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Review Article

Water Crisis in Urban and Sub-Urban Areas: A Global Perspective

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Abstract

Water Scarcity is one of the most important environmental hazards world-over associated with atmosphere, hydrosphere, lithosphere, and biosphere. In spite of receiving intensive orographic rainfall, different sources of fresh water; most parts of the population is facing increasing water scarcity day by day. It is more prevalent in the under developed as well as developing countries, than in comparison to the developed ones. The water scarcity is having multiple reasons behind it. in the broader sense, the causes behind the water crisis are mainly of two types. They are either natural or anthropological. The present paper tries to focus on the mechanisms of water scarcity from the perspectives of physical processes and anthropogenic processes. Today's water scarcity in the developing and under developed world is mostly triggered by anthropogenic activities decreasing water supply both in relative term and absolute term. This paper finally presents some measures that can be taken to reduce the hazardous effects of water scarcity for sustainable development of the ecologically fragile ecosystems. At the end, this paper also tries to throw some light as a solution to this problem (in a long term way) for betterment of inhabitants of those water scarce regions of the world.

Keywords: Anthropological, Crisis, Developing country, Global, Sub-urbans, Under-developed country, Urbanization, Water.

1. INTRODUCTION

Water is essential for life on Earth, but it is also important for social and economic development. Natural water resources are becoming more and scarcer, and global water use is increasing, which means that a global water crisis is a realistic threat. Looking at the 'Water Conflict Chronology' published by Gleick (2009), one can assume that the trend will continue and that scarcity of water resources will lead to more disputes. In the same publication, the concept of 'peak water' is described, in comparison with 'peak oil'. A known challenge for water management is the uneven distribution in time and space of water resources. Precipitation is very variable from decade to decade, from year to year and from season to season. During the wet season, typically 3–4 months, 60–80% of the yearly runoff is obtained. The dry season yields less than 10% of the yearly runoff (Shiklomanov, 1999). The availability of water, measured as annual discharge flowing mainly through the rivers from continents to the sea, was reported to be 45,500 km3 (Oki and Kanae, 2006). UNEP (2008) reports a somewhat different value, as the difference between total precipitation (119,000 km3) and evaporation on the land (74,200 km3), which equals 44,800 km3. A more detailed review of water availability is given by Shiklomanov and Rodda (2003). However, much of the water available can in fact not be used. This is of high importance for e.g., irrigation; however, if the water is used for human consumption, care should be taken about the water quality in terms of e.g., eutrophication and the occurrence of blooms of toxic cyanobacteria (Dejenie et al. 2008). This may have an adverse influence on public health due to direct effects of water quality and indirect effects related to breeding spots for malaria vectors (Yohannes et al., 2005; Amacher et al., 2004), although positive effects on reducing malaria transmission were also reported (Sharma et al,. 2008).

A city's impact on water, referred to as its "water footprint", traditionally analyses water quantity and quality, hydrological cycle of groundwater and

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surface water, utilities, connectivity to the water network, and to a certain extent land use/ settlements (Yohannes et al., 2005). Expanding the concept of a city's "water footprint" visualizes the entire amount of water directly or indirectly embodied in any well-defined water consuming entity - its industrial and service sector development and changing energy needs. A city's water footprint would help further investigate the impacts a city has on water resources at a local, as well as, global level. Most mega-cities have an external footprint beyond their direct boundaries. When applied to cities, the water footprint methodology will help determine the diverse impacts of urban populations' consumption and therefore their indirect water footprint and where these effects are felt (Dejenie et al. 2008). By better understanding the wider water risks that urban areas and the regions supplying products, water, and services are facing, provides the cities' and regional governments and population the necessary information to take action in order to reduce, mitigate, or avoid those risks (Shiklomanov and Rodda, 2003). The aim of this paper is to encompass the present water distribution scenario, the causes of problems of water crisis in the developing and under developed countries of the world. Hence, six major cities of the world from different sub-continents are chosen and problems of those cities are discussed separately with their local as well as global aspects (if any).

2. Mexico City, Mexico

In Mexico City, over-exploitation of aquifers has contributed to the continued subsidence (five-40 cm per year), increasing the chance of catastrophic flooding. The dependence on distant water supplies has resulted in social and environmental conflicts with communities in the donor basin; in addition to the high energy costs (0.6% of the country's total electrical energy generated) associated with pumping water over 1000 meters in elevation and 150 kilometers away. Mexico City's population exploded over the last century, growing from 1.75 million people in 1940 to currently over 21 million in the metropolitan area, making it the fifth largest metropolitan area in the world (City Mayor Statistics, 2011). In the 1950s, the City government forbade any further construction in the City, thus shifting growth outwards to the state of Mexico (Tortajada, 2006). From 1970 – 2000, the majority of the population growth continued in the State of Mexico with 320 % growth vs 35 % growth in Mexico City (Rojas et al., 2008). Over the last decade, metropolitan Mexico City's population growth has slowed down to 15 %. Metropolitan Mexico City (Zona Metropolitana Valle de Mexico, or ZMVM) is comprised of 16 boroughs encompassing Mexico City, 59 municipalities in the State of Mexico, and one municipality in Hidalgo (CONAPO, 2005). The metropolitan area accounts for the country's highest concentration of economic activity – Mexico City and the state of Mexico produce 33 % of Mexico's GDP (Rojas et al., 2008).

2.1. Catchment area

The metropolitan area of Mexico City lies in the Valley of Mexico basin, its water supply mainly stems from the northern aquifers of Mexico Basin, an extensive high mountain valley that is naturally closed, meaning there is no outflow to other water bodies. Nearly half of Mexico City's water stems from groundwater (Sosa- Rodriguez, 2010); however, 2007's extraction volume of 59.5 m^3/s was almost three times of the basin's natural recharge rate (Burns, 2009). The metropolitan area's second most important water supply depends on inter-basin transfers from the Balsas (Cutzamala River) and Lerma (Lerma River) basins that provide 43 % of the total supply (Sosa-Rodriguez, 2010). The Lerma System was built in 1942 and traverses 62 kilometers and is distributed to the City by gravity, while the Cutzamala System was developed in 1976 and is transferred from 60-154 km away, pumped over 1000 meters (Tortajada, 2006). The Cutzamala transfer system is actually one of the largest in the world due to the quantity (approximately 485 million m^3 annually) and altitude (1,100 meter) that the water traverses to reach Mexico City (CONAGUA, 2011).

2.2. Drinking water

Mexico City generally has better access to water and service as it has more economic and political power than neighboring Mexico and Hidalgo states. Though Mexico state represents 45 % of the metropolitan area, it only received 35 % of water from external sources in 1990. Of metropolitan Mexico City's 2.5 million water connections in 2000, 67 % were domestic, but it is estimated that this only accounted for 64 % of actual connections – the rest being illegal (Tortajada, 2006). Those that do not have access to water from pipes, they pay private vendors from 6 to 25 % of their daily salaries (Tortajada, 2006).

2.3. Water governance and management

Mexico's water is managed by the National Water Commission (CONAGUA), whose tasks are the 1) administration of national waters, 2) management and control of the hydrologic system; and 3) promotion of social development (http://www.conagua.gob.mx). CONAGUA is an administrative, normative, technical, consultative, and decentralized agency of the Ministry of the Environment and Natural Resources (SEMARNAT) and is divided into thirteen regional administrations based on watershed/basin boundaries (www.ibid.org). Since 1997, the Mexico Valley Watershed Regional Administration manages the metropolitan area of Mexico City's water supply. Though this watershed encompasses 16,438 km^2 and 116 municipalities in total, 92 % of its users are in the ZMVM (http://www.conagua.gob.mx/ocavm) Currently, legal instruments are lacking to protect areas of recharge, and a series of adaptations to the National Water Law, General Law of Ecological Equilibrium, and General Law of Human Rights would be necessary (Burns, 2009).

