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Chapter 4

Urban water infrastructure: current status and challenges in India

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ABSTRACT

It is projected that by 2025, more than 50% of the population in the Global South will be living in urban areas accounting for a population of 3.75 billion. As the resources are limited, expanding cities in the Global South are facing severe crisis with regard to resource depletion, lack of space, equitable access to critical infrastructure, among other problems. Moreover, the existing infrastructure is aged and is in a dilapidated condition, requiring immediate attention. Adequate supply of water is not only important for living, but also from the perspective of hygiene, public health and control of diseases. However, despite the provision of adequate water, the incommensurate mismanagement of wastewater leads to non-hygienic conditions. Thus, provision of water supply infrastructure should necessarily go hand in hand with appropriate collection and management of wastewater. Further, management of rainwater and prevention of urban flooding through appropriate implementation of storm water drainage is crucial. In this chapter, we review the current status of urban water infrastructure in India. The review includes domestic water supply systems, sewerage systems and storm water drainage systems. The challenges that are being faced towards the evolution of water-sensitive urban areas are identified, and the way forward for surmounting those challenges is proposed.

Keywords: water supply systems, sewerage systems, storm water drainage, water infrastructure in India

4.1 INTRODUCTION

The percentage of urban population in India has increased from 17.9% in 1960 to approximately 35% in 2021 (World Bank, 2023). Not only has the urban population increased but also the number of urban agglomerations, leading to more centres of demand aggregation from the point of view of providing infrastructure. Currently, the number of urban agglomerations with a population of more than a million in India is more than 50. There are more than 300 cities in India, which have a population more than 100,000. According to projections by the UN, percentage of urban population will be more than that of rural population by 2050. Second, as India is making rapid strides in its economy and is poised to become a $5 trillion economy by 2026–2027 (Mint, 2023), the infrastructural needs will also be much greater than what are being provided now. Also, the aspirations of its people for better infrastructure will grow rapidly. In the 2023 Union Budget, capital investment outlay is increased steeply to $122 billion, accounting for approximately 3.3% of GDP (Ministry of Finance, 2023).

The rapid urbanization imposes enormous stress on all the urban infrastructures. Two of the basic components of any urban infrastructure are water supply and sanitation systems. The existing water supply systems in many of the cities are many decades old and are becoming either dysfunctional or highly inefficient from the perspective of service delivery. There is a significant loss of water in the distribution systems. Energy-intensive pumping operations are not optimized. Many of the cities do not have any sewerage system for collecting and treating the domestic wastewater. They also do not have proper storm water management systems. The untreated or partially treated wastewater is causing severe environmental damage. Lack of proper sewerage system is leading to the pollution of both surface and groundwater bodies. Although major floods do not occur frequently and do not last for large number of days, they cause enormous economic damage, besides loss of precious life. It is estimated that the flooding of just the outer ring road in Bengaluru on 30 August 2022 caused an economic loss of around Rs. 2250 million (Indian Express, 2023). The Mumbai floods in 2005 are estimated to have caused an economic damage to the tune of Rs. 200 billion. Thus, significant attention has to be paid to the water infrastructure development in India in order for the country to sustain the rapid economic development. The following sections provide a review of the present status of urban water infrastructure in India and outline the challenges that are being faced towards the evolution of water-sensitive urban areas.

