Working paper series

WP/SG/04/2016

Sustainable use of groundwater resource in peri-urban areas of coastal Ganges delta under hydro-climatic and anthropogenic scenarios:

Research note

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June, 2016

Declaration: Following research note describes about the analytical framework for groundwater system mapping used in the project "Shifting Grounds: Institutional transformation, enhancing knowledge and capacity to manage groundwater security in periurban Ganges delta systems" funded by the Urbanising Deltas of the World programme of the NWO, Netherlands Organisation for Scientific Research under grant number W.07.69.104.

Citation: Hasan, Md. Rezaul. 2016. Sustainable use of groundwater resource in peri-urban areas of coastal Ganges delta under hydro-climatic and anthropogenic scenarios: Research note. WP/SG/04/2016, Shifting Grounds project working paper series. South Asia Consortium for Interdisciplinary Water Resources Studies, Sainikpuri, Secunderabad, Telangana and Bangladesh University of Engineering and Technology, Institute for Water and Flood Management, Dhaka, Bangladesh.

First published in June, 2016.

Further information about this report –

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Funded by: NWO Netherlands Organisation for Scientific Research

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Preface

This research note is one of the activities of the project namely "Shifting Grounds: Institutional transformation, enhancing knowledge and capacity to manage groundwater security in peri-urban Ganges delta systems" under the Urbanising Delta of the World-Integrated Project. The project combines knowledge/research, sustainable development and capacity development in an integrated manner. It aims to build knowledge and capacities among local parties in Bangladesh and India to support institutional transformation processes in the peri-urban delta areas of Khulna and Kolkata that leads to a sustainable and equitable management of groundwater resources.

The development of a sound understanding of the subsurface geology and how groundwater resources respond to different stresses is one of the most critical steps in managing groundwater in urban, peri-urban and rural areas. Under the groundwater system mapping of the "Shifting Grounds" project, this research note has been developed based on extensive literature review and pre-scoping visits to pilot study sites. It provides a conceptual framework for assessing groundwater resources in urban-peri-urban-rural interface subject to natural and anthropogenic influences. Groundwater issues are prominent at the local scale in terms of quantity and quality; this is plausibly an outcome of natural and anthropogenic stresses at different scales- from local to regional.

Key words: Ground water, Ganges delta, periurban, sustainable development, Khulna

Sustainable use of groundwater resource in peri-urban areas of coastal Ganges delta under hydro-climatic and anthropogenic scenarios: Research note

I. Background and present state of the problem

Sustainability issues with groundwater resource

Groundwater Water security risks interact with poverty pathways across a number of dimensions, including sustainability of resources (e.g. surface water and groundwater), providing water to different competing needs, and sustainable growth from agriculture and other water using sectors. As long as resources are aplenty, conflicts among different users are minimal; whereas conflicts escalate as water becomes increasingly scarce in terms of quantity and quality. Increasing competition for water resources between agriculture, industry and domestic needs has threatened economic development, food security, livelihoods, poverty reduction and the integrity of ecosystems in many countries. Of particular concern has been the increasing demand of groundwater, which has led to groundwater production exceeding the level of sustainability (Jones, 2011), manifested in gradual and permanent lowering of the water table, deterioration of water quality and saline intrusion in coastal areas.

By 2030, the global population is projected to reach 8 billion with a concomitant increase in demand for irrigation water, while the proportion of the population living in urban areas is expected to rise to almost two thirds. Much of this growth will occur in low- and middle-income countries where the availability of groundwater can be an important catalyst for economic development. Urban-rural tensions are an inevitable consequence of growth, with the most serious risk of conflict occurring at the rural-urban interface (RUI) and in peri-urban areas where groundwater is often the only source of water supply (Foster et al., 2000).

Groundwater in peri-urban areas

In the developing world, it is the rural inhabitants who are amongst the most destitute (IFAD, 2001), and it is those living close to the RUI and the peri-urban settlements who are most seriously threatened by rapid urban growth. For many rural inhabitants, access to a secure source of groundwater provides the only means of escaping abject poverty. Because of its relative ease of extraction, almost ubiquitous extent, negligible treatment requirements, low susceptibility to drought (Calow et al., 2002) and minimal infrastructure costs in comparison to surface water, groundwater provides the rural poor with the prospect of generating income as well as meeting domestic needs. At the RUI, the security of essential groundwater supplies is seriously compromised. Rural inhabitants, and particularly the rural poor, face numerous challenges. There is emerging evidence of contestations and conflicts around multiple usages of groundwater at the rural-urban interface in South Asia (Narain, 2009; Khan and Kumar, 2010; Prakash et al., 2011). Increased climatic variability, degrading surface water sources, land use change coupled up with unequal caste-class-power structures, rules, norms and practices create pressure on already strenuous groundwater tables. Lack of access to groundwater during critical periods affects the livelihood securities of the vulnerable and contributes to the incidence of poverty.

As long as resource is sustainable, groundwater use has many positive impacts, including benefits such as increased productivity, food security, job creation, livelihood diversification, and general economic and social improvement. Historically, in countries like India and Bangladesh, groundwater has played a significant role in irrigated agriculture. In Bangladesh, the groundwater based irrigation has grown from 38 percent in 1985 to 79 percent in 2008 (Habiba et al., 2011, 2013). However, increased abstraction has compromised resource sustainability in some places in the form of excessive lowering of groundwater table, which has also negatively affected the drinking water uses as many hand-tubewells became non-functional (IWM, 2010). Low-income households have been the worst victims because of higher cost of deeper tube-well construction. While groundwater based irrigation has been limited in the southwest coastal region because of high levels of salinity, increased irrigation pumping in the districts north to the region has been a concern in terms of increased salt water intrusion in the coastal aquifers (FAP, 4). In India, groundwater irrigation has contributed to about 60 percent of all irrigated areas (Shah et al., 2003). While, this has largely contributed to rural and economic growth, scarcity in resources has affected rural people likewise.

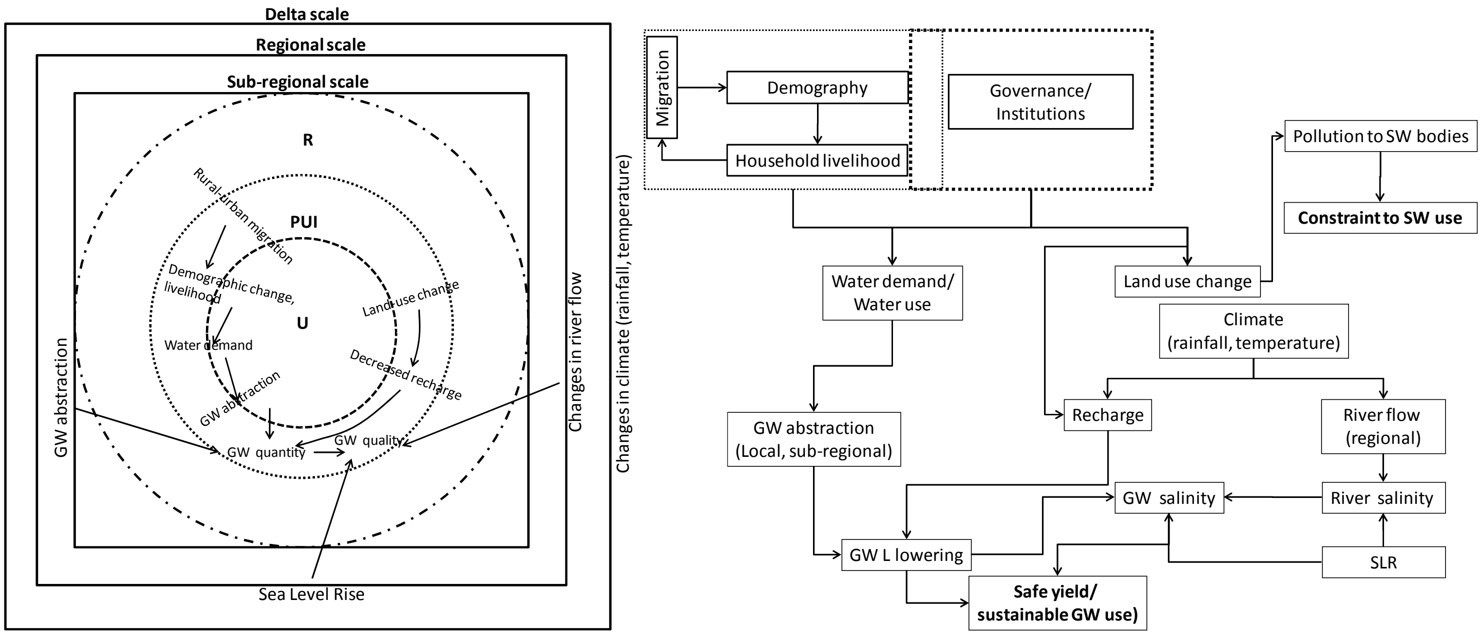
Drivers of change over multiple scales impacting peri-urban areas in coastal Ganges delta