2.4. Main water issues

Mexico City has a long history of manipulating its water, stemming all the way back to 1324 when the Aztecs founded Tenochtitlan on a small island in the Lake of Mexico. Suffering from frequent droughts and floods, the Aztecs built a system of drains, dams, dykes, aqueducts, and constructed chinampas (an accumulation of aquatic plants and mud surrounded by swamps) to regulate water flows and quality, protect against flooding and droughts, and create more land for housing (Sosa-Rodriguez, 2010). During the Spanish colonization, the hydrology of the Basin was even further altered through the construction of infrastructure to drain the lakes and rivers from the Basin, which resulted in increased risks associated with devastating floods, low water quality, outbreaks of waterborne diseases, and the sinking of the city (Sosa- Rodriguez, 2010).

2.4.1. Over-extraction

As Mexico City's population exploded during the past century, existing infrastructure to supply water became insufficient to meet demand, which resulted in intensified groundwater extraction and water transported over greater distances (Sosa-Rodriguez, 2010). Currently, 4 of the 14 aquifers in the Valley of Mexico Basin are overexploited (CONAGUA, 2011). The per capita rechargeable water available for the Valley of México in 2010 is calculated at 163m^3, whereas in 2030, it is predicted that rechargeable water per capita will be 148m3 (CONAGUA, 2011). Though, the City has land set aside for conservation, where groundwater sources could recharge, the frenzied population growth has led to many legal and illegal settlements. These are with 20 % of illegal settlers living in riverbeds (Sosa-Rodriguez, 2010; Tortajada, 2006, Jordan et al., 2010).

2.4.2. Inter-Basin Transfers

Despite water being supplied from further off Lerma and Cutzamala Rivers, thereby alleviating aquifer exploitation slightly in the Valley of Mexico, the dependence on distant water supplies has resulted in social conflicts with communities in the donor basin that did not receive compensation for the exploitation of their resource in addition to overexploiting their water sources (Sosa-Rodriguez, 2010). In the Lerma Basin, soil fertility has decreased and agriculture is mainly rain-fed in contrast to irrigation previously (Tortajada, 2006). In 2008, the cost for operating the Cutzamala System required the equivalent of 0.6 % of the country's total electrical energy generated that year and 6.4 % of CONAGUA's annual budget (CONAGUA, 2011). Though there were plans to extend the Cutzamala System at an estimated initial investment of $502 million, the projected increases could be equally achieved through addressing the leakages in the distribution system (Tortajada, 2006).

2.4.3. Pollution

The City's wastewater is disposed of to surrounding rivers for removal to the sea, but this water polluted with untreated wastewater is also used to irrigate vegetables and cereals as farmers have found the high concentration of fecal bacteria to be an extremely effective fertilizer that increases their crop yield (Sosa-Rodriguez, 2010).

2.5. Management measures implemented/ solutions explored

2.5.1. Institutional reform/privatization

Acknowledging that water could no longer be considered a public good (and, as a result, subsidized heavily by the State), but as an economic good – Mexico City launched an initiative to develop a pricing system based primarily on fixed tariffs through private sector participation in different stages of production, distribution and sale of water (Tortajada, 2006). The immediate measures included updating the legal and institutional frameworks and charges for discharging effluents into the sewerage system (a previous charge was only one-off payment to the National Water Commission). Longer-term measures were water charges based on metering and rehabilitating the distribution network to reduce leakages by 10–15 %. Until then, several institutions were involved in water management, creating over-lap of functions and unclarity; in 2003, the Water Systems of Mexico City (Sistema de Aguas de la Ciudad de México (SACM)) was formed. The private sector became responsible for distribution, metering, billing, and customer Support, and maintenance of the secondary networks, and was given service contracts for specific activities over a limited period of time (Tortajada, 2006). Property rights to the infrastructure and control over the introduction of a new pricing system remained under the City government's control. An initial investment of $152 million in 1992 and close to $3 billion in 1994 was required to replace a system of fixed charges with based on actual consumptions. The private sector had to offer the city government financing for the activities during the first stage and were responsible for detecting leaks. Initial response from officials, businessmen, academics, and the broader society was generally positive to the change (Tortajada, 2006).

2.5.2. Integrated River Basin Management

Created through the National Water Law, the Board of the Basin coordinates between the three levels of government, users, and societal organizations. Auxiliary institutions are the Basin Commission operating at the sub-basin level, the Basin Committee operating at the micro-basin scale, and the Groundwater Technical Committee operating at the aquifer level.

2.5.3. Flooding

With the objective of avoiding floods, diminishing the risk of drainage failures, and transporting wastewater to a treatment facility, CONAGUA began building the Túnel Emisor Oriente (TEO) in 2008 with a foreseen completion date of 2012. It will be 62 km long, 7 meters in diameter, and have a capacity of draining 150 m3/s wastewater.

2.5.4. Recharging groundwater

Water infiltration programs to recharge groundwater and rainwater harvesting recently started; however a slow start and minimal actions reflect the weak awareness and lack of environmental culture that still exists (Jordan et al., 2010). Mexico City began artificially recharging its aquifer with treated wastewater and rainwater in 1992 to combat subsidence. This practice is limited however as rainwater and wastewater are extracted in one shared pipe, and the associated cost of treating this larger volume of water is too high (Sosa-Rodriguez, 2010). Treated rainwater and wastewater is also used to irrigate green areas, fill lakes and canals, and cool industrial processes (Sosa-Rodriguez, 2010).

2.6. WWF involvement

In partnership with La Fundación Gonzalo Río Arronte I.A.P (FGRA), WWF is developing new water management models for Mexico. The goal is to develop an adaptive management model for each Basin that involves all stakeholders (civil society, government, and academia) and restores/preserves the natural ecosystems to ensure the continuing provision of environmental services upon which all are dependent (http://www.wwf.org.)

3. Buenos Aires, Argentina

Greater Buenos Aires is officially comprised of the autonomous city of Buenos Aires and 24 municipalities in the state of Buenos Aires. The Argentinean Statistics Bureau (INDEC) acknowledges that six additional municipalities partially fall under the Greater Buenos Aires population, however this number is not reflected in the 2010 census data (INDEC, 2010). The official population of 12,801,364 inhabitants in Greater Buenos Aires accounts for 32 % of Argentina's population and correspondingly contributes 40 % to the national GDP. While Argentina had tremendous economic growth and high per capita income in the 1990s, this came to a crashing halt in 2001 as the country defaulted and the corresponding financial, economic, and political crisis ensued. However, already prior to the crisis, poverty was increasing in metropolitan Buenos Aires (more than 30 % in 1995) and society became polarized with the middle class increasingly disappearing (Jordan et al., 2010). Poverty skyrocketed to 60 % in the state of Buenos Aires and 20 % in the city immediately after the crisis but is currently at 42.7 % (28.3 % in the suburban area; Jordan et al., 2010; GobBsAs., 2004).

3.1. Catchment area

Metropolitan Buenos Aires is found in the La Plata sub-basin, whose 130,200 km^2 make up part (4.2 %) of the world's fifth largest river basin – the La Plata, extending over 3.1 million km2, five countries (Argentina, Bolivia, Brazil, Paraguay, and Uruguay), almost 50 major cities, and supporting over 100 million inhabitants (UN WWAP, 2007). The mouth of the La Plata River is 230 km wide and separates Argentina from Uruguay. Within the La Plata sub-basin, factories found along the banks of metropolitan Buenos Aires are responsible for 98 % of water abstraction (UN WWAP, 2007). Though groundwater was historically extracted in metropolitan Buenos Aires, users are now supplied with treated water from the La Plata River. For those not connected to the water network, groundwater is extracted from the Pampean and Puelche aquifers (AABA, 2010). The three main watercourses that form the base structure for the region's drainage network are the Luján, Reconquista, and Matanza-Riachuelo Rivers (AABA, 2010). The Luján River, 128 km, has the largest catchment area of nearly 3,300 km2 and runs from southeast-northeast before discharging into the La Plata River (AABA, 2010). The Reconquista River is 82 km long, drains a catchment of 1,738 km^2 (the lower 40 % is comprised of urban and semi-urban populations), and discharges into the Luján River. The Matanza-Riachuelo River (known as Riachuelo from its lower catchment) is 510 km long and eventually discharges into the La Plata River (AABA, 2010).

