# 6 Rivers and water security

## Supply adaptation strategies in the city of Chennai, India

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## Introduction

The shortage of potable water in many parts of the world is a cause for concern at the local level in human communities (UN Water 2006; Anand 2007; UNFAO 2007; Back and King 2009; Cook 2012). Urban and rural regions in many countries suffer shortages of potable and industrial/agricultural water due to their geographical location, growing populations, unmet supply expectations, poor policy management, and overexploitation of available supplies (Bates, Kundzewicz et al. 2008; Bakker and Allen 2012; European Commission 2013). Despite recent technological and funding enhancements though, many strategies to improve supply have not helped to create water security (IWA and WWC 2012). Successful water management requires supply enhancements, demands related conservation practices, and encourages environmental conservation in equal measure (Heiland 2009; Loftus 2011; Government of South Africa. 2013). This chapter assesses the impact of this situation on the contribution that the three rivers (and their associated water bodies) that flow through the metropolitan area of Chennai (formerly Madras), India, make to that city's water resources.

The chapter notes that the rivers in question, the Kotalaiyar, Coovum, and Adyar, are terminally degraded within the urban area, and consequently can have little bearing on the solutions to current or future Chennai water supply problems until they are rehabilitated. This situation requires the urban communities in the metropolitan area to seek alternative sources of supply, while imposing more effective waste and other pollution management practices in relation to those rivers. This case study is, therefore, a description and analysis of a *failed* river system in community water resources terms, a case that has some similarities with those described in Chapters 4, 5, 7, and 10 of this volume.

## The Chennai river system

Chennai is both a City and a Metropolitan Area in the Southern Indian state of Tamil Nadu. The area, with a growing population of more than 8.6 million, faces daily supply and demand management related threats to its existing water resources, plus the already growing hydrological cycle-based water scarcity brought about by climate change. The population density of the district is about

27,000 inhabitants per $km^2$, and this concentration has been growing at about 7.8% per year over the decade 2001–2011 (TNWRD 2011).

Metropolitan water demand is 900ml/d for the urban domestic sector (households), while only 700 to 730ml/d can be supplied (Lakshmi and Ramalingam 2012). Hence there is a supply gap. Thus, extra-supply initiatives have been the main policy focus in the past, but the resulting desalination plants, alternative river-based supply schemes (out of State), the Krishna and Veeranam supply schemes (described later), and most other remedial measures have failed to improve the water scarcity situation, essentially because the major perennial supply system, the three rivers of Chennai, is heavily polluted and barely usable, while its alternative, ground water, is rapidly moving in the same direction (Deccan Chronicles 2011). Also, although Chennai has 100% pipe connections, water supply is intermittent, therefore what the metropolitan area requires is completely re-focused management initiatives designed to improve the quality, conservation, and use efficiency of its existing river system (Deccan Chronicles 2011).

Three main rivers traverse Chennai, the Kotalaiyar River (draining at Ennore shore in the north of the city), the Coovum River (Koovam) in the central region, and the Adyar River in the south. A fourth river, the Otteri, a Nullah or minor watercourse, runs through north Chennai and meets another but artificial water course, the Buckingham Canal, that travels parallel to the coast, linking the Adyar and Coovum rivers. All these watercourses are heavily polluted with effluent and trash from domestic and commercial sources within the urban area. However, only one, the Adyar, which is much less polluted than the Coovum or the Kotalaiyar, is de-silted and cleaned periodically by the State government. This action is due to the need to preserve its protected estuary that forms the natural habitat of several species of birds and animals (Ramanujam, Devi, and Indra 2014). Finally, there are several artificial lakes of varying size fed by the rivers that are located on the western fringes of the city: The Red Hills, Sholavaram, and Chembarambakkam lakes. These intercept part of the perennial river flows prior to the urban area, and supply Chennai with part of its potable water needs. Groundwater sources in the metropolitan area are mostly brackish, but are also used to supply the urban area.