The spread of urbanization is accompanied by the growth of peri-urban areas (Allen, 2003; Narain and Nischal, 2007). Peri-urban areas undergo a continuous and dynamic process of land use change as a result of economic and demographic forces including changes in the agriculture and cropping profile, conversion of agricultural land into residential, commercial or industrial development. Urbanization alters periurban land entitlements, water access and rights, while contestation for periurban resources creates conflicts and weakens resilience, thereby increasing vulnerability (Khan et al., 2013; Narain et al., 2013). From a hydrological point of view, these changes in land use have a direct impact on the water cycle, in particular, the behaviour of runoff generation and the pattern of water demand. One of the perceived effects of human interventions is a disruption of the delicate balance of the hydrologic cycle and of the ecosystem that rely upon it. Recent evidence shows that ground water level has dropped in many areas with immediate effect on plant growth and the availability of drinking water. Urban wastes and wastewater flows to the peri-urban areas degrade the environment and offset the natural balance in the ecosystem or hydrologic cycle.

Sustainability of groundwater resources in terms of both quantity and quality in peri-urban area is thus shaped by a number of inter-linked socio-economic, institutional and biophysical factors or processes, which operate at different spatial and temporal scales and require approaches to resource management that are quite distinctive and rarely fully understood. As illustrated in Figure 1, bio-physical processes operating from delta scale to regional to sub-regional or local scale may become important determinants. The groundwater aquifers are three-dimensional systems, in which replenishment may take place from any or all directions, albeit very slowly; abstraction impact could be seen in any or all directions, manifested over years and decades, with impacts both on upstream and downstream riparians; pollution movement is typically very slow (order of meters per year), with transport controlled by local hydraulics as well as regional aquifer hydraulics depending on the position in the groundwater system.

The growth of cities creates new demands for land at the periphery. They provide the land and water needed for the growth of cities. The growth of cities creates new demands for land at the periphery. Peri-urbanization process is prominent in

Figure 1: Conceptual framework for sustainable groundwater use in peri-urban coastal Ganges delta



Source: Constructed by the author.

Khulna in Bangladesh and Kolkata in India, where urbanization sustains mainly by acquisition and conversion of agricultural land and water bodies in the peri-urban areas (Khan and Kumar, 2010). Because of lack of adequate surface water sources, constrained by salinity, dependence on groundwater has grown over the years. Rural-urban migration contributes to changes in demography, with increases in population often seen concentrated in peri-urban areas. With land use change in urban areas together with changes in demography and economic activities, water demand and water-use patterns also undergo a change. For example, there was a growing tension between urban and peri-urban area in Khulna because of the Khulna City Corporation's (KCC) plan to access groundwater resources from the peri-urban block Phultala to meet its unmet and increasing water needs (Khan and Kumar, 2010). Court orders eventually prohibited the use of these resources by KCC, rendering the KCC investments in transportation pipelines and pumping stations ineffectual.

In peri-urban area itself, increased groundwater abstraction may also cause changes in the same direction, leading to growing conflicts among different users. For example, peri-urban areas in Kolkata suffer from decreasing groundwater tables, salinity and arsenic contamination, affecting access of safe drinking water while agriculture is suffering from dry spells during summer months. Pre-scoping visit under the present study revealed that in Sonarpur block, in deltaic south central Kolkata, decreasing groundwater tables, salinity and arsenic contamination have a direct impact on access to safe drinking water. Industries like Pepsi compete for water with rapidly growing housing complexes, while agriculture is suffering from dry spells during summer months. Pressures and conflict over access to groundwater exist between urban domestic, industrial and rural agricultural users. Around Kolkata, an exponential growth in private tube wells in peripheral areas has largely benefited better off farmers, but has also contributed to inequity across different class and caste groups leading to water insecurity (CSE, 2006). Likewise, land conversion in the peri-urban areas in Khulna to support urban expansion has created conflicts over water access and depleted water resources (Khan et al., 2013; Narain et al., 2013). Conflicts have been reported among communities in peri-urban areas in Khulna because of declining groundwater tables. A pre-scoping visit under the current study hinted that in peri-urban villages of Batiaghata block south of central Khulna, conflicting situation surfaces frequently amongst the shallow tube well owners with regard to ground water usage for irrigation. Practice of fresh water prawn culture has created additional pressure on the already strenuous aquifers, resulting into acute water crises during dry periods.

An important impact of land use change (controlled by vegetative cover and the process of urbanization) on groundwater is the reduction of recharge, which can increase the problems of groundwater lowering several folds. Recharge will also be affected by climate change and variability. In the coastal Ganges delta, groundwater is already impacted by different degrees of salinity and arsenic in different aquifers. Lowering of groundwater levels would mean a negative impact on groundwater quality (particularly, salinity) because of changes in local hydraulic gradients. At the sub-regional scale, increased abstractions in areas where salinity constraints are minimal are also likely to contribute to changes in hydraulic gradient. For example, Khulna is vulnerable to over exploration in upstream areas that may lead to intrusion of saline water into major groundwater sources (Zahid and Ahmed, 2006; Adhikery et al., 2012). Processes operating at regional level, such as changes in river flow and sea level rise, also impact the salinity intrusion. For example, the possible impact of sea level rise on lateral seawater intrusion (World Bank, 2010; Salehin et al., 2016) and vertical salinity intrusion from saline river waters (Salehin et al., 2016; Sanchez et al., 2015) (where river salinity is determined by the combined effect of fluvial river flow and sea level rise) are being increasingly recognized. At the delta scale, changes in precipitation as a result of climate change will have a direct impact on the cross-border flow (between India and Bangladesh) in rivers which drain rainfall-induced runoff from the three big upstream basins, namely, the Brahmaputra, the Ganges, and the Meghna.

In response to observed limitations in groundwater resources, future urban water supply is expected to come from surface water sources, use of which is however constrained because of the effect of urbanization. In Khulna, urban wastewater is discharged to the peri-urban areas, which degrades surface-water quality (Khan et al., 2013; Narain et al., 2013). The most prevalent water-related challenges confronting peri-urban residents include water pollution, increased demand and encroachment of water bodies. Urban wastewater and solid waste have degraded water sources like the Mayur River; water chemistry analysis indicates that the river is heavily polluted.

Such understandings becomes very critical in a transitory periurban context marred by rapidly changing landuse and livelihood patterns with institutions not always equipped enough to manage the fast changing needs, demands and aspirations.Following paper that forms part of the socio-economic system mapping of the research project titled “Shifting Grounds: Institutional transformation, enhancing knowledge and capacity to manage groundwater security in peri-urban Ganges delta systems” aims to create an analytical framework to understand aforesaid questions in a holistic way. The idea is to see whether peri-urban is a space of opportunity or degeneration with reference to groundwater and livelihoods. The aim is to assess whether it creates a space of interaction between actors and groundwater resource leading to enhancement of income, productivity, wellbeing, resilience and adaptive capacities or multiple interests creates conflicts, exclusion and poverty. The scale of analysis is household, where comparison will made between villages of peri-urban Khulna and Kolkata.