3.2. Drinking water

Aguas y Saneamientos Argentinos (AySA) is the primary water service provider in the metropolitan area serving the city of Buenos Aires and 17 municipalities; while Aguas Bonaerenses serves the remaining municipalities (information presented hereafter is for AySA as it is the predominant service provider). Almost 95 % of the water supply stems from the La Plata River (4,442,065 m^3 per day), while the rest is extracted from the ground (231,416 m3/day) and is treated at one of three plants (AySA, 2009). AySA is building two additional water treatments plants that will increase capacity by 947,040 m^3 daily (AySA, 2009). AySA's tariff system is based on a fixed rate plus metered consumption system. The rate structure classifies users according to category (residential or nonresidential), the zone where the building is located, and the services provided; sewer services cost twice the amount of the fixed fee for drinking water service; finally, low-income customers are eligible for a subsidy. As of 2007, only 12.8 % of the connections were billed under a metering system, thereby encouraging relatively high consumption (Garzon et al., 2009).

3.3. Wastewater treatment

AySA has four wastewater treatment systems that currently only treat 5.3 % of wastewater before discharging it into the La Plata River (Jordan et al., 2010). To improve this situation, AySA is in the midst of constructing another wastewater treatment plant "Del Bicentenario," which will increase the City's treatment capacity by 120,000 m^3 per hour (currently 2,249,494 m^3 per day is handled (AySA, 2009).

3.4. Water governance & management

During the 1990s, the Argentine government privatized public services in order to improve service and attract foreign capital to finance the required investments; however the economic crisis of 2001 saw the State reclaim a centralized role in service provision (Almansi et al., 2010). The institutional structure for providing water and sewerage services in the city of Buenos Aires and the surrounding metropolitan area intends to separate institutional responsibilities for policymaking, sector planning, regulation, and service delivery. In the Metropolitan Area, issues of inter-local relevance are under the authority of the National Government, the Autonomous City of Buenos Aires, the state of Buenos Aires, and the municipalities; however, the Autonomous City of Buenos Aires's government (Capital Federal) has the dominant role since "it has the largest territorial entity, population and a concentration of economic activities" (Jordan et al., 2010). Water and sanitation service planning is under an economically self-sufficient entity with public and private legal capacity, which receives 1.12 % of the rate collected for water and sanitation services (Garzon et al., 2009). The Water and Sanitation Regulatory Authority (ERAS) oversees the concessionaire's compliance with applicable regulations, supervising the quality of services, and protecting users' interests; it receives 1.55 % of the rate for water and sanitation service to fund its operations. The national government retains 90 % of AySA's stock (90 %) and AySA's employees hold the remaining 10%.

3.5. Main water issues

In addition to expanding service coverage to un-served areas and rehabilitating and renovating infrastructure, the main issues confronting metropolitan Buenos Aires are:

3.5.1. Pollution

Pollution levels in Buenos Aires' rivers are so high that they could be considered "open sewers", which is particularly the case for Riacheuleo and the La Plata, making pollution the greatest environmental risk for the metropolitan area (UN WWAP, 2007; Jordan et al., 2010).

3.5.2. Flood

Flooding is a common problem for Argentina, but Buenos Aires is particularly at high risk as it is located in an area with low-relief energy, has high groundwater levels as it lies on the banks of the La Plata River, which also experiences water level increases due to rainy Southeast winds and ocean tides, and its canalized streams overflow after convective rains (Jordan et al., 2010; UN WWAP, 2007).

3.5.3. Over-abstraction

From 1940 – 1991, groundwater was intensively extracted due to the rapid rise in urbanization and corresponding industrial and private consumption demands without proper land-use planning and infrastructure development (AABA, 2010). As a result of over-abstraction, reduced surface area to recharge water reserves, saltwater intrusion from low-lying areas of the estuary, the absence of sewer drainage pipes, and the elimination of untreated industrial effluent, aquifers, in particular free surface aquifers, experienced intense chemical deterioration (AABA, 2010).

3.5.4. Institutional Weakness

Though the water concession was meant to attract private companies who could bring the needed infrastructure and service upgrades, growth of service networks has been lower than planned, particularly in low-income sectors of metropolitan Buenos Aires (Jordan et al., 2010). Governance issues, institutional weaknesses and lack of control mechanisms are responsible for the failure of the concession (Jordan et al., 2010).

3.6. Management measures implemented/ solutions explored

3.6.1. Groundwater recharge

After the early 1990s, all groundwater-pumping stations were eliminated from the domestic water supply network and water from the La Plata River was used instead (AABA 2010). Aquifers were able to recover even further with the closure or decreased production from many industries as a result of Argentina's economic crisis in the late 1990s and early 2000s (AABA 2010).

3.6.2. Pollution

Through the Environmental Management Plan for the Matanza-Riachuelo River Basin, launched in 1995, the National Government, government of the Province of Buenos Aires, and the government of the City of Buenos Aires are attempting to address the causes of pollution in the metropolitan area (UN WWAP, 2007).

3.6.3. Citizen and NGO engagement

In 2004, a group of residents living in the CMR area filed a claim against the national government, the Province of Buenos Aires, the government of the Autonomous City of Buenos Aires, and 44 businesses for damages suffered as a result of pollution from the Matanza-Riachuelo River. The lawsuit resulted in a landmark decision from the Supreme Court in 2008, which ruled on the side of the residents and determined that the defendants were liable for restoration and future prevention of environmental damage in the river basin (http://www.farn.org.ar/participacion). The

Environment and Natural Resources Foundation (FARN) took part in the case as a third party, along with various other civil society organizations. Throughout the entire process, FARN played a vital role in analyzing the defendants' submissions, submitting briefs and "amparos" (claims of constitutional violations), and coordinating the efforts of the different organizations. Since the ruling, in which the Supreme Court named FARN as a "permanent independent monitoring body for Riachuelo cleanup," the organization has maintained its leadership role. Alongside a number of other NGO's and WWF's Argentinean Associate – Fundacion Vida Silvestre Argentina (FVSA), FARN maintains the information flow related to the CMR cleanup and has staff dedicated to monitor the Riachuelo Case's evolution of the complex 8-point plan, which covers a wide range of issues (hydrological, environmental, territorial/ land-tenure, human health, access to information and public participation) and provide legal analysis and independent opinions on these issues to the implementing judge (http://www.farn.org.ar/riachuelo/caso.html).

4. Nairobi, Kenya

In the last century, Nairobi has rapidly grown from a small railway station in 1899 to one of Africa's 15 largest cities. Today it is the most populous city in East Africa with over 3.5 million inhabitants. The high percentage of informal settlements, as well as an average annual population growth of 2.8 % (though this has slowed down from the 4.5 % growth between 1995 and 2005 (UN-HABITAT, 2001), has challenged the local authority's capacity to deal with water scarcity in an effective and sustainable way.

4.1. Catchment area

Nairobi mainly receives its drinking water from rivers originating in the Aberdare Range and the Mt. Kenya water catchment area. The Aberdare Range, extending over 160 km, is situated north of Nairobi. Protecting the mountain rainforest ecosystem is of major importance for the city's water security. A healthy ecosystem guarantees that quality water is available for the metropolitan area, reducing the costs for treatment and the danger to human health. Although the Aberdare National Park (76,619 ha) is a protected area (International Union for the Conservation of Nature, Category II), the overall catchment area has experienced logging in the past (Dudley & Stolton, 2003). Recent studies however show a reduction of environmental degradation along with a 111 % increase of protected indigenous forest cover (62,000 ha in 2000 to 131,000 ha in 2010) (Mungai et al., 2011; Mafuta *et al.*, 2011).

