi-dimensional effects on water security in the peri-urban areas. A significant portion of the peri-urban population depends on crop farming, daily labour, private service, and small businesses. These people are relatively poorer, have smaller assets bases, attain a lower education level, and have less access to political or social leadership. They are likely to be more vulnerable to climate-change induced hazards and disasters. The increasing heat stress during the summer season is likely to bring discomfort to their lives, particularly to the elderly and people doing physical labour.

The domestic water demand for drinking, bathing, and washing-cleaning is most likely to increase due to the rising temperature and humidity, particularly during the pre-monsoon season. The increased demand will add to stress for the women, who usually take the burden of household water collection. The increasing trend in rainfall should help reduce on-farm soil salinity and irrigation water demand. The increasing trend in rainfall towards the end of the monsoon season should also be beneficial for the *aman* rice (rice grown in the wet season) which is a dominant rain-fed crop in the coastal region. On the other hand, such rainfall may delay land and soil drainage and hamper the cultivation of *rabi* (winter) crops. Also, the standing rice plant, when close to maturity, may not withstand the rainfall accompanied by wind during this time and may wilt on the land surface, resulting in huge yield losses as happened in 2012 due to rainfall in early November. The decreasing trend in sunshine duration is likely to affect crop growth and yield. It is usually associated with an increasing foggy environment which has a detrimental effect on crop productivity. Since the volume of rainfall has an increasing trend and the rainfall intensity is more or less stationary, it is expected that groundwater recharge would increase in future. Even so, more local rainfall will increase the recharge primarily to the upper aquifer, which is saline. Moreover, with time, the peri-urban areas will experience more urbanization, hence less recharge due to an increase in paved areas. The combined effect would very likely be a significantly lower recharge in future. As a result, water stress in the peri-urban areas may further increase.

The Mayur River is considered to be one of the potential sources of water supply for both urban and peri-urban areas in Khulna. With an increase in paved areas, decrease in depression, and increase in rainfall, the surface runoff and hence the freshwater flow to the Mayur is likely to increase. However, the river is currently the recipient of urban and peri-urban wastewater and solid waste. Without adequate wastewater treatment and solid-waste management, the situation will worsen and the peri-urban communities, particularly the poor, elderly, women, and children, will suffer from the direct and indirect effects of water pollution, unpleasant odour, loss of aquatic resources, and so on.

Increasing temperature and humidity would create a more favourable condition for the formation of cyclones in the Bay of Bengal. Increase in the frequency of severe cyclones is evident from the occurrence of two recent devastating cyclones—Sidr in May 2007 and Aila in November 2009. These cyclones, accompanied by high storm surges, caused widespread damage to properties and the loss of human and animal lives. Increase in soil salinity, due to long-standing saline water on farmlands from storm surge inundation, has affected crop cultivation. The study team observed that in some of the affected areas, such as the Koyra area in Khulna, crops cannot be grown even today due to excessive salt content in the soil. Consequently, the lives and livelihoods of the people have been significantly affected. Many people from those areas have migrated to urban and peri-urban areas of Khulna in search of new livelihoods. Since the Alutala area is under tidal influence, and the Mayur, the main drainage channel of the area, has been silted up, malfunctioning of the Alutala regulator and/or any breach in or overtopping of the polder in the event of such a storm surge may create long-term waterlogging, increase soil salinity, and reduce farm productivity in the peri-urban areas.

Increasing water levels, accompanied by higher rainfall, may exacerbate the flooding problem in Chhoto Boyra and the waterlogging problem in Labonchara. More agricultural lands in Alutala may come under tidal influence, the soil salinity of those lands may increase, the cropping pattern may change, and some of those lands may be converted for shrimp aquaculture. Thus, some of the current cropped lands may become shrimp *ghers* (enclosures for culture fisheries) in future and the sharecroppers, small farmers, and agricultural labourers may be adversely affected by such change in land use.

An extreme rainfall event occurred in Khulna during 25–6 June 2012. During this event, 171 millimetres of rainfall occurred in two days, and the highest rainfall intensity was 40 millimetres/hour which lasted for an hour. Khulna city experienced unprecedented flooding and drainage congestion at that time. Regular activities of the city were halted in these two days. Commercial activities came to a stand-still and people were stranded in their houses. This flooding caused huge damage to properties, infrastructures, and businesses.

This extreme event indicates a probable change in the rainfall pattern. On the other hand, the unprecedented urban flooding indicates the aggravating adverse impact of unplanned urbanization on the natural drainage system and urban drainage infrastructure.

The anticipated changes in future climate are likely to have an impact on human health. There is already a prevalence of water-borne diseases such as diarrhoea, cholera, typhoid, dysentery, and jaundice, and skin and eye infections among the peri-urban communities in Khulna. The summer season is the peak time of occurrences of such diseases. Incidences of such diseases may increase in future due to an increase in flooding and waterlogging from increased rainfall and river water levels. Waterlogging, particularly in Labonchara and Chhoto Boyra, areas that are already facing such a problem, may increase. The prevalence of mosquitoes may increase in such waterlogged areas. Moreover, outbreaks of cholera, typhoid, and diarrheal diseases may occur after flooding as floodwaters in the peri-urban areas become contaminated with human and animal wastes. Informal interviews with the local people indicated that the rainfall pattern in the area has changed and people are now suffering frequently from fever, diarrheal diseases, headache, allergy, and nausea.