4.2 HISTORY OF WATER INFRASTRUCTURE IN INDIA

4.2.1 Water supply systems

The existence of piped water supply systems in the modern era dates back to the 13th century, when a 5.5 km long pipeline made of lead was laid for supplying water to the city of London (Walski, 2006). In India, the first organized piped water supply system was commissioned in the city of Mumbai (then known as Bombay) in 1858. Originally Vihar Water Works supplied 3.2 million litres of water. In 1872, a parallel pipeline was laid to carry additional 3.7 MLD. Tulsi Water Works project was commissioned in 1879 (Narasimhan *et al.*, 2019). The second city to commission piped water supply in India was Kolkata. A 27.3 MLD capacity system was commissioned in 1870. It comprised of Palta filter plants; 1.067 m diameter cast iron pipe to carry water from Palta to Tallah and a pumping system to deliver water from Tallah to consumers. In 1872, the city of Chennai (then known as Madras) started sourcing water from Kosasthalaiyar River at Tamaraipakkam and transported it to the city through a 28 km long open channel, and then distributed it in nearby areas through cast iron pipes. The Delhi Water Works at Chandrawal, with a capacity of 4.5 MLD, was commissioned in 1890 to cater to approximately 1.9 lakh people. From 1912, the water was drawn directly from the river when the capacity had to be enhanced (Narasimhan *et al.*, 2019). Sizes and capacities of water supply systems have grown significantly since then. For example, Chennai city at present has a capacity to treat 1494 MLD. The total length of water pipes is 6697 km and number of consumers is 876,891. The Municipal Corporation of Greater Mumbai (MCGM) has a capacity of 3800 MLD to treat water, sourced from seven lakes. The distribution system comprises of two master balancing reservoirs, 27 service reservoirs and more than 6000 km long pipe network.

4.2.2 Sewerage systems

Historically, there has been evidence of early water supply and sanitation systems in The Indus Valley civilization, dating back to period between 2350 and 1810 BCE. These systems comprised of private bathing places and latrines, which are connected to a network of underground drains made of bricks that carried the wastewater to outside the city walls to soak pits. The network of sewer systems that existed in ancient cities such as Rome and Constantinople became dysfunctional in the middle ages. Cities started building sewerage systems once again from the mid-nineteenth century onwards in response to public health issues arising out of rapid industrialization. The great stink of London in 1858 led to the commissioning of a vast underground drainage system (UGD).

The sewerage system in Mumbai was first commissioned in 1867 in Colaba and Worli areas. The city prepared a master plan for the first time in 1979, which got completed in 2003. For a long time, the city of Mumbai did not have sewage treatment plants (STPs). In Chennai, the sewerage system was commissioned in 1890. A master plan was made in 1907 to cater to an expected population of 6.5 lakhs in 1961 (CMWSSB, 2023). The system comprising of mixed gravity and forced mains transported to the sea on the north-eastern boundary of the city. The first STP with a capacity of 23 MLD was commissioned in 1974. A combined UDG was introduced in the main city of Kolkata during 1859–1875, which collected sewage and storm water and discharged into marshy lands, ponds and open spaces in East Kolkata area. Even now the inner city does not have a STP and the sewage is treated in the vast East Kolkata Wetland (EKW) network system. The naturally treated wastewater, rich in nutrients, is taken to bheries (ponds) where algae and fish are grown. Since 2002, EKW has been designated as a Ramsar Site. Unlike the other three metropolitan cities, Delhi had an elaborate sub-soil drainage system predating British times since the reign of Shahjahan. Shahjahani drains were filled up by the British and a system of surface drains was constructed, which emptied into two main subsoil drains (Prashad, 2001), which in turn carried the wastewater to Yamuna. They accelerated the drainage and water works project in Delhi from 1881 onwards.

4.2.3 Stormwater drainage systems

In India, in historical times, the stormwater management focused more on rainwater harvesting than on flood protection. Farmers in the Kutch area in present-day Gujarat used rainwater harvesting for agriculture. There is evidence of the existence of tanks since third century BC. The practice of tank irrigation probably started in the early centuries of the first millennium (Shah, 2008). The Chola kings in Southern India also built many rainwater harvesting tanks for supplying water for agriculture in the 11th century. Although most of the tanks were built for irrigation, Coimbatore District Epigraphs mention that the 30 wetlands in Noyyal river basin in Coimbatore were built in the 8th and 9th centuries for both irrigation and flood protection (Pragatheesh & Jain, 2013).