Historically, Chennai has often faced the problem of water supply shortage, as its three rivers are not major watercourses, and there is a consequent reliance on the annual monsoon rains to replenish the artificial lakes and groundwater storages scattered around the metropolitan area. The city's ground water resources have also been depleted to very low levels in many areas, forcing many residents to buy their drinking water from suppliers whose source is further afield, while even the monsoon can fail. Thus, most Chennai districts are currently water starved (Chennai Metropolitan Water Supply and Sewage Board 2008) because of their inability to use the rivers as a source of potable water. The city of Chennai is itself part of the larger Chennai Metropolitan Area, which includes some urban areas and villages outside of the core city. In addition to Chennai city, the jurisdiction of the Chennai Metropolitan Water Supply and Sewage Board (CMWSSB) extends to urban outlying regions covering about 164.6$km^2$, and rural regions covering about 142km$^2$. The urban outlying areas are called Adjacent Urban Areas (AUA), and the rural regions are called Distant Urban Areas (DUA) (CMWSSB 2011).

The Chennai Metropolitan Development Authority (2007) noted that the current water supply-demand policies and management systems in Chennai need improvement, although little was being achieved. In this situation, droughts or floods can cause administrative and policy chaos through decreased demand satisfaction, further reduced water quality, and increases in the water-poor population within the city. To manage supply and demand in Chennai, and in any centre facing these problems, there is a need to develop effective conservation practices regarding the rivers and canals that traverse the Metropolitan Area, to bring them back to a situation where their *potential* to supply much of the metropolitan area's water requirements through proper planning and implementation of future drought-proofing projects (Chapter 3, this volume), matches their *ability* to do so (Sivakumar 2013). Planners must also pay attention to past project failures, and learn from these (Planning Commission 2007). The adaptation programs most often recommended are the simple ones of reduce demand, reuse and recycle, accurate inventories of water resources, and accurate household surveys of actual use (Waldron 2008). Therefore, the major policies for Chennai in the short to medium term include reworking and renovating the river water supply systems, ponds, and Kollams (traditional storage tanks), and improving distributed quality through effective treatment and monitoring stations (Srinivasan 2008; Government of India Ministry of Water Resources 2012). In addition, the strategy of using closed conduits for carrying water to households, and selective supply hours, would also improve conservation and water security in the city (CMWSSB 2008, 2011).

## Water resource management: important variables to consider in Chennai

There are three sides to effective water resource management: 1. appropriate policies and regulations for administering water supplies; 2. modern water utility infrastructure managed using up-to-date methods; and 3. effective supply and demand side management (UNEP 2012). Administrative programs include upgrading customer advisories (for the user), improving utility productivity measures, providing effectual informatics, implementing practical approaches and goal setting for future management, enhancing education and creating awareness, improving local participation, and managing grievances and feedback (GWP 2011). River and ground water extraction controls, water pricing, the imposition of fines within an appropriate regulatory system, and a code of conduct for the public and for relevant administrative entities, should also be major policies within the administrative system for water utility management that require periodic attention (UNESCAP 2010).

Water resource management is like any other management system; it is often flawed and failing. Attempting to carry-through on the aforementioned approaches indicates that the water management systems in many countries require change and reinforcement. In this regard, India, China, and South Africa are introducing new technologies, administrative measures, and conservation techniques to improve their adaptability (Government of South Africa 2013; Rademeyer, van Rooyen, and McKenzie 1997). Administrators use strategies to create and implement policies to manage water to create security and adapt to stress factors. But, although there is need to understand the impact of demand on the available water, it is equally necessary to consider the overall situation – people, environment, economic conditions, and, nowadays, climate change. Consideration given to the impacts of climate on water security and on environmental sustainability is vital when planning for the required adaptation of management policies (UN Water 2006; GWP 2011). Thus, changes in overall supply-demand management systems are required to establish a firm foundation for adaptive societal responses to water supply crises.