The baseline survey also revealed that about half of the peri-urban residents were not aware of the possible impacts of climate change. Almost all respondents who were aware of the impacts mentioned that crop yields had decreased, while pest attacks, physical stress in work, and human diseases had increased. Most people mentioned that the extent of saline water areas was increasing. These perceptions of the local people were more or less congruent with the results of secondary data analysis.

Adaptive Response and Strategy

Several adaptive responses and strategies, both planned and autonomous, are observed in the Khulna area, which emerged to cope with water insecurity aggravated by urbanization and climate change. The planned strategies include infrastructure development and supply augmentation, while autonomous strategies involve water harvesting and conservation practices, collective action, and changes in livelihoods and agricultural practices.

Poor drainage facilities and high-intensity rainfalls are causing frequent and worsening urban flooding in Khulna city and its peri-urban areas. This situation is likely to worsen due to increased rainfall and sea-level rise induced by climate change. The KCC and KWASA have been working on plans to develop climate-resilient urban drainage infrastructure, implement a building code that would address the vulnerabilities, and protect the surface-waterbodies. There are about 47 canals, locally called khals, in Khulna which are encroached on at many places by land grabbers. Most of these khals are hydraulically linked with the natural drainage system of the city. These khals are losing their efficiency and existence due to lack of proper maintenance. Recently, the KCC has initiated implementation of several development projects to mitigate urban flooding and drainage congestion.

The KCC and KWASA have been trying to augment water supply to meet the increasing urban demand. A plan to import groundwater from a peri-urban area through a pipeline was severely resisted by local activists and civil society. It was eventually postponed by a court decision in a case filed by the Bangladesh Environmental Lawyers Association (BELA), although at that time 40 per cent of the project funds had already been invested. A plan of KWASA to import river water from a location some 40 kilometres away from the city is facing uncertainty since the salinity level at the source has already exceeded the projected level. They have also planned to construct a surface water treatment plant and an impounding reservoir to augment water supply in the city. However, these plans and strategies are solely aimed at addressing urban water supply and vulnerabilities.

To address water vulnerability due to urbanization and climate change in the peri-urban areas, the peri-urban communities themselves have devised a range of autonomous adaptive strategies. Rainwater harvesting provides water for domestic uses in many households in these areas. In some, rainwater is conserved in small household ponds. But rainwater is not available throughout the year, and there is a need for skill and support to build adequate infrastructure and maintain it. Rainwater is also conserved by building dikes around the agricultural lands to practise culture fisheries.

New forms of collective institutions to address water insecurity are emerging in the peri-urban areas of Khulna. Residents are collectively installing DTWs that are shared by the community. It is to be noted that urban residents are required to pay a fee to get permission from KWASA to install DTWs inside the city. Peri-urban residents are also collectively taking privately owned ponds on lease to re-excavate them and conserve freshwater for drinking and household uses.

Agriculture in peri-urban Khulna is almost entirely dependent on surface water and rainwater. Surface waterbodies have been diminishing because of the spread of urban built-up area, encroachment by urban users, and urban wastewater pollution, resulting in changes in cropping practices of the farmers. They rarely cultivate *boro* rice (rice cultivated during the winter and pre-monsoon seasons) and are switching from rice to vegetables which can be irrigated with wastewater. Salinity-tolerant crop varieties are also being introduced as the soil and water salinity are increasing. Some farmers are converting their agricultural lands to practise fish farming. In extreme situations, farmers sell off their agricultural lands to developers and move to non-agriculture based livelihoods.

Peri-urban residents still experience water insecurity even after bringing in these changes to their lives. The situation is particularly bad during the dry season when the water in the Mayur and nearby khals becomes extremely polluted. People with no other choices have to use this water for washing and bathing. In some areas, women and children have to walk long distances to collect drinking water. People are forced to drink tube well water contaminated with arsenic and iron in the absence of an alternative safe source of water. Sometimes they have to consume the contaminated water to avoid the hard work and uncertainty in collecting water from the distant sources.

Way Forward

This study identified water insecurity and vulnerabilities in the context of urbanization and climate change in peri-urban Khulna. The findings of the study indicate that freshwater is scarce in the area due to high levels of salinity in the groundwater and surface water, and pollution of the Mayur River, an important freshwater body that can be saved to serve both the urban and peri-urban areas. The existing water insecurity would further aggravate with the continuing trends in urbanization and climate change.

The Master Plan for the city projects that the metropolitan area will be more than doubled in its areal extent in the nearby future. At the same time, there is no clear indication on how KWASA will meet future water demands in the urban and peri-urban areas, given the existing freshwater scarcity. Although adaptation measures are being planned through the construction of climate-resilient urban infrastructures and augmentation of freshwater supplies for the city, not one of these measures addresses water insecurity in the peri-urban areas. Peri-urban communities are adapting to their water insecurity through collective actions, water conservation practices, and changes in livelihoods and agricultural practices. A formal or informal institutional arrangement could strengthen their adaptive capacity.

Although the Mayur River is shared by the urban and peri-urban areas, solid waste and wastewater from the urban areas, encroachment, and flow control have transformed the river into a closed wastewater body at the urban–peri-urban interface. A potential adaptation measure to combat the Mayur River pollution, not yet explored by the city organizations, could be to install a number of effluent treatment plants (ETPs) and duckweed-based treatment systems at suitable locations and to treat the wastewater at desired qualities for disposal to surface waterbodies. A detailed cost–benefit analysis indicates that the benefits of reviving the river as a freshwater source would outweigh the costs incurred in the revival by a significant margin. The river can be revived to create a freshwater source for the urban areas and mitigate water insecurities for the peri-urban areas.

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