Many of the present-day urban storm water infrastructures are based on the modern urban sewer systems developed after the 1850s in Europe, and for a long time they have been managed by public health officials. Thus, they were based on the concept of fast conveyance of stormwater outside the cities (Bertrand-Krajewski, 2021). In India too, although metropolitan cities have had a long history of municipal drainage systems dating back to the British period, the storm water collection networks were originally designed as a combined system for sewage as well as storm water runoff. The first combined sewer was commissioned in Kolkata in 1876 for a design rainfall of 6.35 mm/h (Gupta, 2005). The provision of a separate storm water drainage system in urban areas has started only in the last couple of decades. For example, the stormwater drainage master plan for the core city was prepared by the Corporation of Chennai only in 2009 (Greater Chennai Corporation, 2023). In fact, a dedicated manual for storm water management was published by the Ministry of Housing and Urban Affairs, Government of India in May 2019.

4.3 CURRENT STATUS AND CHALLENGES WITH WATER INFRASTRUCTURE

4.3.1 Water supply systems

The goal of Atal Mission for Rejuvenation and Urban Transformation (AMRUT 2.0) is to provide tap water connections to households in all the statutory towns by 2026. This means approximately 26.8

million new tap connections have to be provided in the coming four years (Bassi, 2022). This calls for a significant amount of investment into water supply infrastructure. There are other challenges as well, when one considers the availability of water and status of service delivery by the water utilities. Rapid urbanization, population growth, dwindling water sources, ageing water supply infrastructure and inappropriate governance is pushing many towns and cities into a severe water stress situation. For example, the per capita consumption in Chennai and Bengaluru is only 90 and 100 LPCD, respectively. Although it is reported that the per capita consumption is more than 150 LPCD in Hyderabad, only 70% of the supply is through pipes. In these cities, water is either being sourced from faraway places or expensive desalination technology is being sought. Delhi sources water from as far away as 220 km, while Chennai gets its water from far away Krishna and Cauvery rivers. Such systems are not resilient. As the utilities are unable to bridge the gap between demand and supply, households are pumping water from aquifers, many times violating the pumping norms. People are also pushed to procure water from private vendors who supply water through tankers at exorbitant prices. This is resulting in a complex urban water supply ecosystem, which is partly controlled by public utilities, and households, and the rest by private vendors (Narasimhan *et al.*, 2019).

Water supply is highly unreliable and intermittent in majority of the towns and cities. The water flows in the distribution system for only two to three hours a day. Typically, intermittent water supply results in customers paying more to access water services through alternative means (Charalambous & Laspidou 2017). The intermittent operation of piped water supply systems also results in: (1) increased possibility of water contamination; (2) increased energy consumption, (3) low pressures and (4) increased cost to customers due to the need for investing in local storage facilities. Although the Government of India aims to transition from an intermittent system to a 24 × 7 rapidly, only a few cities have made this transition successfully. The lack of funds with utilities and the perception that private companies offer better services than the public organizations, among other reasons, are driving the utilities to go for public–private-partnership (PPP) for making this transition to continuous system, which in turn requires tariff restructuring. This is creating socio-economic problems.

There is a significant loss of water in the distribution system. The unaccounted water is as high as 52% in the city of Delhi and the average value is around 40% across many cities (Satpathy & Jha, 2022). Only some cities such as Mumbai and Bengaluru have a high percentage of metered connections. The percentage of metered connections is less than 50% in Kolkata and Chennai. Although Mumbai boasts of 81% of metering and unaccounted water of only 20%, piped water coverage is only 76%. There is an inequitable supply of water, with slum areas enduring the most of water shortages. Further, water tariffs for domestic consumption in most of the cities are highly subsidized leading to significant water wastage. There are several other issues related to access and water quality, as discussed by Water Aid India (Water Aid, 2018).