4.2. Drinking water

4.2.1. Ground water

According to the Nairobi City Water and Sewerage Company, the water supply of 482,940 m³ per day stood against an estimated demand of 650,000 m³ per day for 3.5 million people in 2010. Currently, only 50 % of Nairobis inhabitants have access to piped water and only 40 % receive water on a 24-hour basis. The rest obtain water from kiosks, vendors, and illegal connections. In the year 2003, up to 50 % of piped water from the northern dams and reservoirs did not reach the city due to leaks in old pipes and illegal connections (Dudley & Stolton, 2003). Ground and surface water both play an important role for Nairobi's water supply; the main water supply is transferred from dams north of Nairobi. Groundwater, which represented 21 % of the city's total water supply in 2002, is currently abstracted from the Nairobi aquifer suite (Mogaka, 2006, Mafuta, 2011).

4.2.2. Dams and springs

Thika (or Ndakaini) Dam, Nairobi's main water souce, is located on the Eastern slopes of the Aberdares. It was completed in 1996 with a storage capacity of 77 million m³. The Thika Dam is further linked to Ngethu Water Works by a 4 km long tunnel. The water works started operation in 1974, and was completed in 1995 with a capacity of 220,000 m³ per day. The water reaches Gigiri in Nairobi through a 36 km long pipeline. Water treatment is claimed to be 379,200 m³ per day. Sasumua Dam is also located in the Aberdares, the catchment stretching from the South Eastern to South Western slopes. The construction was completed in 1955, and extended in 1968, reaching a storage capacity of 15.9 million m³. It is connected to Kabete in Nairobi through a 60 km long pipeline, where the yield is 52,800 m³ per day. The Dam on Ruiru River was built in 1950 and designed for a storage capacity of 2.9 million m³ of water. Currently, the water is piped over 25 km to Kabete in Nairobi andthe yield is 22,800 m³ per day. The Kikuyu Springs, three springs North West of Nairobi, were first opened in 1913. The spring water is piped to Nairobi over a distance of 10 km. The yield from Kikuyu Springs is 4,000 m³ per day. (http://www.nairobiwater.co.ke/water_quality/?ContentID=4).

4.2.3. Nairobi Aquifer Suite

There are approximately 4,800 boreholes in Nairobi, with an estimated daily supply of 65,000 m³ for domestic, 60,000 m³ of industrial water, 3,000 m³ for livestock uses and 28,000 m³ for irrigation in the Nairobi Aquifer Suite catchment area (WRMA, 2010).

4.3. Wastewater treatment

The 2009 Census found out that only 48 % of households in Nairobi have access to waterborne sewerage (GoK, 2010). Eighty percent of wastewater is treated in two facilities at Ruai/Dandora and Karinga in Nairobi (http://www.nairobiwater.co.ke/water_quality/?ContentID=7); however, due to over-raged infrastructure and overloading the treatment plants, regular breakdown of machines and equipment reduces the capacity to 74 %

and 39 % respectively. Additionally, the Ruai treatment plant, does not meet the prescribed discharge standards for Biological Oxygen Demand (BOD), Chemical Oxigen Demand (COD), and Total Suspended Solids (TSS). Effluents from the Ruai treatment plant are discharged into the Nairobi River. Uncontrolled wastewater discharge, which does not meet environmental and discharge standards, is common in Nairobi (Mafuta et al., 2011).

4.4. Water governance & management

Over the last decade, water legislation and management have improved significantly in Nairobi. The "Water Act 2002" provides a comprehensive framework of regulations, institutions, and management bodies for water supply and wastewater treatment. National, regional, and local boards have been established for service, management, and supervision. The Nairobi City Water and Sewerage Company (NCWSC) provides water under contract from the Athi Water Services Board (AWSB). AWSB is a state corporation under the Ministry of Water and Irrigation constituted to provide water and sewerage services. (http://www.awsboard.go.ke/) Main planning and strategic documents for water sustainability in Nairobi are the "Draft Strategic Plan for the Period 2010/11 to 2014/15" (by NCWSC and WRMA), "Preliminary Water Allocation Plan of the Nairobi Aquifer Suite: Long Term Water Resources Management Strategy"(by WRMA), and "Strategic Guidelines for Improving Water and Sanitation Services in Nairobi's Informal Settlements, 2009 (by NCWSC and Athi Water Services Board).

4.5. Main water issues

Nairobi faces severe water scarcity. Water demand exceeds water supply by about 200,000 m³ per day. Surface water is highly polluted. Up to 50 % of drinking water is lost due to insufficient, outdated infrastructure and illegal connections. Only 50 % of households have access to piped drinking water. Nairobi still has inadequate capacity to manage the increasing demand for water, especially in Nairobi's informal settlements, where water is sold at water kiosks, often at a higher price than piped water. Untreated waste and wastewater both pose a danger to human health and lead to eutrophication, deoxygenation and habitat modification of riverine systems.

4.5.1. Old infrastructure

Old infrastructure causes leaks and losses. In 2003, about 50 % of drinking water from the Aberdare Range did not reach the city (Dudley & Stolton, 2003). According to the AWSB, unaccounted for water has only been reduced from 65 % to 42 % since its inception. Most of the unaccounted for water is lost through illegal connections and technical losses due to underground leakage from the dilapidated piping system (Mufata et al., 2011).

4.5.2. Insufficient access to piped water

Currently only 50 % of Nairobi's inhabitants have access to piped water and 40 % receive water on a 24-hour basis (http://www.nairobiwater.co.ke/about_us/?ContentID=1) Nairobi's informal settlements are most affected: an estimated 60 % of Nairobi's inhabitants live in informal settlements (NCWSC & AWSB, 2009). Nairobi has over 200 slum settlements with inadequate access to quality water and sanitation, and 44 % of Nairobi's residents live below the poverty line (SID, 2004). Insufficient connection to piped water often leads to excessive water prices at water kiosks. According to NCWSC and AWSB, about 22 % of residents of informal settlements have a household connection, while an estimated 75 % purchase their water mainly from resellers at water kiosks, operated by community groups or individual entrepreneurs, or push-cart vendors. Water is sold at about KSH 100 to 250 per m³ (US$ 1.1 to 2.6). This price is above NCWSC's average water price of KSH 45/m³ (US$ 0.5) and well above the official price for water in informal settlements of KSH 10-15/m³ (US$ 0.1–0.16).

4.5.3. Water quality

The Nairobi aquifer groundwater quality is generally good. It meets the drinking water standards for most constituents, except for fluoride (Foster and Tuinhof, 2005). According to NCWSC, water derived from Kikuyu Springs is only treated by chlorination (http://www.nairobiwater.co.ke/water_quality/?ContentID=5). The rest of the surface water, which currently accounts for the bulk of Nairobis water, is heavily polluted and therefore has high treatment costs. Pollutants are agro-chemicals, heavy metals, microbial, and persistent organic pollutants (UNEP, 2007). Degradation of upstream ecosystems results in poor water quality and rising costs for water treatment. At Sasumua Dam for example, natural water purification provided by a healthy ecosytem would be less expensive than the physical and chemical purification that is actually necessary (Msafiri, 2008). The NCWSC currently spends US$170,000 monthly on chemicals and US$110,000 anually for de-slugging the Sasamua Dam (Mufata et al., 2011).

4.5.4. Implementation problems

Although the water sector reform puts new management rules in place that provides a legislative framework for sustainable approaches, implementation challenges still persist in Nairobi. Unplanned construction, limited resources, high costs of operation and maintenance, local political interference, high debts and liabilities, lack of autonomy to make major investments, inequitable distribution of water, sewage used by farmers with subsequent public health implications, industrial waste discharge into the sewer network by industries and other consumers, and financial demands from riparian communities further endanger Nairobi’s water security (Muirui and Kaseve, 2008).

