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# Adapting to periurban water insecurity induced by urbanization and climate change: insights from South Asia

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## Abstract:

This paper describes how urbanization and climate change shape water security in four periruban locations in South Asia. Urbanization processes create new demands for periurban water sources and create competition as well as opportunities for conflict. These arise from the links between land tenure and water security, the acquisition of village land and water sources to support urban expansion and the physical flows of water from rural and periurban areas to the city. The effects of these are aggravated by changes in climatic variables such as frequency and intensity of rainfall, occurrence of extreme events, sea level rise and salinity intrusion. The paper then descibes the sociotechnical mediation of water insecurity through technological and institutional innovation by water users as well as changes in household level practices for water use and agriculture. The paper argues for straddling the rural-urban divide in planning for water resources and promoting research to understand the social, institutional and agro-ecological context of adaptation interventions.

## Keywords:

Climate Change, Periurban, South Asia, Urbanization, Water Insecurity.

## 1 Introduction

Urbanization and climate change are mostly seen from either a rural or an urban perspective, where the vulnerability and adaptation needs of the periurban residents are often ignored. Urban development plans see the periurban as a transitory spatial diffusion to the rural, and an unimportant component for development. In this paper we conceptualize the periurban not as the peripheral geographic fringe of a city, but broadly as a transitional contested space identified by unique biophysical and socio-economic features and processes. Thus the periurban dynamics of vulnerability and water security are also seen from a different perspective, linking them closely to two important stressors – urbanization and climate change. Urbanization processes create new demands for land and water, which jeopardize the water security of periurban residents. The effects of these pressures on periurban water sources are aggravated by climate change. These take the form of changes in the frequency and intensity of rainfall, occurrence of extreme events such as floods and droughts, sea level rise and salinity intrusion. In this paper, we look at the implications of urbanization and climate change for the water security in four periurban locations in South Asia and how the vulnerable social groups adapt to these changes.

### 1.1 Vulnerability and Adaptation to Periurban Water Insecurity: Conceptual Groundwork

Urbanization has been an important trend of the 20th century. Most cities grow by acquiring land and water resources from the periphery. These peripheral areas, often labelled as 'periurban', serve as the recipients of the city's wastes, while providing the much needed land and water for urban expansion.

While there is not a universal definition of periurban, there is in general growing consensus that the definition goes beyond a geographic location (Douglas 2006; Dangalle and Narman 2006; Narain 2009a,b; Narain and Nischal 2007; Simon et al. 2006; Hilner 2010). Since periurban areas are involved in a process of transition, it is not possible to define them precisely spatially but some common features and processes can be identified. Dangalle and Narman (2006) note some of these; periurban areas are situated within the metropolitan areas of a country but are often outside the formal urban jurisdictions; being a zone in transition, both agricultural and non-agricultural activities exist simultaneously, though the agricultural and rural characteristics are gradually replaced by urban landscapes and attendant changes in people's lifestyles. The continuous flow of people both from the urban core and the rural hinterland results in a complex social fabric.

#### 1.1.1 Assessing vulnerability

However, the impacts of these processes in the periurban are not the same for everybody; some individuals and groups are more vulnerable. The most vulnerable groups, individuals or places tend to be those that experience the most exposure to perturbations or stresses, are the most sensitive to perturbations or stresses (i.e. the most likely to suffer from exposure) and have the weakest capacity to respond and ability to recover. Vulnerability is defined therefore as the susceptibility to harm, rather than a measure of harm alone (Nelson et al. 2010).

#### 1.1.2 Adaptation

IPCC (2007) defined Climate Change Adaptation (CCA) as an adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderate harm or exploit benefit opportunities. The concept of adaptation demonstrates the role of human agency in relating to environmental and physical stresses; people are not passive recipients of adverse environmental changes, but exercise ingenuity and creativity in minimizing their negative impacts on them or exploiting them to benefit themselves. Within discourses on climate change vulnerability and adaptation some scholars see vulnerability in relation only to extreme events. In this research, we have seen vulnerability as a chronic phenomenon, much on the lines of Mustafa et al. (2008).

Adaptation can be autonomous, initiated by the communities or households themselves; or it can be planned, initiated by the agencies of the state. Often autonomous adaptation measures fill in a void left by the absence of planned adaptation measures. Autonomous adaptation involves the use of various forms of assets or capital (physical, financial, natural, social and human) on the part of households.

#### 1.1.3 Water security

Water security, for the purposes of this paper, is defined in terms of the uncertainty attached to the availability of water. We deliberately do not use an objective yardstick or threshold for this as it may be difficult to develop this for periurban contexts that have a wide variation in sources or access to water, that may also change from time to time and vary across groups and individuals.

### 1.2 Urbanization and Climate Change: Compounding Periurban Stressors

Periurban communities and processes are subject to multiple stressors. Urbanization and climate change, two dominant stressors, add pressure to or bring about changes in the periurban biophysical and socio-economic domains. Since periurban vulnerability and resilience are inherently different from those in the urban or rural contexts, their implications for the periurban are also different.