Finally, the water supply system in any location is intricately linked to the effective functioning of the hydrological cycle, which is the balance of precipitation, temperatures, and evaporation levels (Iglesias et al. 2010). Water security is the availability, accessibility, affordability, and allocation of sufficient clean potable water for all people. In turn, this cycle is affected by climate change, which has the potential to cause acute imbalances in water resources (IPCC 1997, 2008). Climate change in this context is made up of the effects of rising temperatures, changes in wind circulation patterns, and changes in ocean currents, among other factors. The global increase in temperature (2000–2016) is 0.5 degrees higher than the average warming between the years 1960 and 1990 (EPA 2012). Temperature changes can impact rainfall and sea temperatures, leading to increases in droughts or floods. Temperature rise may also denote an increase in surface or soil water evaporation (i.e. reducing surface resources). This increases the demand for water to support food production for city populations, amongst other pressures. Thus, the water cycle is becoming increasingly distorted and uneven (IPCC 1997, 2008). This is now recognized as the climate-related water crisis (Huhne and Slingo 2009).

In consideration of all these variables, the aim of this chapter is to identify the context of river water resource management in Chennai, to assess the contribution of the metropolitan rivers to solving the existing supply problems (Butterworth 2007), to describe the community supply and demand initiatives that have arisen in response to these problems, and to analyse the core policies and adaptation strategies required to combat the supply reduction impact of looming climate change. From this analysis, it is possible to provide recommendations for change. The key problem in Chennai is that past supply restrictions and poor water quality management policies have led to the current water security and scarcity issues, and it appears that there are few possible solutions to this problem within the current framework of policy planning and demand-related conservation practices in relation to the three rivers of Chennai.

## The water supply system in Chennai

### *Rivers and surface water bodies*

The Kotalaiyar River on the north side of the urban area is 136 km long and drains into the Bay of Bengal. Its northern tributary (the Nagari river) originates in Andhra Pradesh and joins the main river in the Poondi dam. From the Poondi reservoir, the river flows through rural areas, then enters the Chennai metropolitan area, to join the sea at Ennore Creek. The river flows for 16 km within the Chennai city area. The total catchment area of the river is 3,757 $km^2$, and the bed width ranges from 150 to 250 metres. The discharge capacity of the river basin is 110,000 $m^3$ per second, and the anticipated flood discharge capacity is about 125,000 $m^3$ per second (Kanthimathinathan 2015).

In 2011, the Chennai Water Resources Department (WRD) initiated a subproject under the national *Irrigated Agriculture Modernisation and Waterbodies Restoration and Management* (IAMWARM) project to rejuvenate nearly 200 lakes in this river basin (Lakshmi 2011), and to reduce the formation of sand bars near the mouth of the river. Finally, while the estuary of this river is heavily polluted with effluent released by the industries in the region, the upper reaches remain a source of water for agriculture and villages (Jagadeshan, Anandasabari, and Poornavel 2015).

The Coovum River in central Chennai is the shortest classified river draining into the Bay of Bengal. This river is about 72 km in length, flowing for 32 km in the urban area and for 40 km in the rural area. The river is highly polluted in the urban area (Chennai City). Along with the Adyar River running in parallel to the south, the river trifurcates the city and separates Northern Chennai from Central Chennai. Owing to the intensive use of surface water upstream for agriculture, indiscriminate pumping of groundwater leading to reduced base flow in the river, the formation of a sand bar at the mouth of the river, the discharge of untreated sewage and industrial effluents, and residential encroachment along the banks, the river, especially downstream, is highly polluted (Ramakrishnan 2009).

Once a fresh water source and a fishing river, it is today simply a drainage course inside the city of Chennai, collecting the surpluses of 75 small tanks in a minor basin. The total catchment area of the river is about 400 square kilometres, and the bed width ranges from 40 to 120 metres. The capacity of the river is 19,500 $m^3$ per second, and the anticipated flood discharge is around 22,000 $m^3$ per second (Lakshmi 2012). Of the three main rivers, it has borne the brunt of the city's unplanned urban growth. Upstream, the Kesavaram dam diverts the river into the Chembarambakkam Lake, which supplies drinking water to the city of Chennai. Thereafter, the flow of water in the river downstream is much reduced.