4.3.2 Sewerage systems

Central Pollution Control Board (CPCB) has recently carried out surveys for the national inventory of STPs in India (CPCB, 2021). It is estimated that a total of 72,368 MLD of sewage is generated across all the urban centres in India. Compared to this, the installed capacity of STPs is 31,841 MLD and the capacity of proposed STPs is 4827 MLD. Thus, there is a huge 49% gap between the amount of sewage generated and the installed capacity for treating it. Only 1093 STPs are operational out of a total of 1631 STPs. In all, 102 STPs are dysfunctional, 274 are under construction and 162 are proposed to be constructed. Only 578 STPs out of 1093 operational STPs are able to comply with the norms specified by the CPCB/State Pollution control boards. These numbers indicate that only 12,200 MLD of sewage or only 16% of total sewage generated in the country is actually being treated completely. There is a significant variation in the geographical/state-wise distribution in the installed capacity for sewage treatment. While the state of Maharashtra accounts for 26.7% of installed capacity, states such as Bihar and Jharkhand account for less than 2% installed capacity. In fact, there is only one STP of 10 MLD capacity functioning in Bihar when the study was undertaken. A study found that the

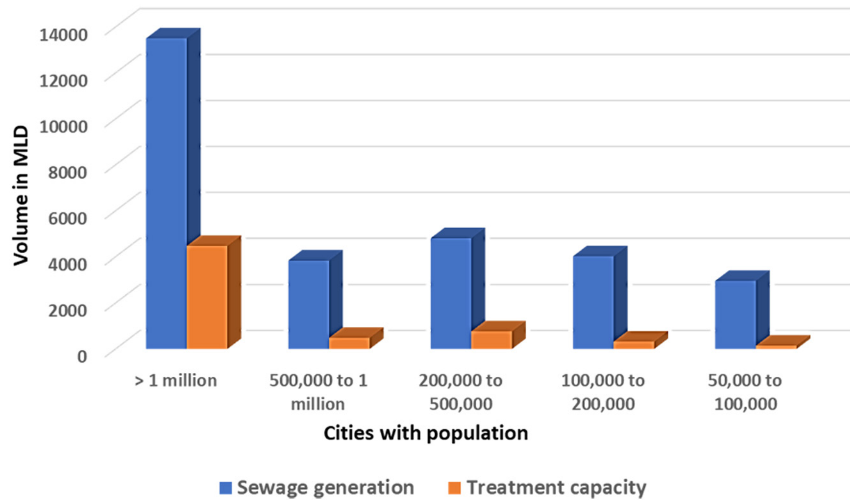

Figure 4.1 Wastewater generation and treatment capacity at city level in India.

most adopted treatment technology is sequential batch reactor (490 STPs accounting for 10,638 MLD capacity), followed by the activated sludge process (321 STPs accounting for 9486 MLD capacity). Wastewater generation and treatment capacity gap is shown in Figure 4.1.

The above-mentioned statistics indicate that the main problem afflicting the wastewater management in India is not only the lack of capacity for treating the sewage, but also the inability to operate and comply with the effluent standards. This mainly stems from the lack of funds for operation and maintenance, prioritization of funds for other purposes and the lack of skilled personnel for efficient operation. One of the major factors behind the underutilization of the capacity of STPs, especially in the case of newly installed plants is the inefficiency in the collection of generated sewage. There have been instances where the treatment plants have been installed but the coverage of the town or city with the UGD to collect and transport it to STP is not 100%. In some cases, although the UGD exists, households refuse to connect to the system because the tariff is high. Also, there have been instances where households practice on-site grey water recycling in their back yards and send only the toilet water to the UGD. These factors are affecting not only the functioning of STPs but also are resulting in frequent blockage of the UGD due to deposition of solids. These issues should be linked to the process of consent to be given by the municipality during house construction.

As per the directive of the National Green Tribunal (NGT), all the states and union territories have drawn plans for reuse of treated wastewater for different purposes. As of now, among others, Delhi (405 MLD; 12.5%), Haryana (192 MLD; 16%) and Tamil Nadu (211 MLD; 6.6%) have drawn up plans for reusing treated sewage for industrial and construction activities, horticulture, irrigation, washing (roads, vehicles, trains) and so on. There is a significant potential for increasing the percentage of treated wastewater reuse in all the states. However, challenges exist for retrofitting the existing sewerage systems for reuse because it may be required to separate grey and black waters. Also, on-site grey water treatment and reuse may reduce the flow rate in the sewerage system leading to solids deposition and frequent maintenance problems.