II. Objectives with specific aims and possible outcomes

This PhD work is part of the "Shifting Grounds: Institutional transformation, enhancing knowledge and capacity to manage groundwater security in peri-urban Ganges delta systems" project under the Urbanising Delta of the World-Integrated Project. The “Shifting Grounds” project combines research, sustainable development and capacity development in an integrated manner. It aims to build knowledge and capacities among local parties in Bangladesh and India to support institutional transformation processes in the peri-urban delta areas of Khulna and Kolkata that leads to a sustainable and equitable management of groundwater resources. This PhD research investigates the present situation of the complex, fragmented and composite groundwater aquifers in the study area (Khulna and Kolkata) in terms of quality and quantity and assesses the impacts of natural and anthropogenic influences at regional and local scales under different scenarios. The outputs of this study together with the studies to be conducted by another PhD (on the evolution of existing institutional rules and social arrangements and their functioning) and Post-Doc (on mapping of groundwater use for different livelihood activities as well as conflict and cooperation among users) researchers in the project will provide insights into possible institutional transformations to support a more sustainable and equitable use of groundwater resources.

The proposed research will be carried out for the fulfillment of the following objectives:

i. To investigate the evolution of peri-urban area as a result of urbanization process in Khulna and Kolkata in the Ganges coastal delta;

ii. To assess the impacts of urbanization process, including physical, socio-economic and institutional forces, on groundwater resources;

iii. To analyze the impacts of hydro-climatic and anthropogenic processes, operating over in larger delta system over different time scales, on sustainable groundwater use in peri-urban area;

iv. To investigate if sustainable groundwater use can be achieved by considering balanced use of groundwater and available surface water resources.

Expected Outcome

Assessment of sustainable groundwater use, that in peri-urban areas, as an outcome of inter-linked socio-economic, institutional and biophysical processes operating at different spatial and temporal scales is rarely conducted and the relative importance of the multi-scalar processes is fully understood. Assessment of change in land use and hydro-geological assessment of vulnerable coastal aquifers are often carried out in silos. This study will allow theorising land use change and corresponding impacts on groundwater, and an improved understanding of the linkages between socio-economic, institutional and bio-physical processes and an integrated assessment of different interacting factors having influence on sustainable groundwater use. This study will also provide a unique opportunity to compare the way different factors interact in two settings in two countries in the same Ganges delta and explore how country level aspects have resulted in different management outcomes. While there may be similarities in the hydro-geological and other physical settings, there are expected to be dissimilarities in institutional setting, and to some extent socio-economic setting between the two study locations.

III. Review of state-of-the-art literature

The development of a sound understanding of the subsurface geology is one of the most critical steps in managing groundwater in urban, peri-urban and rural areas. This helps estimate aquifer configuration and extents, thereby providing guidance for more effective characterisation efforts and enabling improved input to groundwater models and improved predictions of groundwater flow-system dynamics. Understanding the geological processes responsible for the original deposition of the rock or sediment framework in the Ganges delta is thus important. Besides, it is important to understand the regional and local level aquifer system, the availability of groundwater shaped by geology, climatic variability, major river systems, land use patterns and recharge process. A look into the historical use of groundwater resources and the consequences of different bio-physical and socio-economic processes on the groundwater resources sustainability will help formulation of a conceptual framework of analysis.

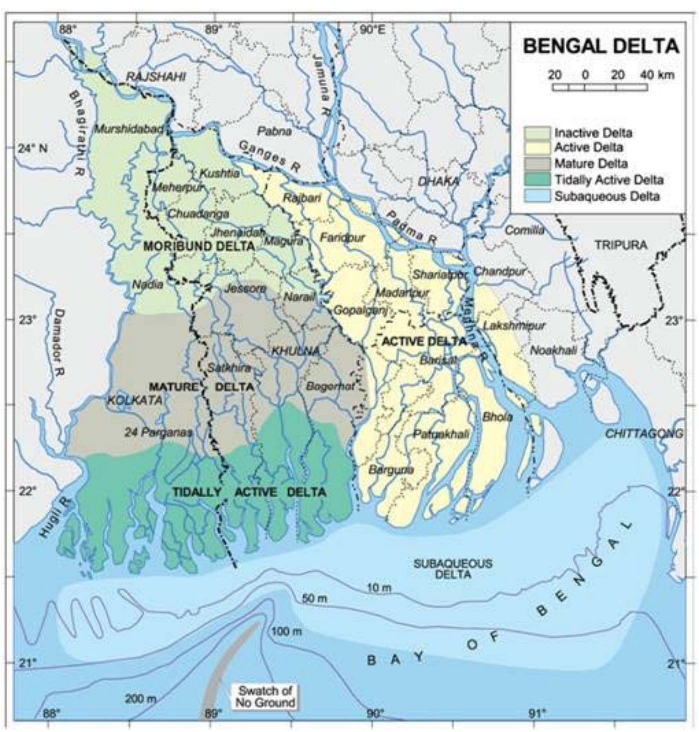
Against this backdrop, a review of literature is presented in this section. The review has principally focused on the groundwater systems in the Ganges delta and the vulnerability of groundwater resources to different climatic and anthropogenic processes which operate at different spatial and temporal scales.

The Ganges Delta

The Ganges delta covers a large area of the Bengal basin (the lower part of the Bengal Basin), distributed over Bangladesh and a major part of West Bengal (India) with an area of about 80,000 sq. km. Sedimentation in the basin started during the Late Cretaceous (Alam, 1989; Lindsay et al., 1991), with a fluvio-deltaic landscape evolving during the Quaternary (Umitsu, 1993) which also characterises the present-day basin topography. The present-day aquifer-system occupies the uppermost few hundred metres of the sedimentary sequence deposited since Mio-Pliocene time, overlying a basin-wide marine clay at 1200–2000 m below the ground surface (Burgess et al., 2010). The Bengal aquifer system is made up of unconsolidated Pilio-Pleistocene-Holocene sediments, which host a number of regional aquifers. Moreover, avulsion of the major streams in the area, which are either tributaries or distributaries of the Ganges or Brahmaputra, within a time scale of 100 years, has resulted in a recent sediment sequence of about 100 m of overbank silts and clays incised by channel sands (Coleman, 1969; Umitsu, 1987; Goodbred and Kuehl, 2000; Allison et al., 2003).

The rivers Ganges and Brahmaputra flow into the present Ganges delta from the northwest and the north, draining the northwestern and northeastern portions of the Himalayas to the Bay of of Bengal over the delta. At the extreme south, the delta is about 360 km wide along the Bay of Bengal. The delta can be divided into four major categories: i) Moribund delta, ii) Mature delta and iii) Active delta and iv) Tidally active delta (Figure 2) (Passalacqua et al., 2013; Benerjee, 2013; www.banglapedia.org). The *moribund delta* refers to the western part of the deltaic plain, bound on the east by the Ganges and Gorai- Madhumati Rivers, comprising an area of about 18000 km^2 in southwestern Bangladesh and West Bengal. The *mature delta* covers an area of about 31500 km^2 in the two countries, while the eastern *active delta* covers an area of about 16500 km^2. The *tidally active delta,* dominated by coastal tidal currents, refers to the southwestern part (the Sundarbans region) of the Ganges delta in the coastal zone, covering an area of about 13500 km^2.