For centuries, the Coovum has been an integral part of the socio-economic and cultural life of Chennai. Until the early twentieth century CE, it was a clean river, and navigable. Earlier, it played a pivotal part in the far-flung maritime trade between the Roman Empire, South India, and Sri Lanka. Archaeologists have discovered ancient wine jars, and Roman and Chinese coins on the banks of the river. In the late eighteenth century, Pachaiyappa Mudaliar, the renowned philanthropist, bathed in this river before offering prayers at the Komaleeswarar Temple in Komaleeswaranpet (Suresh 2012). Currently, the urban part of the river is highly toxic and completely non-potable; upstream, however, the unpolluted part is still being used for the drinking water needs of many villages.

A study of the river was undertaken as part of a World Bank–funded project (TNSUDP 2015), and showed that it is 80% more polluted than treated sewage. Fish can survive in the water for only 3 to 5 hours, even after the river water they are exposed to has been diluted with fresh water. The Public Works Department sources contacted during the research for this chapter suggested that government agencies like Chennai Corporation and business units and retail outlets on the banks of the river were responsible for the pollution (Sethuram 2014). The water has almost no dissolved oxygen, and instead there are traces of heavy metals like copper, as well as sewage and sludge. Due to its narrow width and the approximately 3,500 illegal dwellings along its banks, it has not been recently desilted, which has closed it to river traffic. In 2003 about 9,000 families lived along the river, in addition to 450 shops and commercial buildings (Ramakrishnan 2009). There are 700-odd points along the river bank where sewage flows straight into the river; 127 of these are authorized sewage outfalls into the river (85 of these are currently in use). Nearly 30% of the estimated 55 million litres of untreated sewage being let into the waterways of Chennai daily, including that from facilities operated by the Chennai Metropolitan Water Supply and Sewerage Board, gets into the Coovum river, while 60% flows into the Buckingham Canal, and the Adyar River takes the rest.

On a more positive note, the Adyar River, 42.5 km long and on the south side of the urban area, contributes to the maintenance of the remaining estuarine ecosystem of Chennai (Periakali et al. 2009). Despite the high pollution levels, boating and fishing take place in this river. The river collects surplus water from about 200 tanks and lakes, small streams, and the rainwater drains in the city, and has a combined catchment area of 860 $km^2$. It discharges between 190 and 940 million cubic metres of water annually to the Bay of Bengal. The discharge is seasonal with between 7 to 33 times more than the annual average occurring during the Northeast monsoon season between September to December. The river is also supplied by surplus water from about 40 ponds. The normal discharge of the river is 39,000cuft/s whereas the anticipated flood discharge capacity is about 60,000cuft/s. During the floods of 2005, the river had a discharge of 55,000cuft/s (Krishnaveni and Gowri 2008).

The Adyar Estuary has long been a haven for migratory and resident birds. The environmental conditions in the estuary provide low salinity, good shelters, and high plankton availability as a good nursery for fish (Ramanujam, Devi, and Indra 2014). The flow of tidal water in and out of the creek allows for the easy travel of boats, and once encouraged fishing. However, with the city's sewage and effluent from its various industries emptying into the river, the biological activities in the region have been affected. Recently, with the opening of the Adyar Estuary Nature Park (Adyar Poonga), painted storks, grey heron, large egret, and black winged stilt have returned: "Painted stork has not been seen in the Adyar Estuary for many years. Getting to see painted stork this year is very good news," said Mr. K.V. Sudhakar, President of the Madras Naturalists' Society, in 2011 (Lopez and Oppili 2016). Around 200 species of birds have been reported in the Adyar area in the past, he added, however many species had vanished from the vicinity because of rapid urbanization. According to officials, increased availability of fish in the waterbodies of the 58-acre area and improvement in habitats are some of the reasons for the migration of birds to the park. In a further contribution to the clean-up, in 2012, the state government allotted 3,000 million rupees towards the construction of 337 sewage cleaning systems in the waterways in the city, including 49 locations in the Adyar river, 105 in the Coovum river, and 183 in the Buckingham Canal (Dina Malar 2012).