Urbanization alters periurban land entitlements, water access and rights, while contestation for periurban resources creates conflicts and weakens resilience, thereby increasing vulnerability. These can be understood from the consequences of urban land development projects moving into the periurban areas, or urban elites taking control over periurban water resources. Urbanization also has a significant impact on the periurban biophysical systems and processes. Urban wastes and wastewater flows to the periurban areas degrade the environment and offset the natural balance in the ecosystem or hydrologic cycle. Urban heat island effects spill over to the periurban areas and change the local environment and micro-climate.

Climate change, commonly seen as its direct or indirect manifestations, is generally accepted as a stressor or shock, exposure to which shapes vulnerability in the local context. Climate change, as conceptualized in the physical sciences, is seen as a long-term gradual change in the climatic variables such as annual or seasonal amount of rainfall, annual number of rainy days, or the mean maximum temperature in a given month. Climate variability, which is also an element of change in the climate, is of particular interest when it is important to see the variation in the extremes of certain climatic variables, such as extreme rainfall events or prolonged drought conditions. An understanding of climate variability can be useful to interpret the vulnerability and adaptive capacity in situations where extreme conditions occur frequently.

Climate change impacts add to the urbanization effects already in place in periurban contexts. For example, excessive groundwater withdrawal for urban water supply may limit water availability in the urban as well as the periurban areas. Reduced rainfall due to climate change will reduce groundwater recharge and further limit the water availability. Urban communities are generally more resilient to these compounding stressors than periurban communities, primarily because of high-functioning urban service delivery systems, stronger actors and better institutions. Less resilient and more vulnerable periurban communities adapt through various practices, which are discussed later in this paper.

## 2 Urbanization, Climate Change and Water Insecurity

### 2.1 Research Setting in South Asia

The four research sites, in three countries of South Asia, selected for this study are Khulna (Bangladesh), Gurgaon and Hyderabad (India) and Kathmandu (Nepal) (see Figure 2.1). Each location comprises a cluster of villages around the city where a periurban interface is emerging and where some conspicuous effects of urbanization on the peripheral villages are noted.

**Khulna**, a southern coastal metropolis of Bangladesh, is the third-largest city in Bangladesh, located on the banks of the Rupsha-Bhairab river. Urban wastewater flows to the periurban areas through another smaller river, which lost its natural tidal characteristics because of salinity control interventions. The urban and periurban areas suffer from high salinity levels in groundwater. **Hyderabad** has experienced growth of new residential colonies, sprawling out in the direction of newly developing industrial, educational and research centres, and along high value lands and lines of highest accessibility (Alam and Khan 1972). However, this development has proved to be quite unsustainable and has turned out to be a serious threat to the city and its environs due to the lack of environment management. **Gurgaon**, a district in the North-West India, has grown significantly over the last two decades. Its growth has been led and characterized by a real estate boom since the 1990s. The most important factor of this growth has been its proximity to the capital Delhi and an international airport, as well as neo-liberal economic policies to invite industry. The growth of Gurgaon brings in many environmental stresses including severe decline in groundwater levels. Similarly, **Kathmandu**, the capital of Nepal has undergone a rapid process of change due to continued urbanization and conversion of agricultural land into residential dwellings. The process of urbanization and development of physical infrastructure in the city core have put pressure on the natural resources in the periurban and rural areas. One such pressure has been manifested in sand mining from the hillocks and terraces, which has serious implications for local hydrology.

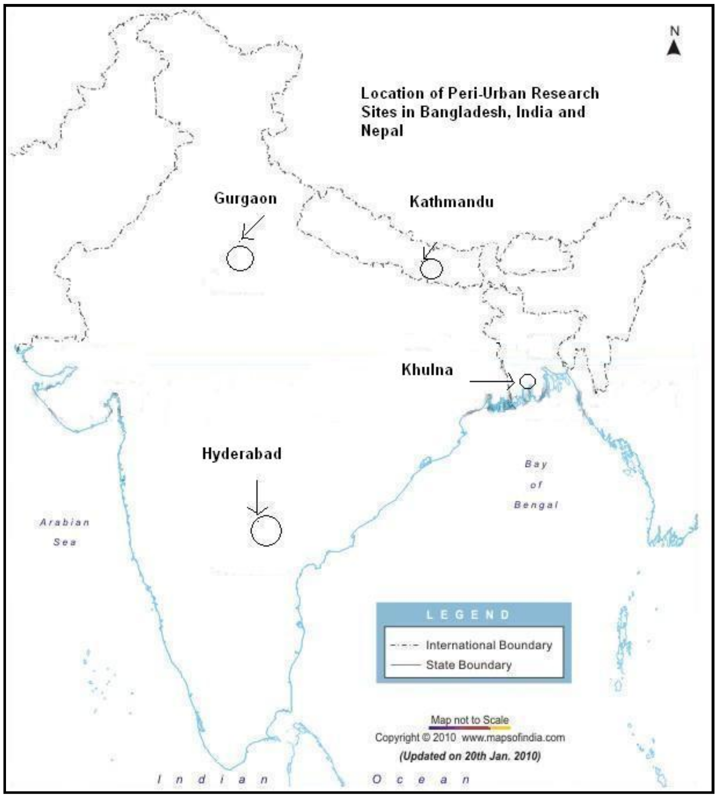


Figure 2.1: Research locations in South Asia.
Source: www.mapsofindia.com (improvised further to show locations).