The rapid expansion of cities in India and other nations in the Global South poses challenges to the provision of conventional sewerage systems in per-urban areas during the transition period, that is, before the peri-urban areas are brought under the city corporation. Therefore, on-site sanitation systems such as septic tanks are commonly adopted in peri-urban areas. However, there may not be proper disposal of septic tank effluent due to lack of space. Also, there may not be a proper disposal of grey water. In such cases, it may be advisable to go for collection and transport of grey water and septic tank effluent using small bore system, and subsequent treatment by nature-based systems.

4.3.3 Stormwater drainage systems

Historically, among the three water infrastructure systems, the provision of stormwater drainage (SWD) facilities has been getting the least attention and priority from the urban local bodies. In parallel, rapid and unplanned urbanization has led to disappearance of natural drainage channels and many water bodies, which used to act as detention ponds to reduce peak flows. These factors, along with the impact due to climate change, have increased the frequency of both fluvial and pluvial flooding in almost all the urban agglomerations in India.

Mega cities as well as small towns in India severely lack effective SWD facilities. The major factors contributing to the failure of SWD systems in Indian cities, among others, are: (a) inadequate coverage, (b) inadequate capacity, (c) bad maintenance and choking due to indiscriminate dumping of solid waste and (d) conventional design. For example, the total stormwater drains length in Chennai is approximately 1894 km, as compared to the total road length of about 2847 km. Besides, although the core city has integrated storm water drain facilities, added areas included within the Greater Chennai Corporation do not have these facilities. Similarly, the total SWD length in Hyderabad is approximately 1302 km, while the total road length is around 9013 km. On a national scale, at present only 20% of the road network is covered with storm water drainage network and the associated catchment (MoHUA, 2019). Many of the existing SWD systems are very old, have not considered appropriate design rainfall intensity, and are not designed for handling high-intensity storms. For example, core of the SWD in Mumbai city is 70 years old and has been designed for a storm intensity of just 25 mm/h at low tide. Therefore, the city gets flooded even when 25 mm/h rainfall occurs, especially during high tide period. Similarly, Chennai city had adopted a rainfall intensity of 31.39 mm for SWDs for a length of 345 km as opposed to a rainfall intensity of 68 mm/h, as suggested in 2014 by Tamil Nadu Urban Infrastructure Financial Services Limited (TNUIFSL). The rapid assessment report prepared by Narasimhan *et al.* (2016) in the aftermath of 2015 Chennai floods has noted that drainage system was inadequate because of: (a) construction of many bridges across major drainages and (b) blockage of system due to indiscriminate dumping of solid waste into open surface drains, a very common phenomenon in SWD systems in India. As in the case of Chennai city, the micro drainage system is disjointed in many instances and it is not connected properly with macro-drainage system.

Another important factor contributing to the failure of SWD systems is that they are based on conventional design procedures. For example, a good urban SWD should be designed based on hourly or sub-hourly precipitation data. It is also required to have high spatial resolution data. However, such high-resolution spatial data for sub-hourly rainfalls is not available most of the times and designs are typically based on interpolations, leading to uncertainties. Rupa and Mujumdar (2018) state that the SWD design should be based on in-depth understanding of spatial distribution of short-duration rainfalls and uncertainty quantification. One cannot over emphasize the impact of climate change on the intensity–duration–frequency (IDF) curve. Therefore, the design should be based on design rainfall intensity picked up from climate change adjusted IDF curves (Rupa & Mujumdar, 2018). In general, SWDs in India are designed based on the old paradigm of clearing the stormwater from a location as fast as possible. It has now been well recognized that this concept does not lead to sustainable urban drainage systems.