**The Buckingham Canal has an influence on drainage.** This canal is a 796 km–long fresh water navigation canal, running parallel to the coast of South India, from Andhra Pradesh to Tamil Nadu. The canal was formed during drought relief work in 1806. It intercepts all the east-flowing drains during its 44 km path in Chennai connecting all three rivers in the City, however its main function was to join the natural backwaters along the coast to Chennai (Madras) port. It was constructed during colonial times, and was an important waterway during the late nineteenth and early twentieth centuries. The canal also acts as a barrier to sea water intrusion in the coastal aquifers. Now however, as with the rivers it connects, the canal is disrupted by solid waste and the severe anaerobic conditions arising from the sewage it carries. In addition, within the city limits of Chennai much of the canal has been used as the route of the elevated Chennai Mass Rapid Transit System (MRTS). MRTS stations have encroached on the canal, reducing its width to less than 50 metres in a few places. The Buckingham Canal is the most polluted of the four major waterways in the city, with nearly 60% of the estimated 55 million litres of untreated sewage from the city being placed into it daily (Ramakrishnan 2009).

The main alternative surface sources of freshwater are the Cholavaram, Poondi, and Redhills Lakes (Tanks). The lakes are three interconnected reservoirs are used to collect, store, and supply water to the Chennai region via the Kortalaiyar Nagari and Nandi rivers (outside the metropolitan area). The fourth lake is Chembarambakkam, which is also a reservoir used to supply water to the city, but only during drought years. The lakes supply a total of about 7,412 million $m^3$ of water to the metropolitan area.

### *Augmenting these sources*

Chennai has developed or considered alternative supply sources to the basic artificial lake and perennial river systems in the past to increase the supply of potable water (Figure 6.1). These are as follows:

(1) **The Veeranam Project:** The Veeranam Lake is located 230 km from Chennai. This lake draws water from the Cauvery River and provides drinking

water to Chennai. An earlier version of the Veeranam Lake project (1965–1967) was a failure, as it did not produce the necessary amount of water required. The current Veeranam Lake project (from 2004) has managed to reduce the level of interstate water purchase that is required to service Chennai. The total capacity is 1465 million $m^3$ but the project currently only stores about 320 million $m^3$ (180 MLD). The raw water is pumped 20 km and then treated before being transported 200 km to the city;

(2) **The Krishna River Project:** The Krishna River is in Andhra Pradesh State, north of Tamil Nadu. Under an agreement with neighbouring states, the Telugu Ganga Project on this river is to supply 1,100 million $m^3$ per year to meet Chennai's agricultural, industrial and domestic needs. The water received under the Krishna Water Supply Scheme is in two stages, I and II, conveying 400 and 530 MLD to Chembarambakkam Tank (Lake), respectively;

(3) **Ground Water Sources:** The CMA, DUA, and AUA regions obtain groundwater from two main sources, the Araniyar- Koratalaiyar Basin (A-K Basin) and the South Coastal Aquifer (SCA); and

(4) **Desalination:** Desalination is fast becoming an option for urban cities in Tamil Nadu and other states; Chennai already has two plants supplying 100 ML/D each. With the recent increase in industrial demand, water supplies for the domestic sector have been further reduced in Chennai, and desalination plants have been designed to offset this problem. Chennai also has five other small-scale desalination plants with capacities of less than 15 ML/D each.