These cities were selected for this research because of their diversity in urbanization and climate change dimensions. The periurban areas of Bangladesh and Nepal are largely characterized by traditional livelihoods and the population is likely to be hard-hit due to the rapid urbanization process, whereby lands are required for increasing demands for homes. Being nearer to the sea, rise in sea level and consequent impacts are very specific for Bangladesh while in Nepal, the fragile mountain ecosystem is not only disturbed due to urbanization process but also the impact of melting glaciers due to global warming generates much concern for the future. In Gurgaon and Hyderabad, the post liberalization period has seen a different form of development, where the process of change has been induced by growth of the Information Technology (IT) sector. This makes all the four locations unique in themselves, but bound by commonalities in terms of overall trends and adaptation to climate change.

## 2.2 Dimensions of Periurban Water Insecurity

Urbanization processes create new demands and claims on water, which steadily moves out from agricultural into other urban, industrial and recreation uses. Rural-urban water flows to quench urban thirst, acquiring common property water resources for urban expansion and discharge of urban wastes into rural water bodies are other manifestations of periurban water insecurity.

These processes take shape often because of the links between land tenure and water security. With the acquisition of land for urban expansion, periruban residents lose access to water sources located on those lands, as noticed in periurban Gurgaon, where lands were acquired to build water treatment plants and canals to meet the requirements of the growing city. Water may also move physically from the villages to the cities through water tankers, as noticed, for instance, in Kathmandu.

Another manifestation of periurban water insecurity is the acquisition of village common property land and water resources to support urban expansion, as seen both in Hyderabad and Gurgaon. In Hyderabad, a large area formerly covered by village ponds and tanks has been encroached upon to meet the needs of the growing city. Urban and industrial uses increasingly compete for rural water as the former are able to extract water from deeper aquifers using expensive technologies that the locals cannot afford, as done by the farm-house owners in Gurgaon. While on the demand side, there are new claimants on groundwater; on the supply side, the stress is aggravated by shorter rainy seasons with reducing rainfall since the 1980s. The decline in rainfall increases the reliance on groundwater, forcing people to extract more. Thus, both urbanization and climate change act as multiple stressors on periurban water sources. The dumping of urban and industrial wastes and wastewater to rural and periurban water bodies are another important aspect of how the ecological foot-print of the cities is borne by the periphery, as noticed especially in Khulna. This creates potential for conflict among rural-urban water users. These conflicts may exist between upstream-downstream users or among different categories of users, e.g. farmers and fishermen, or urban residents and farmers.

It is important to note that differential vulnerabilities are engendered by differences in asset ownership patterns – particularly in terms of differences in ownership of non-rural assets. The periurban elite, with some holding of assets in urban centres, have much more by way of cushion and are able to diversify their livelihoods portfolio. The landless, who depend on others for their water sources, often lose access to water sources as the latter sell off their lands. Rural-urban migration, occupational diversification and the acquisition or erosion of common property resources that provide a social glue can erode the bases for social cohesion and weaken social capital. Weakening social capital weakens community resilience. Also vulnerable are those whose livelihoods depend on the acquired water sources. In the long run, urbanization processes distribute both risks and opportunities unequally (Narain 2009a). For instance, in Ravirala village in Hyderabad, the most vulnerable are the washermen and fishermen who depend on the water bodies that are vanishing with urban expansion.

### 2.3 Urbanization and Climate Change Effects

Urbanization has various implications for the periurban areas including rapidly changing land use, deterioration of the biophysical environment, social and economic differentiation, and added pressure on the natural resources. Climate change effects acting through changes in climatic variables such as temperature, rainfall and humidity are often compounded with urbanization effects. These common features are manifested in different forms in the four South Asian locations.

### 2.3.1 Khulna

Urbanization and climate change impacts are directly linked with water insecurity in periurban Khulna where salinity in the surface water and groundwater has been a major concern. This coastal area is vulnerable to sea level rise which, along with unplanned urbanization, is causing rainfall flooding, water logging and drainage congestion (Kumar et al. 2011). Urbanization is deteriorating water quality in the open water bodies, and limiting subsistence uses of water bodies such as washing, bathing and livestock rearing. Encroachment and disposal of urban wastewater and solid waste are reducing the conveyance and assimilation capacities of a river shared by the urban and periurban areas (Kumar et al. 2013).