4.5.5. Climate Change

At present, there are no overarching policies or laws explicitly for the management of climate change. There is not much doubt that climate change already affects and will further affect Kenya in the future (GoK, 2010). The 2010 National Climate Change Response Strategy (NCCRS) has outlined the ways in which the water sector should address adaptation and mitigation. More detailed implementation plans, however, will be required (Mumma et al., 2011).

4.6. Management measures implemented/solutions explored

4.6.1. New boreholes and dams

New infrastructure projects, both for the abstraction of surface and groundwater, are planned. WRMA has identified 347 additional boreholes in Kikuyu, Karen, Ongata-Rongat, Thika, and wetland areas with a density of 6–20 boreholes per km². AWSB has developed plans for new dams at Maragua and Ruiru to increase the daily water yield (Mufata et al., 2011).

4.6.2. Management measures for informal settlements

In 2009, the NCWSC and AWSB formulated water management strategies to improve water supply in informal settlements (NCWSC & AWSB 2009). These measures include: network intensification – AWSB and NCWSC, together with community partners, will ensure the intensification of formal networks in both water supply and sewerage and remove informal and illegal water networks – water supply in bulk and introduction of bulk meters; introduction of meter chambers with selected accountable community partners to supervise the process; upgrading of pipes to reduce leakages and bursts and prevent water contamination; facilitation of improved water kiosks that provide safety of the meters and facilitate a higher-quality service by individual or community operators (Mufata et al., 2011).

4.7. Guidelines for groundwater abstraction:

In 2006, a set of guidelines were established by WRMA to protect aquifers and control groundwater abstraction (WRMA, 2006; Mufata et al., 2011). The guidelines include: rainwater harvesting undertaken parallel to groundwater extraction and consideration of maximum pump motor size, density of existing boreholes, and potential for deeper aquifers when new permits are granted. No permit will be granted in notified areas.

4.8. Alternative sustainable approaches?

The rapid and largely unplanned development of Nairobi City, along with over-raged and dilapidated water infrastructure, and the past degradation of the upstream watershed endangers water quality and supply. The Minister of Water and Irrigation has calculated that the costst for protecting the catchment area and building infrastructure would amount to the equivalent of US$ 30–70 million per year; however, these costs cannot be covered by traditional revenue collection from water users (Hoff, 2008). There are approaches that take the increased use of ‘green water’ into consideration: ‘Green water’, the largest fresh water resource on earth, is defined as rainwater that is stored in the soil and that is available for uptake by plants (Li et al., 2010). This resource can be increased by reducing runoff and evaporation from the soil, leading to a larger amount of water available for crops and also to more water that can be used downstream (the so called ‘blue water’). In the Tana Basin, including the Aberdares and Mount Kenya region, innovative soil- and water management techniques applied by farmers upstream could improve water quality and increase water available downstream.

5. Karachi, Pakistan

Karachi, situated in the far south of Pakistan and on the coast of the Arabian Sea, is Pakistan’s most populated city and largest industrial centre. Its water and sewerage infrastructure has not been able to keep up with population growth in the last decades, which has consequently caused water scarcity and even riots in certain areas. Over 50 % of Karachi’s population lives in katchi abadis, informal slum settlements (Kamal et al., 2004).

5.1. Catchment area

At present, Karachi receives water mainly from two sources: the Indus River to the east of the city and the Hub reservoir, a large water storage reservoir constructed on the Hub River in 1981, flowing west of the city. The Hub Reservoir was not able to supply water for several years in the late 1990s and early 2000s as the dam’s catchment area was dry during the monsoon season. A large area of the Hub River catchment near Karachi is protected, including a Ramsar Wetlands of International Importance at the Hub Dam Wildlife Sanctuary. Keenjhar Lake, providing much of Karachi’s water from the Indus, is also a Ramsar site. The semi-arid environment of the Indus Basin is home to more than a quarter of a billion people (Mustafa, 2007). It features the largest contiguous surface irrigation system on Earth, irrigating 80 % of Pakistan’s 21.5 million ha of agricultural land (Wong et al., 2007); in Pakistan, 22 % of the GDP is due to agriculture (ICIMOD, 2010). Being the region’s lifeline, both on the Indian and the Pakistani side, the need for a regulating agreement over the distribution of the precious water resource was recognized, and the Indus Treaty was signed in 1960.

5.2. Drinking water

According to the Karachi Water and Sewerage Board (KW&SB), the Indus supplies 25.4 m^3/s of water, the Hub Reservoir 4.4m^3/s and a remainder comes from the Dumlottee Reservoir fed by wells on the banks of the Malir River (0.9m^3/s). Altogether, Karachi's water supply system receives an inflow of 30 m^3/s, water demand was at 33 m3/s in 2005, resulting in a water supply shortfall. Additionally, the water distribution system in Karachi is, on average, about 40 years old, with many corroded pipes that disrupt effective transmission. Thus, an additional 35 % of the water supplied gets lost due to leakages and large scale unauthorized diversion or thefts. Under the present conditions, water supply is irregular and inequitable, some areas receiving more water than others, and some too little to meet needs. Water is supplied only for a few hours at very low pressure (Master Plan Group of Offices, 2007). Apart from the piped supply connections, water vending through commercial water tankers also exists. Many inhabitants rely on water vendors for their daily water supply, as municipal water does not reach their areas. According to estimates by the Karachi Water Tanker Association, the tankers that supply water from KW&SB-designated hydrants account for about 8 % of the total water supply (Ahmed, 2009).

5.3. Wastewater treatment

The sewerage system has had very little maintenance since the 1960s, and the three existing treatment plants serving the city operate at about 50 % efficiency, experiencing blocked pipes and frequent mechanical failure (). There is a general recognition that the sewerage system is in even greater disrepair than the water system (ADB 2007b). Only 22 % of municipal wastewater is treated (Economist Intelligence Unit, 2011). More than 40 % of Karachi's population is not connected to the sewerage system at all, and there is little separation of municipal wastewater from industrial effluent, which both flow directly into open drains and then into natural water bodies draining into the Arabian Sea. Two of the biggest industrial estates in Pakistan, both located in Karachi, have no effluent treatment plant and the waste containing hazardous materials, heavy metals, oil etc. is discharged into Karachi's rivers and the already polluted harbor (WWF Pakistan, 2007).

5.4. Water governance & management

The authority responsible for Karachi's water management is the entirely government-owned Karachi Water and Sewerage Board (KW&SB). The Karachi Water & Sewage Board Act (1996) and Sindh Local Government Ordinance (SLGO) (2002) regulate water provision and wastewater treatment. KW&SB's estimated budget for 2011-2012 is US$ 304 million (http://www.kwsb.gos.pk/budget.asp) - the budget of the City District Government Karachi (CDGK) for the same time is US$ 820 million (http://asianetpakistan.com/official-news/7438). In 2007, the Health Services Academy under the Ministry of Health published Quality Drinking Water Standards for Pakistan, and a National Drinking Water Policy was passed in 2009. Lab facilities monitor chlorination and maintain quality control according to WHO guidelines at all water treatment plants. In addition, the KW&SB Central Lab monitors the bacteriological quality of city water by collection and testing 900 – 1000 samples per month from the city's distribution system. Water not fit for domestic use is given treatment through sedimentation and filtration and disinfected by means of pre and post-filtration chlorination.

5.5. Main water issues

While a comprehensive national policy and institutional framework for environmental management is in place, there are significant weaknesses in administrative and implementation capacity. The result is that, while an appropriate and necessary administrative capacity exists on paper, its effectiveness is seriously curtailed in practice (WWF Pakistan, 2007).

5.5.1. Supply problems and contamination

More than 50 % of Karachi's population lives in "katchi abadis" (informal slum settlements) and most of them face severe shortage of water as well as the lack of proper sewerage systems (ADB, 2007b). The wastewater generated by the population that does not have a sewerage connection is disposed of in local areas, generally to the storm water drainage system and then directly to open drains. This creates significant localized sanitation and pollution problems, especially in times of heavy rain (ADB, 2007b). Sewage seeping into shallow groundwater often infiltrates into the water supply system through leaky pipes. As a result, Karachi and other cities in Pakistan were hit by major outbreaks of waterborne epidemics in 2006 (ADB, 2007b).