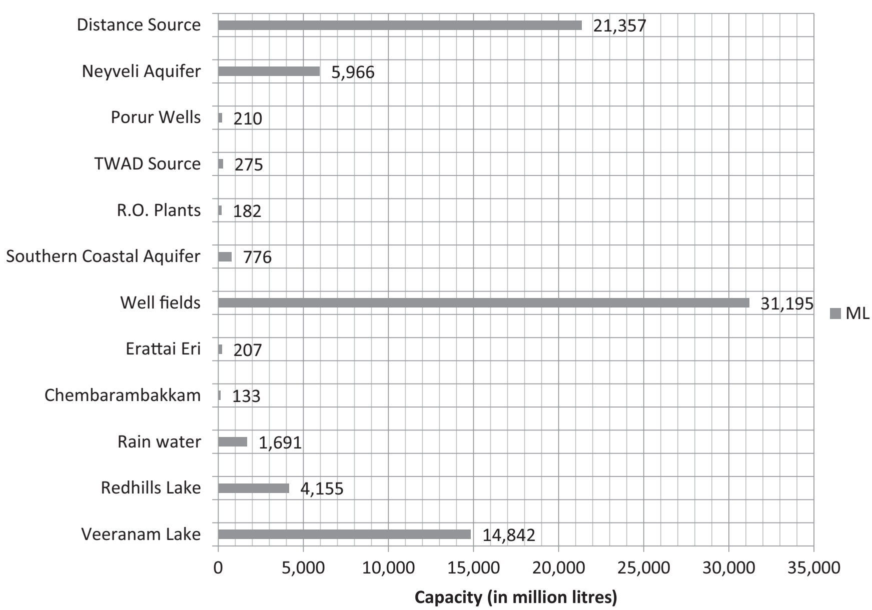


*Figure 6.1* The water resources of Chennai.

Source: the Author

## The rivers and Chennai's water supply status

Local water authorities indicate that the total effective supply from all sources in the Chennai Metropolitan Area is approximately 730ML/D (2012–2015), and the total required is about 900ML/D (Figure 6.2; Lakshmi and Ramalingam 2012). This chapter has shown that it has become obvious that the development of water supplies for Chennai has to be secured *without* any further use of the rivers within the City area at least in the short term, since they are so heavily polluted that they are, to all intents and purposes, irrelevant unless they can be cleaned up. The chief improvements being talked about then involve extraction from rivers and other sources outside the Metropolitan area, and even outside the State (Selvaraju 2004; Lakshmi and Ramalingam 2012). An additional perspective may be gained from a walk through the streets of Chennai. Various problems such as supply pipe leaks, sewer pipe leaks, tankers with people fighting over who gets water first, and even a few places using hand pumps to draw water from bore wells, are seen. Thus, the problem in Chennai is how to deal holistically with the faulty water supply system, degraded ecosystems, the rich and poor divide (not to mention political unwillingness or vested interests, corruption, and so on), which make the water management landscape in Chennai very complex (Figure 6.3).

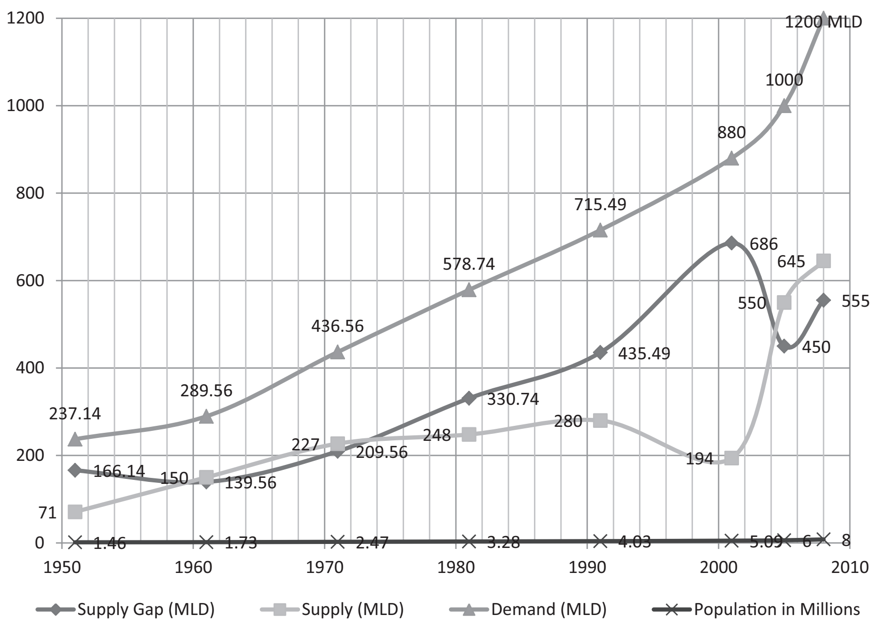


*Figure 6.2* Chennai's population growth, water demand, and supply gaps.

Source: the Author

*Figure 6.3* Chennai's water supply system for many people – storage of water for two or three days in jars.

Source: Photo Courtesy of the Author.