Khulna is one of the fifteen cities worldwide that are the most vulnerable to climate change (IIED, 2009). Climatic data indicate that the mean temperatures in Khulna at the annual or seasonal scales are increasing. This trend is more pronounced in the recent years. Temperature in the hottest month (May) also has an increasing trend (Figure 2.2). The annual number of extremely cold nights is decreasing while the heat index is increasing. Among other variables, sunshine duration is decreasing and humidity is increasing. Annual rainfall and number of rainy days are increasing (Figure 2.3). The monsoon is intensifying more toward the end of the season. The annual maximum daily rainfall and the number of days with high intensity rainfall have remained almost the same in the long term (Mondal et al. 2013).

A climate perception study indicates that temperature related manifestations (i.e. warmer and frequent hot days, warm spell, etc.) of climate change are generally perceived more by the female respondents than the males while other manifestations, such as drought, cyclone, flood and salinity intrusion, are perceived more by the male respondents. These perceptions have statistically significant correlation to the perceived urbanization rates. Figure 2.4 shows that people perceiving faster urbanization tend to perceive higher climate change manifestations in general.

These climatic trends imply that work stress, domestic water demand, and frequency and intensity of cyclone and storm surge may increase in future due to increase in temperature and humidity. However, agricultural water demand is unlikely to increase since rainfall is increasing and evapotranspiration is decreasing. Groundwater recharge is likely to decrease due to increased urbanization while surface runoff is likely to increase due to higher rainfall and urbanization.

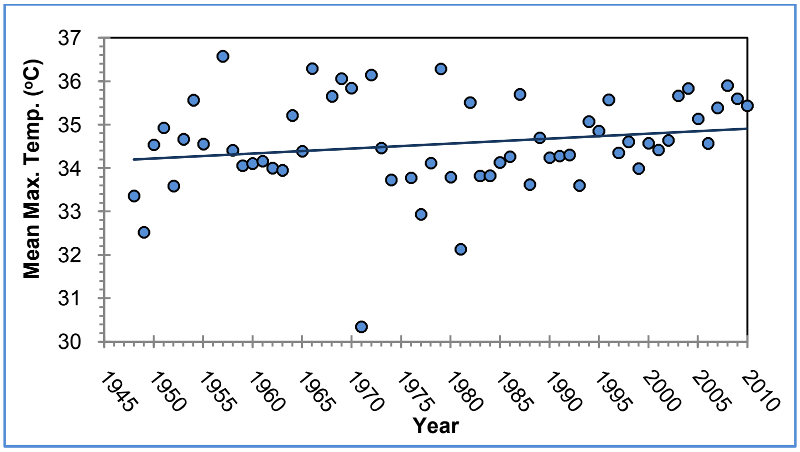


Figure 2.2: Trend in mean maximum temperature in the hottest month (May) in Khulna.

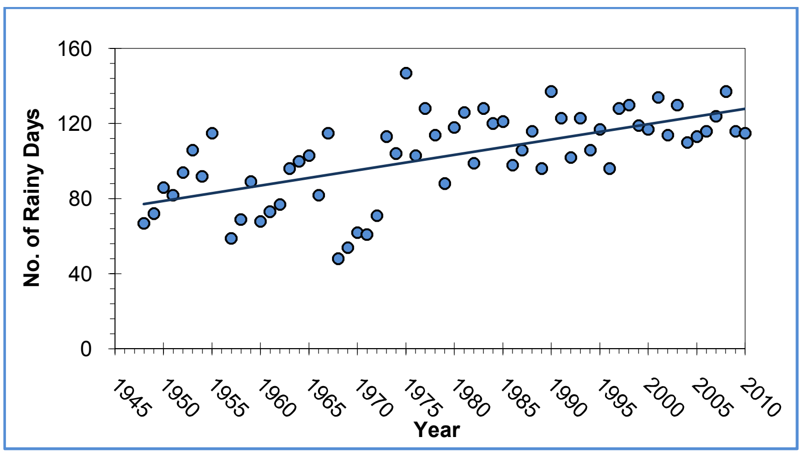


Figure 2.3: Trend in number of rainy days in a year in Khulna.