Figure 2: Map of the Ganges-Brahmaputra Delta

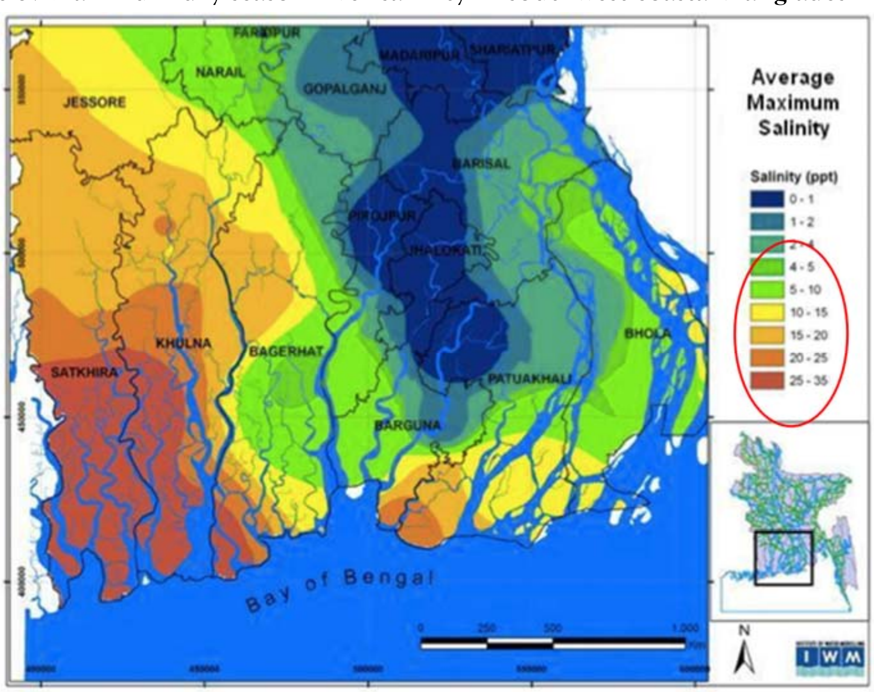


Source: Banglapedia (www.banglapedia.org).

River system

An understanding of the river system in the Ganges delta and its interaction with the groundwater system is imperative since groundwater flow is controlled by the topography and locations of major streams and exchange between rivers and Holocene groundwater aquifers takes place since they are hydraulically connected (Ahmed and Burgess, 2003; Ravenscroft, 2003). The coastal Ganges delta is fed by the river systems of three mighty rivers, the Ganges, the Brahmaputra, and the Meghna, which drain the runoff generated from precipitation in the three big basins of the rivers. While heavy flow during the monsoon may lead to fluvial hazards (e.g. floods), the dry season flow in the rivers is important in-stream water requirements, especially for pushing back the salinity front towards the sea (Rahman and Salehin, 2013). The diversion of Ganges water at Farakka to Hoogly-Bhagirathy river, has reduced the dry season flow and caused river salinity ingression in southwest coastal region in Bangladesh, especially in Satkhira and Khulna as shown in Figure 3 (Dasgupta et al., 2014; Salehin et al. 2011). The Ganges is the most significant river of the Indian part of the Ganges delta. The whole delta is criss-crossed by innumerable large and small channels of which some are decaying, some are active, while some others are being drained only by the tidal flow. In

Figure 3: Maximum dry season river salinity in southwest coastal Bangladesh



Source: Dasgupta *et al.* (2014).

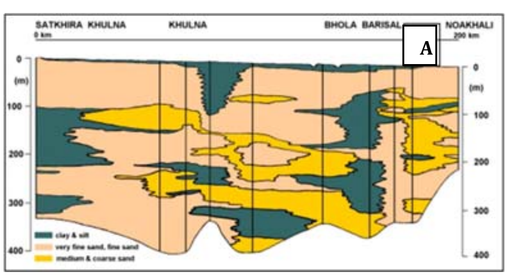
the northeastern part of the delta there are some abandoned or partially abandoned courses of decaying rivers while the eastern and southeastern delta is characterized by the flow of active rivers with heavy discharges. The southwestern portion of the Ganges delta, which includes the world's largest mangrove forest, the Sundarbans, is completely a maze of tidal creeks and channels (Banglapedia: www.banglapedia.org). The rivers in the Ganges delta have experienced changes in courses historically (Halcrow et al., 1993).

Hydrogeology and regional aquifer system

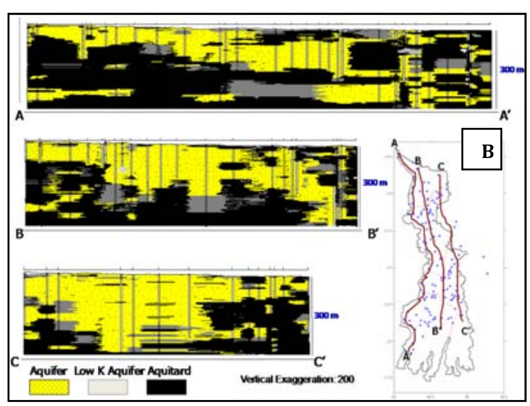
Highly productive aquifers occur within thick unconsolidated alluvial sediments of the Pleistocene and Holocene ages that were deposited by the GBM river system (Shamsudduha and Uddin, 2007). Sediments of very different nature or of different geological age can be found at similar depths since the sedimentation rate was not uniform during that geological time. Aquifers have been conceptualized differently in different studies (e.g. BWDB-UNDP, 1982; Aggarwal et al., 2000; DPHE-BGS, 1999; BGS-DPHE, 2001). The geological cross-section is presented below (Figure 4). In coastal area these aquifers can be classified as follows.

The shallow i.e. the 1st aquifer, the upper Holocene aquifer, extends down to 50 to over 100 m, all over the deltaic and flood plain areas, below a considerably thick upper clay and silt unit in many places. The aquifer sediments are composed of fine

Figure 4: Geological cross-section of the Ganges Delta (A) across the coastal areas of Bangladesh; (B) across the Indian part of Ganges delta.



Source: DPHE-BGS (2001)



Source: Fryar and Mukherjee (2006)

sand with lenses of clay. Age of water from this aquifer is dated as about 100 years old; water in these aquifers are affected by the arsenic contamination in many places. The main or the 2nd aquifer, with sedimentary sequence from mid-Holocene, represents water bearing zone that extends down to 250-350 m and is generally underlain and overlain by silty clay bed, and composed mainly of fine to very fine sand, with some coarser sand in the upper part, occasionally inter-bedded with clay lenses. Water from this aquifer has been dated as about 3000 years old. Groundwater is drawn predominantly from these strata. The deep i.e. the 3rd aquifer, with sedimentary sequence from late Pleistocene to early Holocene, has been encountered to depths of 300-350 m, generally below a silty clay aquitard. This aquifer is composed mainly of gray to dark gray fine sand that in places alternates with thin silty clay or clay lenses. Appearance of clay or silty clay aquitards are not common in all locations i.e. on a regional basis aquifers down to the investigated depth of 350 m seems hydraulically connected. However, in many places 3 to 4 aquifer units are encountered separated by aquitards and limited scale abstraction of groundwater from any aquifer depth does not affect the others.

Groundwater in the Gangetic Alluvial area (the northern part of the Ganges delta) occurs mostly under unconfined condition in the shallow aquifer and under semi confined to confined condition in the deeper aquifers, separated by clay layers. In some areas in the Bangladesh part, the upper aquifer is of leaky or mixed type, and in some areas, absence of any significant clay beds make the entire aquifer system behave as a hydraulically connected, composite aquifer under water table condition (Fryar and Mukherjee, 2006). The depth to water table in the area varies from less than 2 m to 10 m bgl in pre-monsoon period and from less than 1 m to 5 m bgl in post monsoon period with seasonal fluctuation varying from 1 to more than 4 m and the flow of groundwater is towards east and southeast.