***Water quality***

While it is almost impossible to find absolute purity in available water resources across the globe (WHO 2006), especially in India (BIS – Indian Water Quality 2009), a recent study (Janardhanan 2011) indicates that both the quality and amount of water sources within Chennai are particularly bad. The surroundings of reservoirs are not kept clean, and domestic, industrial, construction, residential, commercial, and other activity wastes pollute lakes and rivers. As we have seen, the water in the Adayar and Coovum Rivers, for example, is highly contaminated, and is at present unsafe to use for *all* domestic purposes. The Coovum River is also saline, as there are sea inlets that allow saline intrusion. However, while this water could be desalinated, the smell of the river is so revolting that people must cover their noses before they reach it. This is partly due to regulatory non-compliance and the location of the slum regions close to that river, where people do not have toilets or clothes washing facilities at home.

The most common water-borne diseases resulting from this situation are Diarrhoea, Typhoid, Paratyphoid, Cholera, Dysentery, Protozoal, viral infections, and Helminthic worms. These diseases are pathogenic and contaminate water through sewerage or unsanitary toilets (Cariappa and Khanduri 2003; Sethuram 2014). This issue requires attention if there is to be better management of the quality of water sources in Chennai (Mariappan 2013).

### *Awareness, information, and communication relating to the quality of water from the rivers*

Awareness of the actual quality of water is low in Chennai, even if the state of the rivers is obvious to all on visual inspection. This is because the government does not provide information and test results to local people. The information available currently only indicates the type of quality measures and the available standards, while most actual data from regional chemical, bacteriological, and physical test results are not available (Sethuram 2014).

Regarding the alternative source of supply to the polluted rivers; the groundwater aquifers, Chennai residents indicate that illegal groundwater extraction is high, and quality controls are very sporadic (Sethuram 2014). Janardhanan's (2011) study indicates that there is widespread illegal pumping and sales of freshwater from this source. The major well fields are thus highly exploited, and these well fields are also used for sectors other than domestic water supply. Besides keeping track of the number of wells, it is also very hard to maintain a record of how much well water is extracted, consumed or wasted in these cases. "Currently, 40 million litres of water is drawn from Metro Water's wells in Neyveli, Poondi, Thamaraipakkam and Minjur to augment the supply from reservoirs" (Mariappan 2013). Observation reveals that these wells were dug between 2003 to 2005 to support extra sources, when Chennai began to face droughts and started relying on well and tankers for supply. For this reason, illegal supply points are not going to be capped in the current situation of chronic water shortage.

## Discussion

Based on this investigation, the following points can be made about water supply and demand management in relation to the rivers of Chennai: the total water supply is irregular, unreliable, polluted, and inadequate overall. This is due to both availability problems and accessibility problems. In addition, a noteworthy point is that the water resource database in Chennai is generally inaccurate and unreliable, even though data is collected by the administrative authorities in the region. Hence, accountability and reliability are also low. Also, when data is inaccurate this can lead to the assumption that the stock of water resources is adequate (although distribution problems exist), and the actual demand-supply gap is not considered to require resolution.

The research that this chapter is based on makes it clear that both water scarcity issues and security concerns exist in Chennai. While the evidence does suggest that the various Chennai Water Boards are trying their best to reduce the impact of these issues and improve water supplies from both the rivers and other sources, there are certain obstacles that affect this. These include policy weaknesses, physically inadequate collection and distribution systems, distribution equity issues, water quality issues, problems with information dissemination, and low overall awareness of these problems in the population.

This lack of awareness also extends to the reasons for the climate-change related water shortages that occur every four years due to regular lapses in the monsoon. And this means that the policy system cannot assist consumers to cope with the fact that this regular pattern has been changing recently due to the increased frequency of sudden extremes brought about by climate change (Michel, Pandya, and Mahanta 2009). For example, there are now frequent floods as well as droughts in Chennai and the coastal areas of Tamil Nadu. The increased flooding of the rivers of Chennai though has not aided the authorities in their clean-up; it has instead increased the penetration of saline water into fresh ground water sources. This creates further issues for the security of current and future water supplies. Managing floods requires more effective quality control of the river systems in the city (TNWB 2006).