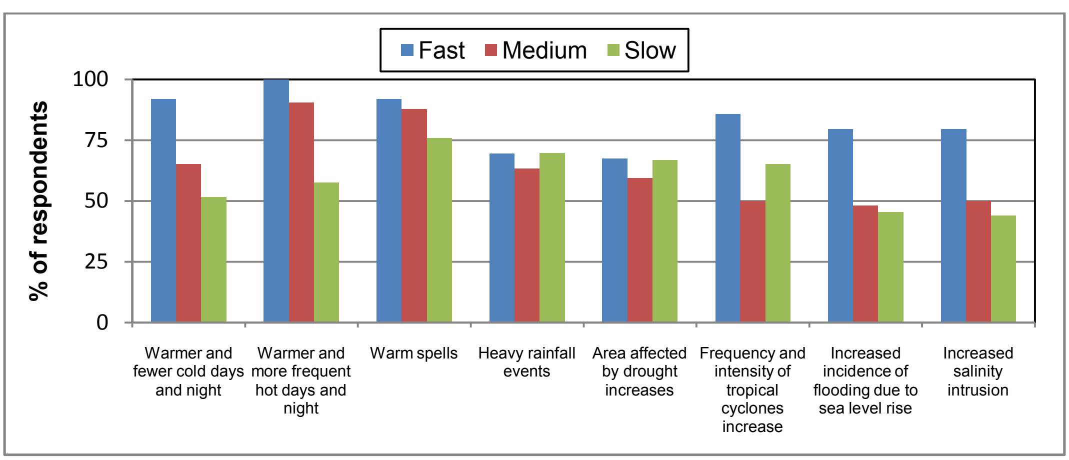


Figure 2.4: Perceived severity of climate change at three perceived urbanization rates in Khulna.

### 2.3.2 Hyderabad

The development in Hyderabad has proved to be quite unsustainable and has turned out to be a serious threat to the city and its environs. High carbon emissions from the increasing numbers of vehicles have been observed to be high (Badrinath and Kharol 2008). Also, aerosol index show that urban areas of Hyderabad are influenced by biomass burning in addition to anthropogenic vehicular pollution. These activities have aggravated the urban heat island effect and in turn affected the micro climate in the newly developing areas. Hyderabad being located in an area with hard-rock aquifer has very limited groundwater recharge while water withdrawal from the aquifer far exceeds the recharge. There has been progressive decline in the fraction of rainfall converted into runoff due to increased usage of surface and groundwater in the catchment areas surrounding Hyderabad (Ramachandraiah and Prasad 2008). Historical data show that the area covered by water bodies reduced from 118 km$^2$ to 110 km$^2$ between 1973 and 1996. Numerous small water bodies in the periurban areas also shrunk, when the city underwent a wave of real estate growth.

Analysis of climatic data from Hyderabad indicates that annual mean maximum temperature is increasing (Figure 2.5). Although annual mean minimum temperature has an overall increasing trend in the long term, the trend is less pronounced in the recent years. The mean maximum temperature in May (hottest month) and the mean minimum temperature in December (coldest month) both have increasing trends. No significant trend in annual rainfall is observed in the long-term rainfall data (Figure 2.6). However, the total annual rainfall ranges from about 300 mm to 1400 mm over a 60-year period, indicating a relatively large annual variability. The monthly distribution of annual rainfall also appears to be highly variable.

A study on public perception indicates that there is often no rainfall when it is needed the most. This is consistent with the high variability in rainfall seen in the observed data. This also has direct implications for groundwater recharge, leading to frequent drought conditions and unavailability of water for drinking and agriculture.

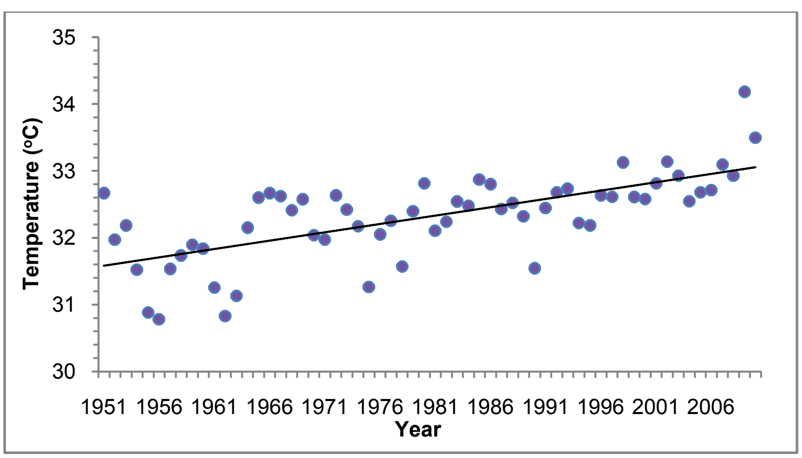


Figure 2.5: Increasing trend in annual mean maximum temperature in Hyderabad.

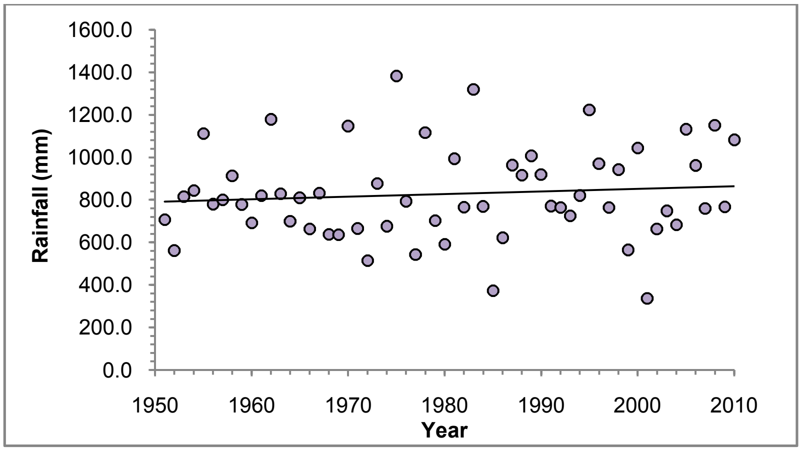


Figure 2.6: Variation in total annual rainfall in Hyderabad.