5.5.2. Revenue recovery

Revenue recover is also a major problem. Although KW&SB has a complex tariff system in place based on customer (domestic, industrial, offices etc.), plot area, measured supply and annual rental value, among other factors, a substantial number of consumers do not pay. Weak enforcement of payment recovery does not allow effective generation of revenue (Ahmed, 2009). The ADB estimated a collection efficiency of 25 % in 2007.

5.5.3. Industrial pollution

Approximately 435 million m3 of wastewater is produced annually in Karachi, corresponding to about 70 % of water provided to households and industry. Of this, only around 20 % is treated, indicating that 340 million m3 of untreated wastewater is discharged directly into the Arabian Sea per year (ADB, 2007b). In 2007, WWF found that water samples from the Karachi harbor showed trace metals in concentrations far exceeding any other major harbor in the world (WWF Pakistan, 2007). The pollution load on Karachi's two rivers, the Lyari and the Malir, and on the coastal ecosystem is immense. The local marine environment is highly polluted and puts the mangrove swamp ecosystem under severe threat. Trace metal concentrations in fish and shellfish harvested from Karachi's coastal areas are very high (Kamal et al., 2004), and industrial pollution discharges combined with mangrove forest ecosystem degradation are resulting in a decrease in shrimp and fish production (WWF Pakistan 2007).

5.5.4. Climate change

The Indus River is extremely sensitive to climate change due to the high portion of its flow derived from glaciers (Wong et al., 2007). Snow and glacial melt contribute more than half of the annual average flow of the Indus River and around 50 % of its tributaries (ICIMOD, 2010), more than any other Asian river. Climate change, causing glacial retreat, is already impacting the glacial regime in the basin (ICIMOD, 2010). Agriculture and other economic activities rely heavily on this water, and changes in water availability can have serious impacts on the lives and livelihoods of millions of people living in the Indus basin, including Karachi's inhabitants at the end of the watercourse.

5.6. Management measures implemented/solutions explored

Infrastructure and engineering solutions have been the predominant focus to resolve water issues in the past. However, the Karachi Strategic Development Plan places water demand management high on its agenda for managing the city's future water supply. Strengthening and replacing affected infrastructure in order to reduce losses, energy use, and bulk water supply requirements are identified as top priority. Approaches are called for such as consistent water metering, public education on water conservation, harvesting rainwater or providing alternatives to piped water for uses that do not require drinking water quality. There has been little notable effort on behalf of the authorities to involve local communities and residents in water supply and sewerage solutions. However, there are examples of how technology, government support, government collaboration, community efforts and users paying at least some costs of infrastructure and delivery service has lead to projects that may be emulated elsewhere. An example of such an effort is the well-known Orangi Pilot Project (Kamal et al., 2004).

5.6.1. The Orangi Pilot Project (OPP)

The Orangi Pilot project in Karachi gives residents in poor communities the resources and engineering expertise to help solve their own environmental challenges. The project was started by an NGO in the 1980s in Orangi Town, a cluster of low-income settlements in Karachi with a population of 1.2 million. The project's initial focus was sewer improvements. Residents constructed sewer channels to collect waste from their homes, and these were then connected to neighborhood channels, which ultimately discharged into the municipal trunk sewer. Infant mortality rates fell from 130 to 40 per 1,000 live births, with 90 % of the population involved (ADB, 2007b). Within 10 years, the program had expanded to cover not only environmental challenges, but had also led to the establishment of schools, health clinics, women's work centres, stores and a credit organization to finance further projects. Today, the Orangi project model is being replicated in other cities in Pakistan, as well as Sri Lanka, India, Nepal and South Africa (http://www.oppinstitutions.org).

5.7. WWF involvement

WWF's Indus Eco-region Conservation Program works to conserve the rich biological diversity of the Indus Basin, identified as one of the world's forty biologically most significant ecoregions, through local community livelihood improvement. Currently, it is in the first five-year (April 2007–March 2012) implementation phase of a 50-year vision and is being implemented by WWF Pakistan in close collaboration with the Government of Sindh, selected Civil Society Organisations, and local communities. Additionally, Kheenjar Lake, one of Karachi's main Indus water reservoirs and a Ramsar site, is an important WWF project site (http://foreverindus.org).

6. Shanghai, China

In the 11th century, Shanghai evolved from a small fishing village to a town; it gained economic and international importance in the 19th century. In the 1980s, the city's economy began to boom, and Shanghai became one of the world's 10 largest megacities. Today, the metroplitan area has more than 23 million inhabitants and the city's GDP (estimated at PPP) ranks 25th worldwide (Hawksworth et al., 2008). The growth of both the economy and population is not predicted to slow down significantly in the coming years.

6.1. Catchment area

The Huangpu River and Yangtze River serve as surface water sources for Shanghai's water supply. The Huangpu River is about 114 km long, originates from Tai Lake and Dianshan Lake in the west of Shanghai, bisects the city and terminates in the Yangtze estuary. It drains an area of 5,193 km², covering 80 % of Shanghai. As 83 km flow through Shanghai's urban area, the Huangpu River is heavily affected by domestic, industrial, and agricultural pollution (Zhang, 2007). The upper reaches of the Huangpu River run through suburban Shanghai, characterized by intensive agriculture activities and animal breeding operations, while its lower reaches flow through urban areas with intensive industrial activities and residential areas (Ge, 1998; Jiang et al., 2011).

6.2. Drinking water

6.2.1 Surface water

The city mainly relies on surface water derived from three major sites along the Yangtze estuary and the Huangpu River. Whereas the city strongly depended on water from the Huangpu River in the past, there is a shift towards the Yangtze River. Water supply from protected areas plays a minor role in Shanghai (Dudley & Stolton, 2003), although there are some promising small scale pilot projects to show how water quality increases after flowing through protected river and lake catchment areas. To a certain extent, groundwater aquifers are protected by law - the use of groundwater is prohibited whenever surface water is available (Regulations of Shanghai Municipality on the Administration of Water Supply, article 12; http://www.shanghaiwater.gov.cn) Deep-water wells are of less importance as suburban and rural households in Shanghai municipality gain increasing access to piped water (Ren et al., 2003).

6.2.2. Water reservoirs

A. Yangtze River / Qingcaosha reservoir

Shanghai's main site for abstraction of water from the Yangtze River is the 70 km² Qingcaosha reservoir (total reservoir capacity of 524 m³, effective capacity of 435 million m³, daily water supply of 7.19 million m³). It is located north of Changxing Island in the Yangtze River estuary and designed to secure 68 days of Shanghai's water supply without refilling from the Yangtze River. Qingcaosha reservoir went into operation in December 2010 and currently provides about 50 % of Shanghai's water. In 2012, Shanghai plans to derive 70 % of its water from the newly opened reservoir in the Yangtze River (http://news.xinhuanet.com).

B. Yangtze River / Chenhang reservoir

The second site for water abstraction from the Yangtze River is located at the mouth of the river and has a capacity of 9.5 million m^3. Until 2010, Chenhang reservoir provided one third of Shanhai's total water supply and was the sole water source for more than 3 million people in northern Shanghai. It is claimed that the reservoir could secure water supply for seven days withour refilling (http://english.sina.com).

C. Huangpu River / upper reaches

The former main water source of metropolitan Shanghai is located near the upper reaches of the Huangpu River. It accounted for about 70-80 % of Shanghai's total water supply until Qingcaosha reservoir was opened (Shanghai Daily, 16th of January 2008). Compared to other megacities in the world, Shanghai's water infrastructure is very modern. Almost 100 % of residents have acces to water and only up to 10 % of water is lost due to leakages in the pipe system (Economist Intelligence Unit, 2011). Shanghai's daily water yield was 609 million m³ in July 2010(http://www.shanghaiwater.gov.cn/swEng/gs).