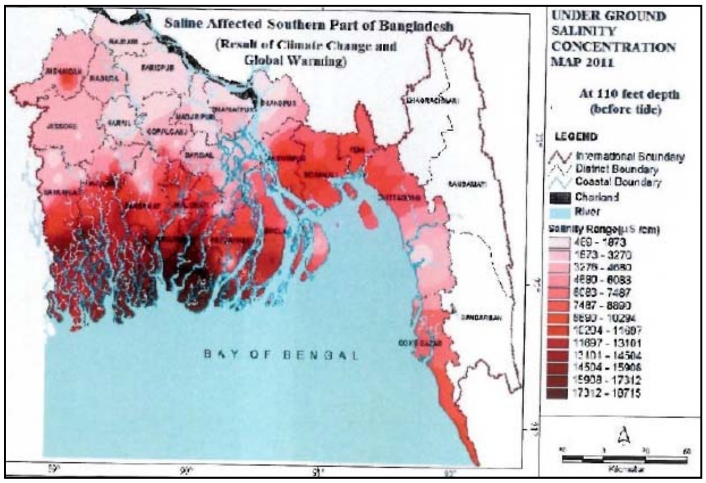
Recharge

Groundwater flow is dependent on the amount and timing of precipitation, and is controlled by the relatively flat topography and locations of major streams, but has been heavily distorted by pumping. The principal source of recharge in the shallow upper aquifer is rainfall. On average, pre-monsoon rainfall contributes 16.23 percent of the annual rainfall, monsoon 82.2 percent and post-monsoon 1.6 percent (GHCN, 2005). A previous study found that recharge has increased substantially (5–15 mm/year) in northwestern, western and north-central districts, but has slightly decreased (−0.5 to −1 mm/year) in the southern parts of the delta and some parts of the northeastern region, and remained unchanged in the rest of Bangladesh over a period from 1985 to 2007 (Shamsuddoha et al., 2010). Besides monsoonal precipitation, flood water together with rainwater in the floodplains with enough residence times also contribute to recharge to some extent. Water levels in almost all river channels rise above groundwater levels in adjacent aquifers during the monsoon season for a few months; however, indirect recharge is restricted to lateral river-bank infiltration during the early monsoon time between April and June (Rahman and Chowdhury, 2003). Recharge in the deep groundwater aquifers is lateral, with the recharging areas lying in the hill regions at the eastern boundary of the basin. Isotopic studies (Aggarwal et al., 2000; Mukherjee et al., 2007; Hasan et al., 2009; Hoque and Burgess, 2012) found the age of water in deeper aquifers to be several thousand years (ka). Deep groundwater is shown to have been recharged in the range 3–9 Ka (mean 7.6 Ka), under climatic conditions similar to the present day (Hoque and Burgess, 2012). Recharge rates estimated from the groundwater ages are close to an estimate of the current rate of deep groundwater abstraction.

Salinity in groundwater

The complex hydrogeology of the coastal aquifers in Bangladesh means that aquifer characteristics are seldom continuous and uniform. The occurrence of brackish and saline water in the coastal aquifers of Bangladesh hence does not follow any regular pattern spatially or vertically, with substantial differences over relatively short distances. Potential salinization sources in the coastal aquifers are generally diverse, including natural saline groundwater, halite dissolution, presence of paleo-brackish water, seawater intrusion etc. Among these, seawater encroachment is the most common and widespread phenomena in coastal areas in Bangladesh. However, vertical infiltration of saltwater due to storm surges or intrusion from brackish tidal rivers can occur more quickly than lateral subsurface migration of saltwater, particularly when inundation events are repetitive (WB, 2010). The salinity in the extensive river network in the southwest coastal area is the major contributor to groundwater salinity in the upper shallow aquifer. The figure 5 shows groundwater salinity distribution in southwest Bangladesh (BADC, 2013). This aquifer is hydraulically connected to the river system, is thus more vulnerable to sea level rise and the resulting increase in river salinity.

Figure 5: Salinity distribution in the shallow groundwater aquifer in southwest coastal Bangladesh



Source: BADC (2013)

Lateral seawater intrusion is an extremely slow process, on the scale of thousands of years, in coastal Bangladesh (WB, 2010). The potential impact of sea level rise on lateral intrusion is expected to be pronounced in proximity to the sea, while it would diminish substantially inland over shorter time scales. The major impact of sea level rise would be via the increase in river salinity, which in turn will contribute to increase shallow aquifer salinity as a major source (Salehin et al., 2016; Sanchez et al., 2015). In the shallow (i.e. 1st) aquifer, fresh groundwater (EC <1000µS/cm) is noticed in areas of Patuakhali, Barishal, Satkhira, Jessore, Narail districts while brackish water (EC 1000-2000µS/cm) occurs in areas of Shariatpur and Gopalganj. Salinity (EC >2000µS/cm) occurs in the shallow aquifers of Shariatpur, Barguna, Barishal, Bhola, Pirojpur and Jhalokathi districts. Water in the second aquifer is fresh to brackish in nature and is tapped extensively for drinking water purposes. This aquifer is comparatively less vulnerable to sea level rise. Fresh water occurs in the main (i.e. 2nd) aquifer of Barguna, Patuakhali, Barishal, Bhola, Satkhira and Jessore district areas. In the deeper (i.e. 3rd) aquifer, fresh water occurs in Barguna, Patuakhali, Barishal, Bhola, Satkhira, Jessore, and Narail district areas. However, salinity distribution in the deep aquifers is not well known.

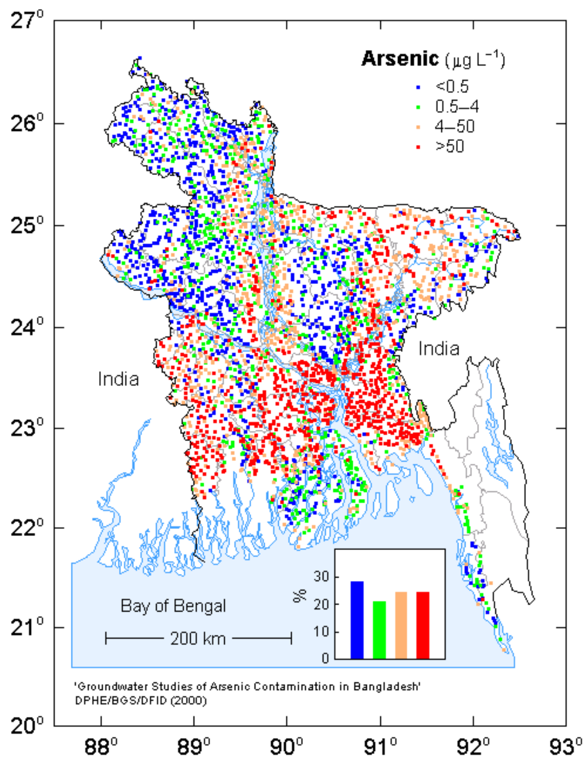
In Indian part of the Ganges delta, the coastal belt of Medinapur, South 24 Parganas, Hooghli and Haora districts, lying in the active delta of the Ganges, groundwater in upper aquifer (within depth of 160m bgl) is brackish with high chloride and high TDS. In the lower deltaic area (the 20-30 km wide coastal zone falling in 34 blocks in two districts: 5 blocks in North 24 Parganas and 29 blocks in South 24 Parganas), a group of fresh water aquifers occur within the depth span of 120-360 m bgl, sandwitched between saline aquifers (Mukherjee et al., 2007). The area is overlain by a thick clay later and underlain by a 20-30 m thick blanket of surface clay below which brackish water aquifers occur within a depth of 120 m bgl in the western part of Hugli river. The thickness of the top clay blanket increases up to 100 m at some places towards further south and south east. A 15-20 m thick impervious clay layer separates the brackish water aquifers from the underlying fresh water aquifers. These freshwater aquifers are again underlain by a group of brackish aquifers separated by a thick blanket of impervious clay layer.

Arsenic in groundwater

Arsenic in groundwater in the alluvial and deltaic plains of Bangladesh and West Bengal (India) has resulted in the worst case of mass chemical poisoning in the world (Smith et al., 2000). The first recognitions of an arsenic problem in the GMB region came in 1983 from West Bengal (Garai et al.,1984) and in 1993 from Bangladesh (BGS and DPHE, 2001).

A national survey of arsenic in groundwater (BGS and DPHE, 2001), using some 3,500 groundwater samples, found that 27 percent of samples from the Holocene shallow aquifer (<150 m depth) contained arsenic at concentrations exceeding 50 μg L-1, and 46 percent exceeded 10 μg/l. This affected an estimated 35 million people, with 57 percent affected by concentrations above 10 μg/l. The occurrence of arsenic in groundwaters in Bangladesh (BGS-DPHE, 2001) is shown in Figure 6 where it is seen that arsenic concentrations exceeding drinking water limits (50μg/l) were concentrated in the south and south-east of the country. A later survey by UNICEF/DPHE of 317,000 tube wells from the south of Bangladesh found that 66 percent contained arsenic above the threshold concentrations with only 10 percent with lower than 10 µg/l (BGS-DPHE, 2001). The northern fringe of Khulna is affected by arsenic while the areas in the south are relatively free from arsenic (Figure 6).