### 2.3.3 Gurgaon

Gurgaon's steady population growth is exerting stress on both the surface and groundwater. The water table has been declining at a rate of about two meters per year since 2006. At this rate, the city will have no useable groundwater left by 2017. This crisis will aggravate with climate change and urbanization. Higher temperatures are likely to increase evaporation from surface storages as well as groundwater, and expanded paved areas will result in faster runoff and less aquifer recharge. It is planned to augment urban water supply by building water treatment plants or by tapping more groundwater resources. This causes increased competition for groundwater, and loss of access and right of the periurban residents to water. This has been a cause of resentment amongst periurban residents (Narain 2009a).

Analysis of climatic data from Gurgaon indicates that the annual minimum temperature is increasing while the annual maximum temperature trend is almost static (Figure 2.7). The mean minimum temperature in January (coldest month) is increasing while the mean maximum is decreasing. Other analyses indicate relatively high mean temperature variability at the monthly and seasonal scales. Total annual rainfall in Gurgaon has been highly erratic with an overall decreasing trend during the last fifty years (Figure 2.8). Among other climatic variables, relative humidity shows an increasing trend in both monsoon and post-monsoon seasons, while evaporation rate shows an increasing trend during the last decade.

Field verification with seasonality analysis indicating colder and shorter winters, and shorter rainy seasons with less rainfall confirms the trends and variability in observed climatic data. These climate change manifestations have influenced agricultural practice modification and technology shift.

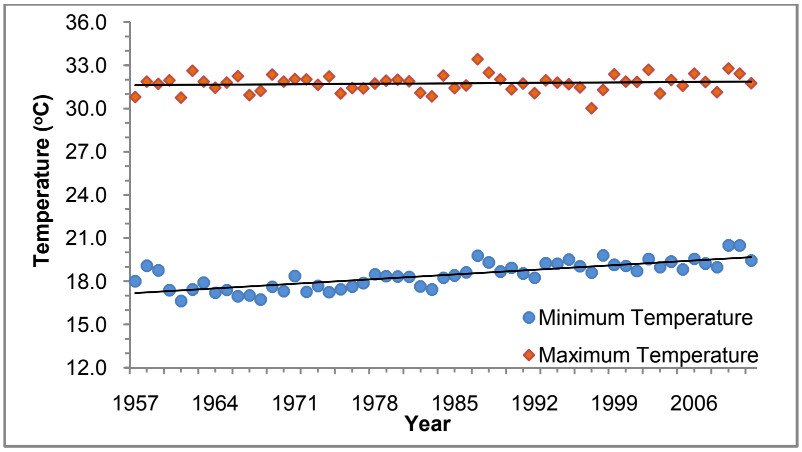


Figure 2.7: Trends in annual maximum and minimum temperatures in Gurgaon.

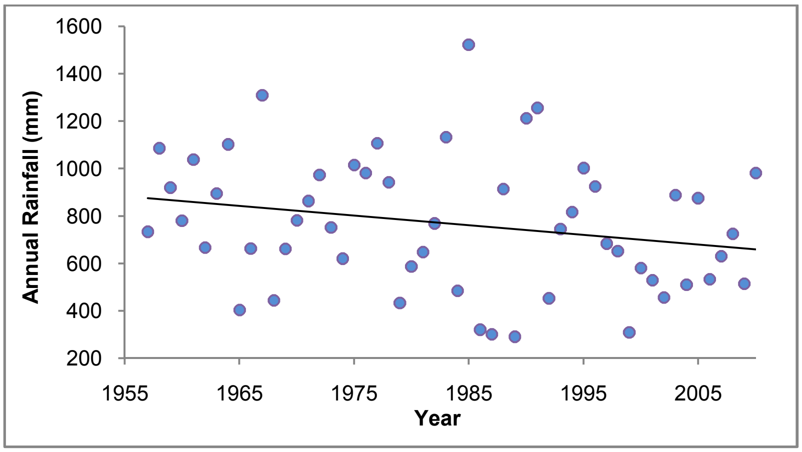


Figure 2.8: Variation in total annual rainfall in Gurgaon.

### 2.3.4 Kathmandu

Rapid population growth and land use change, together with unplanned urbanization, have created several physical, social, and environmental problems in the Kathmandu valley. Increasing water transfer from the rural and periurban areas through informal water markets has resulted in reduced supply for domestic and agricultural uses. This has led to accelerated degradation of traditional water management systems in the rural areas. Further, the inequity in the distribution of natural resources has intensified stresses on the poor and marginalized who still depend heavily on natural resources to sustain their livelihoods. The whole equation of demand and supply of water from rural to urban areas has intensified pressure and competition for available water resources in the rural and periurban areas. This is not only due to increasing dependence on urban areas, but also due to the limit of access and availability of water for use by rural and periurban dwellers.