4.4 THE WAY FORWARD

4.4.1 Water circularity

Currently, the water supply systems are mostly based on linear water balance framework and are finding difficult to bridge the gap between demand and supply without going in for expensive solutions. One way of achieving source sustainability in water supply systems is by transitioning into a circular

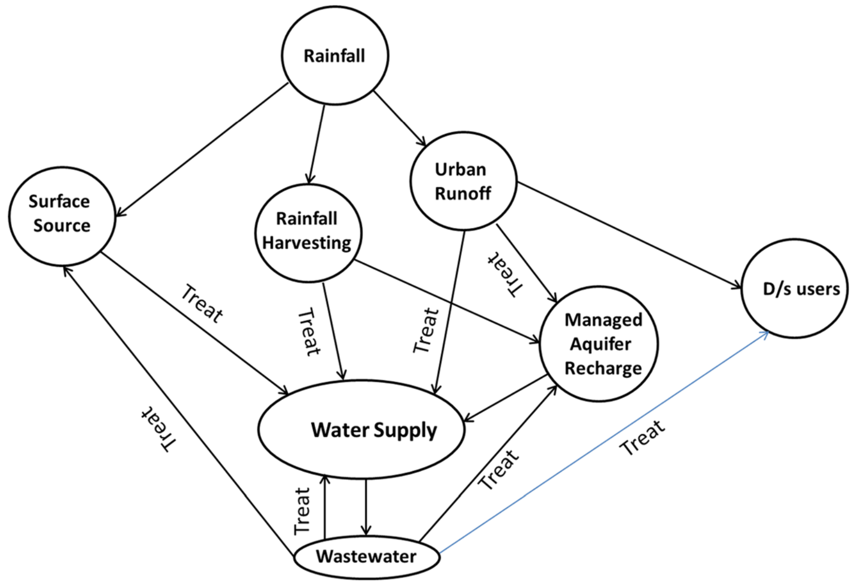

Figure 4.2 Schematic for circular water balance.

water balance framework. This framework will need adaptation of several novel technologies and practices such as: (a) managed aquifer recharge for increasing either groundwater potential for future exploitation or preservation of groundwater quality from getting contaminated due to salt water intrusion in case of coastal cities; (b) rainwater harvesting for both direct use in households and for groundwater recharge; (c) reducing the water demand by adopting novel water saving processes (e.g. using waterless urinals; storing the once used water from sinks for flushing etc.) and (iv) reusing and recycling the treated wastewater for both potable and non-potable purposes (Figure 4.2).

It is obvious from Figure 4.2 that the adaptation of circular water balance framework will require development of novel water and wastewater treatment technologies, tailor-made based on the influent water quality and the water quality required based on the fit for use. For example, treatment technology for treating urban runoff for household use will be different than that is needed for other situations. It is also obvious that adaptation of differential treatment of grey water and black water may result in better returns from the system, depending on situation. It may be also necessary to adopt not just dual pipeline systems but multiple pipeline systems to carry different quality water for different types of use. Water supply systems will be a hybrid of centralized and decentralized systems. Data analysis by Chatterjee and Roy (2021) suggests that a circular balance framework increases gross water availability from 350 to 950 Mm^3 in Chennai city. It has been shown that similar enhancements can be achieved in Bengaluru, Delhi and Coimbatore.

4.4.2 Leakage reduction

It has been mentioned earlier that there is a significant loss of water from water distribution networks, sometimes as high as 50% on input water does not reach the customers. It does not make any economic sense to not address this issue and go for expensive alternatives to procure extra water required for meeting the demand. The detection of leakage and taking actions to reduce the leakage in large water distribution networks is not a simple task. It will require significant amount of time and it will require money. The concept of District Metered Areas (DMA) should be considered in the planning and design, which will make the water auditing in a given network easy, reduce the time for localizing the leak and ease in operation for reducing the leaks (Narasimhan *et al*., 2019). The conquer and divide methodology proposed by Rajeswaran *et al.* (2018) can be adopted for already existing water distribution networks for leak detection.