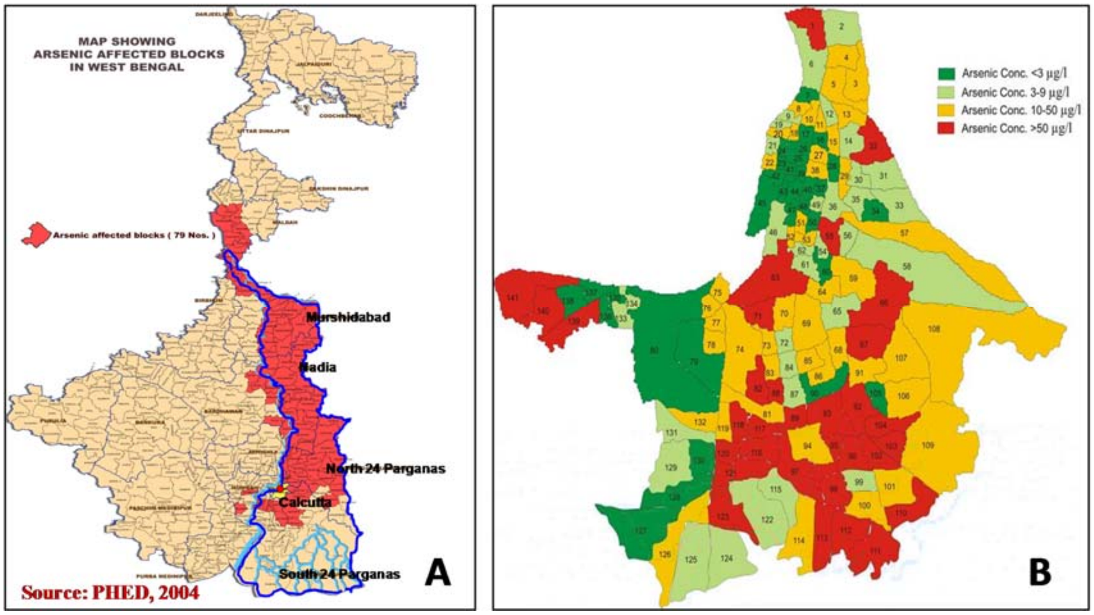
Figure 6: Arsenic concentrations in groundwater in Bangladesh



Source: BGS-DPHE (2001).

The problem is little less severe in India but it is estimated that about 6.5 million people are drinking water with arsenic concentrations greater than 50µg/l. The occurrence of arsenic, as a pollutant in groundwater, has been found sporadically within a linear tract extending NNW-SSE from Kaliachak block of Malda district along the eastern part of Bhagirathi river in Murshidabad, Nadia, North 24 Parganas & South 24 Parganas districts (Figure 7). The concentration of arsenic above permissible limit (0.01mg/l) has been found sporadically in the aquifers in the depth span of 20 to 100 m bgl (Chakraborti et al., 2003; Mukherjee et al., 2006).

Figure 7: Occurrence of arsenic in India: (A) arsenic affected blocks in West Bengal; (B) Arsenic concentrations in groundwater in Kolkata



Source: PHED (2004). *Source*: www.soesju.org

The distribution of arsenic, as described above, is quite strongly correlated with depth, which in turn relates to the age of the sediment and the aquifer properties and flow characteristics. Shallow groundwater, the primary water source in the Bengal Basin, contains up to 100 times the World Health Organization (WHO) drinking-water guideline of 10µgl−1 arsenic (As), threatening the health of 70 million people. Groundwater from a depth greater than 150 m, which almost uniformly meets the WHO guideline, has become the preferred alternative source. The main depth range of the high arsenic is between 10-80m (BGS-DPHE, 2001; McArthur et al., 2004), almost entirely within the shallow aquifer. The vulnerability of deep wells to contamination by As is governed by the geometry of induced groundwater flow paths and the geochemical conditions encountered between the shallow and deep regions of the aquifer. Basin-scale groundwater flow modelling by Burgess et al. (2010) suggests that, over large regions, deep hand-pumped wells for domestic supply may be secure against As invasion for hundreds of years. By contrast, widespread deep irrigation pumping might effectively eliminate deep groundwater as an As-free resource within decades.

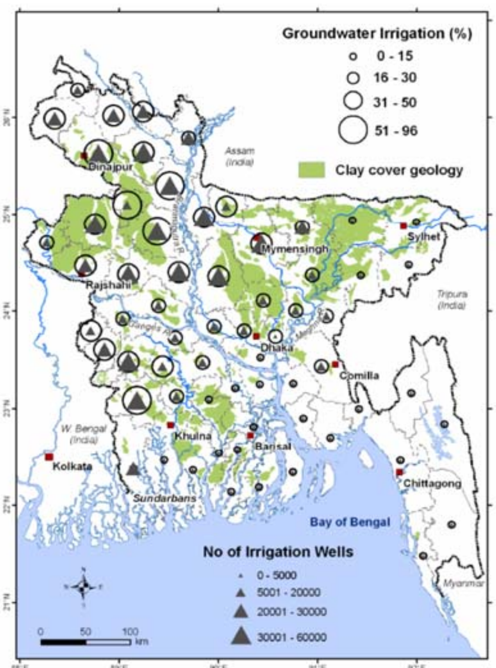
Groundwater extraction for irrigation

Groundwater has rapidly emerged to occupy a dominant place in India and

Bangladesh's agriculture, food security and water supply in recent years, and has had a major positive impact on poverty alleviation. India ranks first and Bangladesh ranks 6th globally in terms of area irrigated by groundwater; the numbers are 39.4 million ha for India and 3.5 million ha for Bangladesh (Siebert et al., 2010). Groundwater is found to be a superior source of irrigation compared to surface water because of better control over water availability and use to the farmers, better yields, higher cropping intensity, and higher profitability (Vasant et al., 2011).

In Bangladesh, the groundwater based irrigation has grown from 38 percent in 1985 to 79 percent in 2008 (Habiba et al., 2011). Increasing demand led to rapid expansion of DTWs and STWs during the late 1970's and the 1980's. The growth of STWs started to dominate since 1990's, with number of STWs growing from 133,800 in 1985 to 925,200 in 2004 (Zahid et al., 2006) (Figure 8), with STWs covering approximately 80 percent of the groundwater-fed irrigation water by 2006 (BBS, 2009). While groundwater is intensively used for dry season irrigation in many parts of Bangladesh (BRRI, 2004; Rashid, 2006; Ravenscroft et al., 2009), its use is comparatively much less in the case

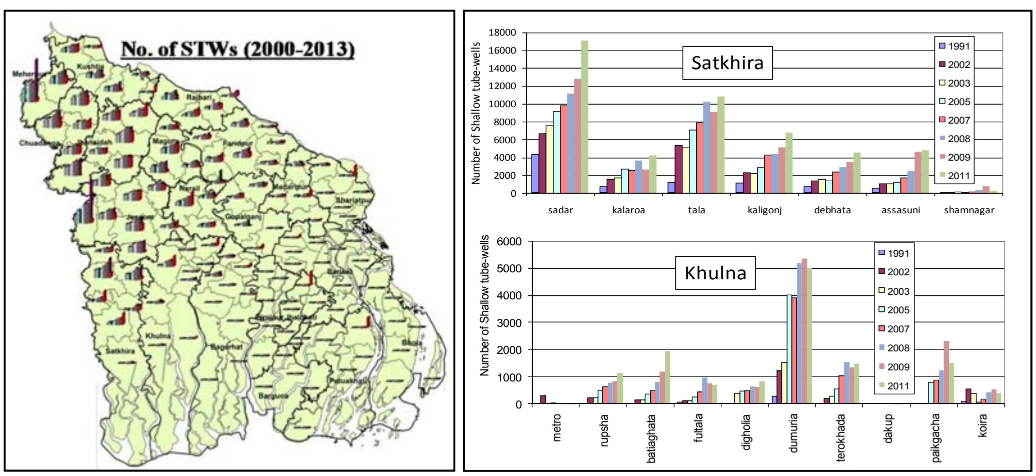
Figure 8: Groundwater irrigation in Bangladesh