6.3. Wastewater treatment

According to the Asian Green City Index, 78 % of Shanghai's wastewater is treated. 73 % of households have access to sewerage service (Economist Intelligence Unit, 2011). The Shanghai municipal government plans to raise the wastewater treatment ratio to 90 % by 2020, with wastewater collection and treatment covering the whole of downtown Shanghai. These steps are meant to ease the extent of pollution of the river systems around Shanghai (Fu et al., 2008; ADB, 2010). A wastewater treatment fee of 1.30 Yuan (US$ 0.20) per cubic meter is currently built into the water tariff in Shanghai. Wastewater and drainage services fall under the Shanghai Sewerage Company.

6.4. Water governance & management

Shanghai Water Authority (SWA) is mainly responsible for water management. There is a comprehensive set of national and local laws and standards for water quality, utilitazion, discharge and monitoring in place (http://english.mep.gov.cn/standards_reports/standards/water_environment). The main legislative framework for Shanghai "Regulations of Shanghai Municipality on the Administration of Water Supply" was adopted in June 1996 and underwent two revisions in 2003 and 2006. Shanghai has established four water companiesand several research institutes (Shanghai Water Supply Planning Design and Research Institute etc.) and stations to monitor water quality. Shanghai Water Authority is reported to have a budget of 4.6 billion Yuan (US$ 0.72 billion), which is 6 % of Shanghai's total city budget.

6.5. Main water issues

Although freshwater is naturally abundant in Shanghai metropolitan area, the city experiences high water stress (Li et al., 2010). Rising demand, pollution, and saltwater intrusion are challenging the existing water reservoirs and threatening the city's water security. All main problems are aggravated by climate change.

6.5.1. Pollution

Intensive long-term research has identified a number of water quality challenges confronting Shanghai. The development of modern and intensive agricultural practices brought fertilizers and insecticides into the urban environment. Residues from these chemicals flow into the river during rainfall events, causing river eutrophication among other impacts (Kung Hsiang and Ying Long, 1991). Low capacity of sewage treatment has resulted in industrial and residential waste being discharged directly into the city's watershed (Ward and Liang, 1995). Pollution sources have gradually changed from point sources to non-point sources, which include fertilizer, insecticides, domestic animal waste from agricultural activities, and wastewater from villages and town-owned factories (Ren et al., 2003). Although metal pollution has been efficiently restricted in recent years, non-point organic pollution has increased as human sewage increases in the Huangpu River (Zhang et al., 2007). Wastewater, as well as industrial and agricultural pollution, has lead to blue-green algae outbreak in Tai Lake and in the Yangtze estuary in warm weather conditions.

6.5.2. Salt water intrusion

Saltwater intrusion is a phenomenon that naturally occurs in the Yangtze estuary during the dry season in winter and early spring when seawater backs into the Yangtze River and mixes with the freshwater, thereby making it unsafe to drink (http://china.globaltimes.cn/society/2011-05/659148.html). According to news releases, saltwater intrusion has become increasingly serious in recent years, and salinity is now a major threat to Shanghai's water security. As a result of a severe drought along the middle and lower reaches of the Yangtze River in 2011, salt water tides persisted until early summer with salt water intrusions in April (9 days), May, and June, a situation that has not occurred in the last decade.

6.5.3. Influence of major hydraulic projects

The Three Gorges Project (TGP), the South-to-North Water Diversion Project (SNWDP), water diversion from the Yangtze to Lake Tai basin, and other water diversions from the Yangtze River influence river discharge in the Yangtze estuary area (Pittock et al., 2009). Studies forecast that the SNWDP's maximum water diversion scheme of SNWDP will aggravate saltwater intrusion as this will cover one-tenth water discharge during the low-level season while the increased discharge of TGP during the dry season can restrain saltwater intrusion in the estuary (Zheng et al., 2011).

6.5.4. Climate change

Due to the city's low elevation and proximity to the Yangtze estuary, Shanghai is highly vulnerable to climate change. A rising sea level might aggravate salt-water intrusion and extreme weather events, such as storms, floods, and droughts, will further endanger the city's water supply. As healthy ecosystems are most resilient to climate change, protection of the catchment areas (Yangtze River and Huangpu River) and PES schemes to compensate upstream communities for protective measures will become increasingly important.

6.6. Management measures implemented/ solutions explored

6.6.1. Infrastructure measures/opening new water sources

To meet rising demand, rely less on polluted water from the Huangpu River, and decrease the threat of salinity, Shanghai built the Qingcaosha reservoir. The Reservoir is located in an area where salinity is the lowest in the estuary and now provides 50 % of Shanghai's daily water supply, which will increase to 70 % in the coming year. It was designed to provide Shanghai with water for 68 days, which reflects the theoretical extreme salt water intrusion situation Shanghai may have to face (://www.chinadaily.com.cn/china/2011-05/26/content_12581749.html), However, 68 days might be insufficient as blue algae, eutrophication, and other problems could further reduce its available capacity.

6.6.2. Increasing consumption tariffs

In 2010, authorities raised the tariff for domestic water by 23 % (http://www.gdrc.org/uem/footprints/index.html). Ma Jun, director of the Institute of Public and Environmental Affairs, advocates raising water prices to promote conservation, but said seawater purification would not be seen as an ideal choice as it consumes large amounts of energy (http://china.globaltimes.cn/society/2011-05/659148_2.html).

6.6.3. Water source protection

A 2008 WWF demonstration project in the upper reaches of the Huangpu River shows how the restoration of rural wetland ecosystems can improve water quality. This project was referred as "WWF–HSBC Demonstration Project of Water Source Protection –Wetland Restoration in Dalian Lake". This resulted in improvement of water quality from Grade V and worse to Grade II-III, meeting drinking water standards (aquatic plants remove 83 tons of suspended particles, 2300 kg of nitrogen and 290 kg of phosphorus per year); increased biodiversity; considerable economic value produced by wetland products of 84,000 Yuan (about US$13,000) of annual net income from 0.5 hectares of wetland restoration area by harvesting crops like wild rice grass, cress, lotus, and ecologically cultured fish.

6.7. Alternative sustainable approaches?

Shanghai has many rivers and creeks, but most of them are polluted and many are isolated from external flowing water systems. If the natural water system in urban Shanghai can be restored more naturally and effectively, it will not only benefit the city's landscape and estuary biodiversity, but also improve water quality of ground and surface water and increase resilience to extreme rainfall. Coastal wetlands, which provide a natural buffer zone against climate change impacts, such as sea level rise and storms, have to be protected. So far, people rely more on dikes. WWF is working with partners to protect the coastal wetlands, not only for migratory birds and aquatic biodiversity, but also to safeguard the city. The large area of coastal wetland is also a good purification means for the inland water (WWF Shanghai, 2008).

7. Kolkata, India

In Indian context, particularly in Eastern India, the impact of Kolkata and it's sub-urbans are extremely important. Until the mid- 1980's, Kolkata was India's most populous city before Mumbai took over this distinction. Among India's cities, Kolkata contributes the third-largest share to the national GDP, owing to its IT sector, which is growing at 70 % annually – twice the national average (ADB, 2007a), and it boasts India's second largest stock exchange after Mumbai. The metropolitan area includes Kolkata, the industrial city of Howrah on the west bank of the Hooghly River, the city of Chandernagore to the North and their associated suburban areas.

7.1. Catchment area

The majority of Greater Kolkata's water is treated surface water from the Hooghly branch of the River Ganges (Dudley & Stolton, 2003), along with groundwater from various deep and hand tube wells and private pumps (Segane, 2000). The river Hooghly is a distributary of the parent river Ganges, whose source is in the Himalayas. The Ganges basin has a population of more than 400 million, making it the most populated river basin in the world, and is part of the composite Ganges-Brahmaputra-Meghna basin draining an area of 1,086,000 km^2 (Howksworth et al., 2009). In its lower stretch, the Ganges merges with the Brahmaputra through a complex system of common distributaries into the Bay of Bengal.