4.4.3 Sustainable urban drainage systems

Over the years, the experience with SWD systems designed and implemented using the conventional paradigm has indicated that these systems are not sustainable. New paradigms such as low impact development, source control, sustainable urban drainage systems, among others have been introduced during 1960s–1990s in order to realize the other goals of an urban drainage system such as increased aquifer recharge, ecological protection and water quality improvement. Sponge city paradigm has been introduced in China since 2014. These sustainable urban drainage systems (SuDS) reduce the peak flow to be carried through channels and pipes and hence the size of the system required to prevent frequent flooding of the area. Several cities across the world have already adopted these concepts in one way or the other, and have addressed the problem of urban flooding. There are many SuDS measures such as swales, bio-retention cells, porous parking lots, roof gardens, rain gardens, detention tanks and so on for reducing the peak flow and for obtaining a desired runoff water quality. This topic is addressed in much more detail in Chapter 23 of this book.

4.4.4 Integrated planning

It can be observed from Figure 4.2 that the adaptation of circular economy will have significant impact on the planning and design of all the three water infrastructures, namely, water supply, wastewater management and storm drainage systems. Rainwater harvesting to increase the water availability to households locally and diverting overland flow for using it for managed aquifer recharge through injection wells will obviously reduce the amount of water that flows into storm drainage system as well as the flood peak. This will influence the sizing of drains. However, catching every drop of water where it falls for some local use will not leave water for downstream purposes. This may affect the ecological services of downstream channels and water bodies which have been receiving this storm water. If one knows how much water can be sourced from rainwater harvesting and treated stormwater facilities *a priori*, then one can decide on the amount of water that needs to be sourced either from surface or groundwater sources and accordingly plan, design and implement the water supply infrastructure. Similarly, if on-site grey water treatment for local recycling is used, then the size of the sewage system will reduce as the amount of water to be carried reduces. However, if all the grey water is captured and recycled, it may have long-term repercussions on the maintenance of the sewerage system due to reduced flows and settlement of solids. Also, the necessity of dual piping system and associated cost in case of centralized wastewater treatment system and recycling may offset the economic benefits accrued from reducing the need for sourcing fresh water from other sources. It is obvious that the recycling and reuse of treated wastewater may work in cities such as Chennai which are water starved as compared to a city in the Gangetic plains where surface water is available in abundance. In those cases, the recycling of treated wastewater should be adopted based on other environmental benefits. Thus, it can be seen that the adaptation of water circularity will necessarily require integrated planning, implementation and operation of the entire urban water infrastructure.

4.4.5 Others

Appropriate government policies are required to make the projects under PPP structure successful. One of the most contentious issues is tariff. Proper pricing for water supplied to households should be arrived at, keeping in mind the difficulties the disadvantaged sections face. There should be a differential price structure for the fresh water and recycled water to promote the use of recycled water on a large scale. There should be a policy for equitable distribution of potable water, especially during periods of scarcity, which many cities in India face due to vagaries of monsoon rainfall. Chapter 25 of this book discusses governance and policy issues in more detail. Government of India intends to move towards 24 × 7 water supplies. However, 24 × 7 systems exist only in a few cities, and it will take some time before we will have 24 × 7 systems in all the municipalities. During the transition period, there should be a proper operation of current intermittent systems to deliver the services optimally. It is essential to automate all the components of water infrastructure (water supply, sewerage system and storm water drainage) using the Internet of Things (IoT) platform, to make these systems smart and wise.

4.5 SUMMARY

In this chapter, we have discussed the present status of urban water infrastructure in India. We have considered water supply systems, sewerage systems and urban drainage systems. The deficiencies in existing infrastructure are brought out. The way forward for addressing these issues through adaptation of water circularity, sustainable urban drainage systems and integrated implementation are discussed. More details on sustainable urban drainage systems, water infrastructure and challenges for implementation of new projects and technologies are provided later in Chapters 23, 24 and 25, respectively.

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