Source: Salehin *et al.* (2015).

for the coastal zone for fear of groundwater depletion and salt water intrusion in the coastal aquifers (ICZMP, 2004). Agricultural land use in the coastal area in general, and in Satkhira and Khulna, in particular, is severely constrained by soil, surface water and groundwater salinity; the result is a much lower cropping intensity in these areas compared to the country's average cropping intensity (PDO-ICZMP, 2004). The irrigation coverage in the coastal zone is only 30 percent of the net cropped area, compared to 50 percent in the country. While irrigation, albeit less compared to the rest of the country, has been principally based on groundwater through the use of STWs in southwest Khulna Division (Akter, 2012), surface water has been the principal source of irrigation water in the southern central Barisal Division. Irrigation has progressively developed in the two districts, with a clearly increasing trend. In Satkhira district, most of the irrigation has been developed in Sadar and Tala Upazilas while in Khulna district, irrigation development has been maximum in Dumuria Upazila (Figure 9).

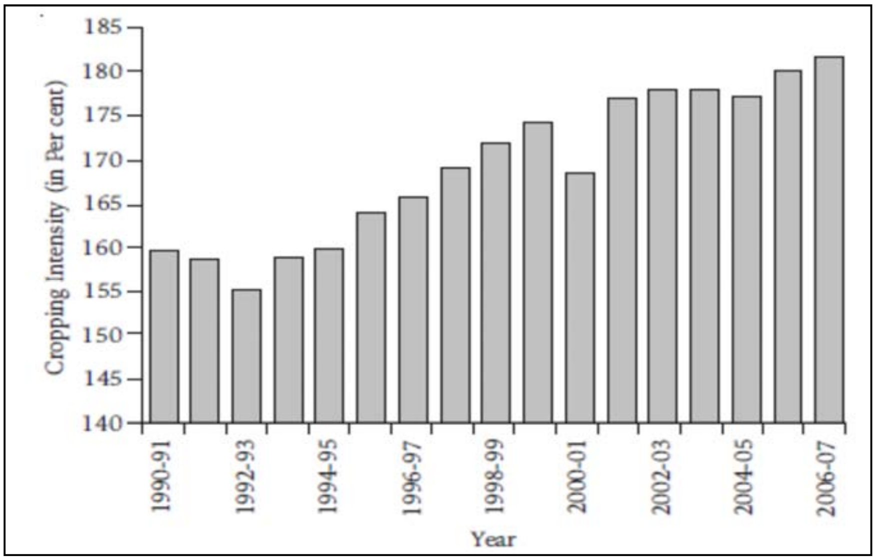
Figure 9: Development of irrigation in: (a) greater southwest coastal region of Bangladesh; (b) in Satkhira and Khulna districts



Source: Salehin *et al.* (2016).

In India, the net irrigated area tripled from 21 million hectares in 1950–1 to 63 million hectares in 2008–9; the share of groundwater irrigation through wells rose substantially from 28 per cent to 61 per cent. The main contribution in this came from rapid growth in tube well irrigation, the share of which rose from zero in 1950–1 to over 41 per cent by 2008–9 (Vasant et al., 2011). The introduction of multiple cropping of nontraditional varieties of seeds with proper irrigation led an increasing in cropping intensity by more than 20 percent between 1980-81 and 2006-07. As shown in Figure 10, cropping intensity in West Bengal increased substantially during the 1990s and thereafter, contributing to the increase in gross cropped area in the state (Figure 10). This rise in cropping intensity is associated mainly with an unprecedented increase in the cropped area of Boro rice.

Figure 10: Growth in cropping intensity for irrigation in West Bengal, India



Source: GoI (2010).

However, despite its huge significance and importance, groundwater irrigation is heading for a crisis and needs urgent attention and understanding in India. The number of irrigation blocks labelled as overexploited is increasing at an alarming rate of 5.5 per cent per year. There is rapid growth in pump numbers and power consumption related to irrigation and clear evidence of substantial water level declines.

Groundwater extraction for drinking water

Commendable success has been achieved in drinking water supply in rural areas of southwest coastal region in Bangladesh through sinking of tubewells in the deep aquifers (PDO-ICZMO, 2004). However, major problems still persist in many areas because of non-availability of suitable aquifers at greater depths and salinity and arsenic constraints in shallow aquifers. City water supply is also based on groundwater. The Khulna city covers an area of 46 sq. km and the population of the city, under the jurisdiction of the city corporation, was about 1 million in 2010 estimation. According to official source, KWASA authority currently supplies about 100 million liters of water every day against the demand for 240 million liters in the city of 1.5 million inhabitants. Prior to the dry season, the daily water supply was about 130 million liters. Besides salinity, there are water quality problems in GW in different wards of KCC area.

Kolkata, one district of West Bengal, is at present the largest city (area 185 km^2 and nighttime population 4.6 million) of eastern India. The present drinking water demand in Kolkata is around 1262 million liters per day (MLD). The Metropolitan Authority supplies through pipeline 1209 MLD of which 1096 MLD is treated surface water and the rest is groundwater. Groundwater resource of the city of Kolkata is being developed on a large scale since the late 50s. The extent of groundwater development can be understood by the following data of groundwater withdrawal from Kolkata Municipal Corporation owned tubewells (Banerjee and Roy, 1992; Sikdar, 1999): 1956 – 55 million litres per day, 1989 – 182 million litres per day and1994 – 227 million litres per day. As a result of this development, there has been a noticeable change in the hydrological regime.

Land use change

An understanding of land use change is basic to driver in periurban transitions. In south-west part of Bangladesh, the major land uses comprise agriculture, shrimp and fish farming, forestry, urban development and other settlement because of increasing demand and huge populations in the corresponding areas (Ahmed, 2011; Mia and Islam, 2005; Quasem, 2011). Literature shows the land use in this area as diverse, competitive and often conflicting (Alam et al., 2002; Islam et al., 2006) and is intensively used for agro and shrimp farming with changes (Mia and Islam, 2005). PDO-ICZMP (2004) showed that per capita agro land in Barisal and Khulna divisions in Bangladesh in 2003 was 0.056 ha and could be decreased to only 0.025 ha by 2050. Islam et al. (2014) shows that the agricultural lands in the Khulna division have been reduced by approximately 50 percent in a span of 28 years (1980-2008). However, the Sunderbans (nearly 40 percent) of the study areas remained almost constant. The rest of the area was covered mostly by agricultural lands, wetlands, settlement and other.

The settlement and other land use type has also been increased to nearly 5 percent. The continuous decline of agricultural land due to salinisation has been attributed to the conversion of agricultural land into shrimp farming in the study area affects the lives and livelihood of the poor people.

The overall land use pattern in the state of West Bengal depends mostly on the physiographic condition of the area. Total geographical area of the state is divided into two major classes i.e. (a) arable land, that includes net sown area and fallow land (b) non-arable land, which includes forest, area not available for cultivation and other uncultivable land excluding current fallow. The percentage of arable land is about 66.8 percent and about 33 percent land is under non-arable category, which includes forest area to the tune of 13.38 percent of total geographical area. Agricultural activities are mostly restricted to the Gangetic plains having fertile cultivable land. The percentage of net shown area is higher (above 70 percent) in Nadia, Murshidabad, North 24-Parganas and Hoogli.

IV. Conceptual framework and methodology

The conceptual framework of research is illustrated in Figure 1. However, it is elaborated for each of the research questions below.

Research question 1: How has the peri-urban area evolved as a result of urbanization process in the Ganges coastal delta?