Recently, Chennai has recorded an increase in its yearly maximum temperature to about 42 degrees centigrade, and this is one sign that should be a sufficient trigger for the Metropolitan Area to take better steps to prevent severe droughts. This, as in South Africa for example, will require going to the extent of transporting existing and available sources in closed conduits from water-rich areas to water-poor areas like Chennai. This will however pose further quality problems. There are several bacterial infections that make water unusable, and their existence creates more water waste and reduces water security. Nevertheless, TNWRD documents indicate that Chennai is prepared to tackle the water biosecurity issues that may rise in this situation (TNWRD 2011).

However, the supply and demand management investigation carried out on the rivers and storages presented here indicates otherwise. Respondent comments on the actual operation of the supply and demand management systems indicate that there are issues and concerns that could intensify with increasing climate change. While climate change may not currently look like a pressing issue in the Chennai rivers case, given the over-riding pollution problem, it is impossible to ignore the fact that droughts occur at least every 4 years, and floods approximately every other year (mild intensities). Thus, while "drought" in Chennai is presently mostly caused by inadequate and polluted flows in the supply chain (the rivers), and is demand rather than purely climate related, it is not possible to ignore the increasing signs of water scarcity and insecurity from the climate change source.

### *Adaptation strategies*

The major causes of Chennai's discontent with its river and groundwater resources are not only related to the polluted and inadequate river flows; they also concern the connected pipe mains (distribution system), which does not supply water on a regular basis. Given these problems, policy changes are essential. Government can enforce policy, if this is made, but policies can be weakened due to corruption and low positive responses within communities (Srinivasan 2008; Michel, Pandya, and Mahanta 2009; Lakshmi and Ramalingam 2012). A favourable societal response is thus crucial in relation to cleaning up the rivers of Chennai. While the "polluter pays" policy is accepted in Chennai, and makes for effective reinforcement, in this case, of the clean-up strategies for the rivers and ground water supplies, without effective information, security of total supplies, and their effective distribution, this approach cannot be sustained (Sopac 2013).

## Conclusions

This chapter suggests that an increase in water use efficiency in Chennai is much needed. The concerns about sporadic supply and low quality from the three rivers and the available groundwater resources are currently not situations that alternatives like desalination are able to totally rectify, but this does not seem not to galvanize local communities and authorities to clean up the rivers. This case study also concludes that Chennai has a greater potential water crisis than that which is produced by the ineffective demand and supply management strategies now in place in relation to its major sources of water, the river basins. This is because, at the same time as the quality and volume of water from its rivers and groundwater sources will continue to cause major policy problems, the metropolitan area will have to cope with an absolute shortage of water from the increasing periods of drought brought about by climate change in Southern India.

The three urban rivers of Chennai, together with the existing polluted and inadequate sources of groundwater, cannot maintain supplies of good quality water now, and this immediate problem is being compounded by poor policy construction and implementation concerning future supplies. Demand and supply management through effective clean-up and conservation, and serious attempts at increasing efficiency of treatment and distribution need to be enhanced by robust policy-making and effective legal frameworks to create room for additional drought-related requirements. There is also a need to enhance new project management capabilities, as there are many failures on record.

The obvious recommendations for policy change in Chennai in relation to the conservation and use of its water supplies (especially from the rivers) are to reduce demand and clean up existing sources, to improve the groundwater recharge system to lessen the threat from seawater intrusion, to provide better training of supply personnel, to obtain better inventories of resources, and to carry out continued surveys of actual use (to allow for effective management of reticulation and storage systems). The major infrastructure policies required include much greater efforts to rework and renovate the rivers, water tanks, ponds, and lakes; to improve quality through monitoring and effective treatment; and to ensure the implementation of simple measures for rainwater harvesting (RWH) and Artificial Recharge (AR) to local aquifers. In addition, creating a system for selective supply hours from existing sources on several days of the month will improve conservation of the river systems, and improve water security in Chennai (IWA and WWC 2012). In turn, the communities involved must develop a sense of ownership and responsibility for the *state* of their rivers and associated water supply networks (Sopac 2013).

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