These problems along with climate change effects have added to the pressures on land and water services in the periurban areas. Climatic data indicate that there is a decreasing trend in annual number of cold days (temperature < 0°C) and an increasing trend in the number of hot days (> 30°C) in the Kathmandu valley (Figure 2.9). Also, there are increasing trends of 0.05˚C/year and 0.04˚C/year in daily maximum and minimum temperatures, respectively. Analysis of precipitation data revealed no significant trend in annual precipitation, number of rainy days, daily intensity index and number and length of dry spells (Sada et al. 2012).

These changes are likely to have various impacts on traditional water infrastructure, water supply systems, groundwater sources and agriculture. Most periurban residents perceive a decrease in crop production, and changes in timing of crop planting and harvesting as consequences of these impacts. Other perceived consequences include water insufficiency, change in cropping pattern, adverse health impacts and increased migration (Sada et al. 2013).

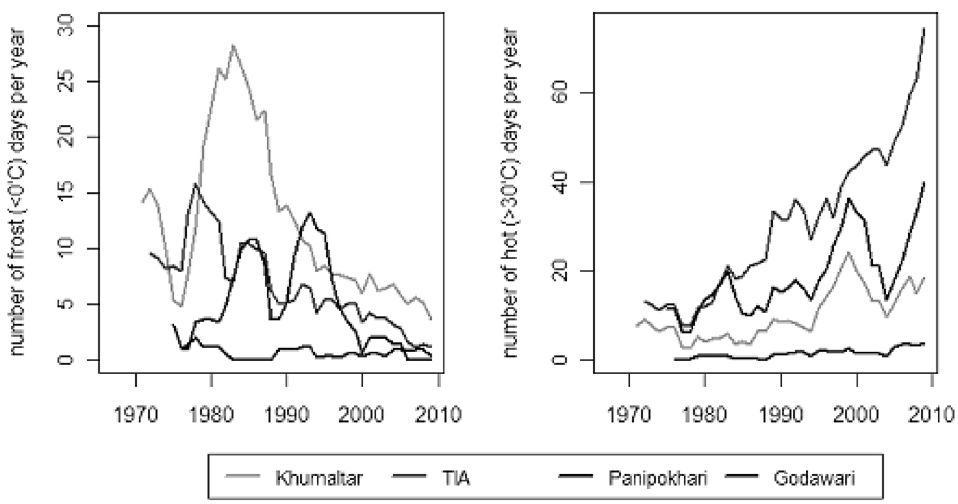


Figure 2.9: Temperature trends in Kathmandu.

## 3 Evolving Adaptation Practices

This section provides details of the wide range of strategies employed by periurban residents in the four research locations to adapt to water insecurity induced by urbanization and climate change. In studying these adaptation strategies, it was observed that both planned adaptation strategies, i.e. those initiated by the state, and autonomous adaptation i.e. those devised by water users themselves are in place.

### 3.1 Planned Adaptation

The planned adaptation measures are particularly conspicuous in Khulna. These can be placed in two categories, namely, those involving construction of climate resilient infrastructure and those aiming essentially at supply augmentation.

### 3.1.1 Building climate resilient infrastructure

In Khulna, an important water security issue related to urbanization and climate change is an increase in urban flooding caused by high-intensity rainfall and unplanned urbanization. State authorities have responded by building climate resilient infrastructure such as climate resilient urban drainage facilities, implementation of a building code and protection of surface water bodies such as rivers and khals (local name for a natural channel). Rainfall-runoff is accumulated in the low-lying detention areas from where it is slowly drained to the surrounded outfall rivers (Khandoker 2004). Many Khals in Khulna have been encroached upon; this blocks the natural flow of water, resulting in increased flooding in Khulna. Therefore protection of these khals and construction of drainage infrastructure have been the immediate steps towards building climate resilient urban infrastructure.

### 3.1.2 Supply augmentation

In the face of expansion of urban population, state authorities have responded by measures for supply augmentation to meet urban demand. In Khulna, for instance, there were initiatives by KCC (Khulna City Corporation) and KWASA (Khulna Water Supply and Sewerage Authority) to transport water from the periurban areas through a piped network to the city which could not materialize however because of resistance from the periurban communities. KWASA has also planned to construct a treatment plant using surface water to augment water supply for the city. In order to deal with increased river salinity and longer duration of salinity, KWASA is implementing an adaptation strategy by construction of an impounding reservoir to provide alternative water supply for a longer period. None of these measures are however targeted at improving water supply for the periurban communities themselves who have devised a range of autonomous adaptive strategies to deal with changing patterns of water availability caused by urbanization and climate change.

## 3.2 Autonomous Adaptation

The autonomous adaptation strategies are further distinguished between those that are predominantly technological or institutional, and those involving changes in livelihood patterns. Technological changes involve the use of new technologies to access, store, or distribute water. Institutional changes are understood as involving new forms of water allocation and distribution, the evolution of new norms for water sharing, and collective efforts to tap water or access water markets. Those involving changes in livelihoods or life-style include changes in water use practices, cropping patterns, settlement patterns or migration.