<u>Conceptual framework:</u> Peri-urban areas in Khulna and Kolkata undergo a continuous and dynamic process of land use change as a result of bio-physical, social, demographic, economic, political and cultural forces, manifested in changes e.g. in the agriculture and cropping profile, conversion of agricultural land into residential, commercial or industrial development. Continuous expansion of urban areas is associated with more and more rural areas gradually being subject to the dynamics of peri-urbanization, involving changes in land use and water demands, thus increasing stress on the already vulnerable groundwater resource. Since peri-urban areas are involved in a process of 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.

Bio-physical and socio-economic forces behind land use change represent both macro and micro level processes and changes; macro level factors include land policies, markets and trades, aggregate population growth and technology development, while micro level factors include land's bio-physical characteristics, the human and economic endowment of the households and community characteristics. Social forces include population growth, demographical change and rural-urban migration. Physical forces include urban expansion and expansion/improvement of road network, the latter (increasing connectivity urban facilities and regional road network) contributing substantially to increasing land value. Economic forces include land value change and associated changes in livelihoods or livelihood growth, and changes of outcome from land. For example, conversion of agricultural land to non-agricultural uses has been associated farmers shifting to other livelihood activities (e.g. agricultural laborers, factory workers, etc.). Aman cropped areas have been converted to shrimp cropped areas, since shrimp farming is more profitable than traditional farming.

<u>Methodological framework:</u> In the first step, a quantitative estimation will be made of the historical trend in land-use changes. This will involve analysis of remotely sensed satellite images in GIS environment to detect land use changes in the urban-periurban-rural envelope. Following collection of city development (master) plans of different agencies (e.g. KDA, KCC and KWASA of Khulna), the historical land use trends will be compared with the proposed plans in the second step in order to theorise causes of land use changes in spatial context and develop a conceptual model of land-use change as an outcome of urbanization and peri-urbanization processes, driven by different physical, social and economic forces. Different scenarios of future land use changes will be developed in the fourth step based on the conceptual model in consideration of different socio-economic scenarios.

Research question 2: How is groundwater resources (quantity and quality) impacted by the urbanization process and associated changes in physical, socio-economic and institutional systems?

<u>Conceptual framework:</u> Groundwater uses in peri-urban Khulna and Kolkata are already constrained by degraded groundwater quality as a result of arsenic and high concentrations of salinity in the upper aquifers. In addition, seasonal (dry season) groundwater table decline in peri-urban and rural areas causes stress on shallow tube well users. City water supply is plagued by the huge imbalance between water

availability and demand. Continuous expansion of urban areas is associated with more and more rural areas gradually being subject to the dynamics of peri-urbanization, involving changes in land use and water demands, thus increasing stress on the already vulnerable groundwater resource in terms of both quantity and quality.

Urbanization will have a direct impact on resource availability through reduction of recharge areas, which can be considerable if the lateral recharge from upstream areas is not enough. Conversion of land to industries and residential areas is likely to increase the use of groundwater and consequently increased lowering of water table, leading to increased inequity. Serious declines will reduce well yields, which can provoke an expensive of borehole deepening to regain productivity. This can induce serious water quality deterioration as a result of ingress of sea water, up-coning, or intrusion of other saline groundwater and high contamination of arsenic due to linkage to groundwater depletion. Population growth and rural-urban migration will increase the city water demand substantially. While construction of deeper wells may be geologically constrained, or may be a partial and temporary solution, there may be a shift towards supply wells developed in increasingly remote peri-urban areas, with the city becoming a major net importer of water. This may bring forth additional stresses to the sustainable use of groundwater in peri-urban areas.

<u>Methodological framework:</u> The focus is on the behaviour of the groundwater system in response to natural and human-induced influences, operating on different spatial scales. In the first step, a data base for aquifer delineation in terms of quantity and quality and setting up for groundwater flow model will be created, with an inventory of all available data relevant for the study. This will be associated with designing primary data collection (principally pertaining to the physical dimension in terms of groundwater level and quality; socio-economic and institutional information will mostly come from the household level qualitative and quantitative field work to be led by researchers from TU Delft and SaciWATERs in the primary study locations selected for in-depth investigation into institutional and socio-economic dimensions of groundwater security. In the second step, a hydrological water balance model will be used to simulate recharge (in spatial context) for different land use scenarios. Two models are being considered for this purpose, the Single Cell Thana model (MPO, 1986) and the Wetpass water balance which is being increasingly used model worldwide

(Paul, 2006). Development of the geological framework is in the third step. The development of a sound understanding of the subsurface geology is one of the most critical steps in managing groundwater. This will mean understanding the geological processes responsible for the original deposition of the rock or sediment framework, which will help estimate aquifer configuration and extents, thereby providing guidance for more effective characterization efforts and enabling improved input to groundwater models and improved predictions of groundwater flow-system dynamics. The next step includes development of an understanding of the groundwater-flow system through analyses of hydraulic head measurements, pumping test results, and other relevant hydrogeological data. Systematic interpretation of information from a variety of sources will help develop an integrated understanding of groundwater systems and hence a conceptual groundwater model at local and regional scales. Numerical models for groundwater flow and variable density transport will then be set-up using available groundwater models, MODFLOW and SEAWAT (Langevin et. al, 1999). The assessment of a set of indicators will be key in the analysis, which includes total groundwater abstraction/groundwater recharge, safe yield (total groundwater abstraction/exploitable groundwater resources), groundwater depletion, groundwater vulnerability, groundwater quality, dependence of agricultural population on groundwater, land use impacts, surface water-groundwater interactions (in terms of quantity and quality).

Research question 3: How can sustainable groundwater use in peri-urban area be affected by hydro-climatic and anthropogenic processes in larger delta system over longer time scales?

<u>Conceptual framework:</u> Both climatic and non-climatic processes are likely to impact the sustainability of peri-urban groundwater resource and use. Changed precipitation will impact the groundwater recharge phenomenon, while sea level rise will impact salinity in the groundwater. While the lateral seawater intrusion process is extremely slow, on the scale of thousands of years, the major driver for increase in groundwater salinity will be increased river salinity as a result of increased sea level. Anthropogenic influence in the form of further reduction of dry season fluvial flows in the rivers will exacerbate the salinity intrusion into groundwater. While irrigation pumping may be limited in the study area and its immediate surroundings because of salinity constraints, large expansion of irrigation pumping in non-saline areas beyond the study area may

alter the hydraulic gradient considerably enough to compound the problems of salinity ingress.

Methodological framework: A number of hydro-climatic and anthropogenic scenarios will be established from published literatures (e.g. those by IPCC) and based on expert interviews. The scenarios will be incorporated into the groundwater models.

Research question 4: Can sustainable groundwater use achieved by considering balanced use of groundwater and available surface water resources?

Conceptual framework: Because of the existing constraints of salinity (and arsenic) and already has seen conflicts among different users, it is likely that continued use of groundwater in various scenarios will not be sustainable. Complementary future water supply has to come from surface water sources.

Methodological framework: Following the assessment of safe yield from the hydrogelogical analysis and comparison with the water demand, the possibilities of using different surface water sources, for example, surface water bodies (river, canals etc.), rainwater harvesting and other relevant options to meet the unmet demand will be analysed from different sources in the primary study areas.

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Shifting Grounds: Institutional transformation, enhancing knowledge and capacity to manage groundwater security in peri-urban Ganges delta systems

The project aims to build knowledge and capacity among local actors to support a transformation process in peri-urban delta communities in Bangladesh and India for a pro-poor, sustainable and equitable management of groundwater resources across caste/class and gender. This will be based on an improved understanding of the dynamic interplay between local livelihoods, the groundwater resource base, formal and informal institutions and links with nearby urban centres in Khulna and Kolkata. These two cities provide a good basis for an institutional comparison, being part of the same Ganges delta system, yet located in different countries.

Funded by the Netherlands Organisation for Scientific Research (NWO), the Shifting Grounds project is executed by a group of academicians, researchers and civil society organisations. Delft University of Technology (TU Delft) leads the consortium and SaciWATERs is the regional coordinator for the project. Other project partners are Jagrata Juba Shangha (JJS), The Researcher, Bangladesh University of Engineering and Technology (BUET) and Both ENDS.

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