7.2. Drinking water

The drinking water for Kolkata Metropolitan Area (KMA) is treated in several water treatment plants with a total capacity of slightly more than 1.4 million m^3 per day located in different parts of KMA (Wetlands Internationals, 2010). Kolkata Municipal Corporation (KMC) claims that 94 % of the city's households are connected to piped water and that water is supplied continuously for up to 20 hours per day. The households not connected to the water supply system mainly extract groundwater through private wells and pumps (Fu et al., 2008). There is no pricing system for domestic water consumption.

7.3. Wastewater

The city of Howrah discharges its sewage mainly into the Hooghly River. Wastewater of Kolkata is discharged into East Kolkata Wetlands (EKW) – 12,500 ha of marshy wetlands connected to the Hooghly branch of the Ganges and eventually flowing into the Sundarbans mangrove forests. After the EKW's former source of inflow from the Hooghly River became increasingly clogged due to silt accumulation in the past decades, its main source of influx today is Kolkata's sewage system. Since the late nineteenth century, the city's sewage water flow has led to the development of a unique ecosystem that organically treats the discharge, which is then used for fish farming and agriculture (WWF India, 2010, 2011, Chaudhuri and Thakur, 2006).

7.4. Water governance and management

The metropolitan area's water is managed by three authorities (Kolkata Municipal Corporation, Howrah Municipal Corporation and Chandernagore Municipal Corporation), with the Kolkata Metropolitan Water and Sanitation Authority responsible for the development and improvement of water and sanitation facilities for Greater Kolkata. Kolkata has a water quality code in place covering pollutants in surface water and has standards for key pollutants in drinking water. Water quality standards for industry are also enforced, and the state government authorities regularly monitor water quality in the Hooghly. Howrah Municipal Corporation (HMC) has a modern water testing lab for drinking water (Economist Intelligence Unit; EIU, 2011).

7.5. Main water issues

7.5.1. In-efficient water use

The strategy of supplying water essentially for free to citizens has led to a huge wastage of water in Kolkata. According to Majumdar and Gupta (2007), the issue of conservation is completely neglected, which over time has also led to mounting government subsidies on water. An analysis of the decade of 1992–2002 revealed that the expenditure for water supply and sewerage increased five times, whereas revenues only doubled. The policy of not pricing water for domestic use has certainly earned the criticism for sending wrong price signals to consumers and thus, promoting wastage (McKenzie and Ray, 2009).

7.5.2. Pollution

Groundwater, being the secondary source of fresh water in the KMA, has been extracted for domestic and agricultural use in large quantities in areas more remote from the river. Kolkata and the Ganges delta lie in a geological zone with naturally occurring arsenic in deeper layers of the bedrock. Thus, groundwater naturally contains varying levels of arsenic. However, levels above the (World Health Organization's (WHO) recommended maximum of 10µg/l of arsenic were found in groundwater samples in 65 of 100 sampled wards in Kolkata over a twenty-year study period (Chakraborti et al., 2009).

7.5.3. Ecosystem destruction

The eastward expansion of Kolkata due to population growth and influx has been accommodated at the expense of natural ecosystems, mainly the East Kolkata Wetlands (EKW). Interestingly, the Basic Development Plan (BDP) for the city, completely disregarding the ecological sensitivity of the EKW, proposes to develop two major townships, namely the

Baishnabghata-Patuli Township, and the East Calcutta townships in the EKW. Reclamation of wetlands for garbage dumping also seems to continue unabated (WWF India, 2011). The Sundarbans, one of most complex and sensitive ecosystem in the world, located 100 km downstream from Kolkata, is severely impacted from the urbanization of Kolkata and the neighboring areas. The Sundarbans, which is part of the delta of the Ganga-Brahmaputra-Meghna basin shared between India and Bangladesh, is home to the largest mangrove forest ecosystems in the world, over 1.400 recorded species, including the iconic Bengal Tiger, Panthera tigris tigris and several other threatened species (WWF India, 2011). Hazra (2010) suggests that of the eight rivers that dominate the landscape in India, only the Hooghly and Ichamati-Raimangal carry freshwater flow of some significance. He concludes by stating that the Indian Sundarbans Delta is experiencing both declining freshwater supplies and net erosion as has been recorded since 1969. An equally pronounced ecological change in Sundarbans includes the threat from pollution due to huge discharges of untreated domestic and industrial effluents carried by tributary rivers.

7.5.4. International dispute

Silt deposition in the Hooghly River, a cause for the blockage of the channels supplying water from the river to the EKW, causes additional problems for navigating the Hooghly to the Kolkata port. This, along with water shortages in the dry season and associated increasing tidal salt water intrusion into the river, was planned to be overcome through the construction of the Farraka barrage across the River Ganges some 300 km upstream from Kolkata. The Farraka dam was to divert up to 1,100 m^3/s of water from the Ganges into the Hooghly River during the dry season (January - June) to provide a steady flow of water. It diverts over 9 % of the Ganges River's historical mean annual flow and over 5 % of the flow for the entire Ganges-Brahmaputra basin (Vörösmarty et al., 2005). About one fourth of the total population of Bangladesh and about one third of India's population live in the Ganges basin. The diversion of up to 60 % of the Ganges' water over 25 years has, amongst other things, caused a reduction of water in surface water resources, increased dependence on ground water, destruction of the breeding and raising grounds for 109 species of Gangetic fishes and other aquatic species and amphibians in Bangladesh (Adel, 2001). Since its operation in 1975, there has been ongoing dispute between India and Bangladesh regarding India's diversion of Ganges water, which cuts off a significant portion of Bangladesh's water supply (Salman and Uprety, 2003).

7.6. Management measures implemented/solutions explored

Kolkata Environmental Improvement Project (KEIP) is a multi-agency body cofounded by the Asian Development Bank (ADB) to arrest environmental degradation in Kolkata. KEIP's objectives include providing affordable access to basic urban services in slums, revamp and upgrade the sewerage and drainage system, and restore the city's drainage.

7.6.1. User charges for water

User charges for water are recognized by the KMC as the most important mechanism for cost recovery (http://kmwsa.gov.in/html/retros.html). One of the major loan covenants of KEIP was the implementation of water metering for every household by 2009/2010 (http://www.keip.in/bl3/aboutus.php), but this has been delayed for political and other reasons (http://www.business-standard.com/india/news/kolkata-assumes-domestic-water-supply-is-free/380556/).

7.6.2. Rainwater harvesting

Rain water harvesting initiatives for supplementing water supply or aquifer recharge is also encouraged by KMC, but so far, the West Bengal Pollution Control Board has only implemented a few projects (http://www.wbpcb.gov.in/html/pressrelease/report_rwh.pdf)

7.6.3. Formation of the East Kolkata Wetlands Management Authority (EKWMA)

The East Kolkata Wetlands Management Authority (EKWMA), is constituted by government officials and NGO representatives, and has been entrusted with the responsibility for conservation and maintenance of the East Kolkata Wetlands (http://www.ekwma.com/index.php?view=default&MenuID=20). EKWMA has initiated the development of an integrated management plan. Inventory and assessments undertaken have stressed the need to adopt an integrated river basin management approach with a shift towards multi-functionality of wetlands.

8. CONCLUSION

The challenge of water supply and sanitation in urbanized regions in developing countries is evident. Causes are not easy to pinpoint, since they are a complex interaction between various factors. It must be understood that these factors can be significantly influenced by e.g., political decisions, instability, poverty etc. Therefore, control of urbanization and water supply and sanitation in urbanized regions is only possible in the context of political stability and public awareness. Once these are achieved, plans for investments with international support are feasible and can be carried out at steady pace, keeping sustainability in mind and in conjunction with programs to reduce population growth. Furthermore, a realistic estimate of the upper limit of the natural sources should be made.

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