### 3.2.1 Technological

In Kathmandu, one of the technological adaptations is capturing roof-top runoff. While roof-top water harvesting structures are absent, simple capturing of roof-top runoff for washing and sanitary purposes has been reported. The technology involves digging a pit in the household premise and diverting the roof-top water and using it for domestic, livestock and other purposes. Roof-top water storage tanks are common and large sized underground water tanks have also been built, though they are fewer in number. In Gurgaon, farmers have adapted through changes in water extraction technologies to dig deeper. Water extraction technologies have changed from manually or animal operated devices to tube wells and submersible pumps to extract water from deeper aquifers. Another technological response is the use of sprinkler irrigation. Sprinklers are found to be an adaptive strategy especially when the land is undulating and soils are sandy, making flood irrigation difficult to pursue.

### 3.2.2 Institutional

In Khulna, new forms of collective institutions have been observed, such as efforts at collective tube wells as well as exploring the opportunities for collectively taking ponds on lease and protecting them after re-excavation for fresh water. In Kathmandu, the uncertainties of water supply have led to institutional innovation in the form of rotational water collection or sequencing the households as they collect water. Women in the community started a rotating system for collecting water and ensuring that everyone gets the basic water needed for drinking and domestic purpose. In Gurgaon and Hyderabad, the most important institutional responses are reliance on social capital and buying water from water tankers. A common adaptive strategy for drinking water is taking water from friends, relatives or upper caste people in the villages. This is especially the case in certain areas which are not served by water utility. Buying water from tankers is yet another adaptive strategy. In periurban Hyderabad, declining groundwater levels have led to farmers finding it unsuitable to cultivate their lands and therefore selling water from their lands to tanker companies. For example, in Aliabad village, when the channels bringing water from the Shamirpet lake for irrigation run dry in drought years, farmers adapt to the situation by sharing water from the higher canal, which carries irrigation water to the neighbouring villages. This is done based on mutual understanding among them.

### 3.2.3 Changes in livelihood strategies

Shift in cropping pattern has been observed in all the periurban locations. In Khulna, farmers have switched from rice to vegetables. The popular dry season boro rice is rarely cultivated now. Other changes in agricultural practices are the use of saline tolerant crop varieties to adapt to increased soil and water salinity and switch to culture fisheries - converting their lands due to unavailability of agricultural water. In extreme cases, periurban farmers finally sell off agricultural land to developers and move to nonagriculture based livelihoods. Other responses include building small dikes around their agricultural lands to practice culture fisheries by preserving rain-water during the harvesting season.

In Lubhu village in periurban Kathmandu, only 8% of the total households have been able to sustain the family for the whole year from agricultural production while 48% of the households have agricultural production sufficient only for 3 months or less. People have adapted to this by shifting to alternative occupations like business, services and offering labour services. Cultivators have responded to decreased water availability by switching from more to less water consumptive crops and diversifying to non-agricultural activities or leaving the land fallow. The availability of water has also been a factor shaping migration and the settlement patterns. In Gurgaon and Hyderabad, farmers have responded by reducing the number of crops. In Gurgaon, farmers are growing one crop instead of two. They have cut down the cultivation of fruits, vegetables and flowers and concentrate now mainly on wheat and mustard in the winter season, and pearl-millet or fodder crops in the monsoon season. In Hyderabad, the adaptive strategies for farmers have been predominantly shifting their cropping patterns from rice to vegetables and fruits. Instead of three rice crops, the farmers now restrict themselves to growing two crops of rice and during the other seasons, grow vegetables. Many have shifted largely towards growing of fruits like papayas and guavas. Some farmers, who are not able to afford a separate tube well for themselves, usually grow rice during the monsoons and vegetables during the remaining months using wastewater from the urban areas. Some also leave their lands fallow and work in the factories or in the city to adapt to a loss of livelihood for a certain period of the year.

## 4 Way Forward

This research has demonstrated how urbanization and climate change impact periurban water security in four South Asian locations and how vulnerable social groups adapt to the situation, innovating both technologically and institutionally. Mainstreaming periurban adaptation practices requires taking a new perspective straddling the rural-urban divide that allows taking into consideration the impacts of urbanization on the peripheral areas. This requires steering away from the conventional rural-urban dichotomy in rural planning and urban development. In particular, it requires a better appreciation of the flows of water between villages and cities, rather than seeing rural and urban water supply as distinct conceptual entities. Urban expansion plans need to be based on studies of local carrying capacity to prevent the ecological foot-print of the cities from spilling beyond the peripheries.

There is no “one size fits all” approach to the sociotechnical mediation of water insecurity in periurban contexts. Research is needed to understand specific adaptation practices suited to local agro-ecological and institutional contexts and then devise ways to support their diffusion.

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