ASSESSING THE VULNERABILITY OF BANGALORE'S WATER SUPPLY TO CLIMATE CHANGE

Naomi Sunu, Wendy Nakigudde, Josephine Chan[1]

Abstract

Bangalore is one of India's fastest growing cities, with the metropolitan region having an estimated population of 9.6 million inhabiting an area of 561 km^2 (Smitha, 2016; Gopakumar, 2012: 37). The city has undergone a process of transformation not only in the Information Technology (IT) sector, but also in its administrative decision to expand the urban agglomeration to include 8 municipalities and 110 villages. This has resulted in problems of access to and supply of water which are increasingly aggravated by the natural population growth and the migration of people into the city. The Karnataka Climate Action Plan also indicates from global climate model predictions that climate change will result in increases in higher temperatures and the frequency and severity of drought conditions for some districts in Karnataka state including Bangalore. In order to meet water access and supply needs for the ever-growing population, the Bangalore Water Supply and Sewerage Board (BWSSB) needs to adopt innovation solutions to both relieve pressure on groundwater abstraction and to move towards more sustainable sources of water. In addition to addressing these existing challenges of water supply in Bangalore, it is of extreme importance that water resource managers are also able to address the predicted climate change impacts. This paper examines Bangalore's preparedness in addressing climate change in relation to water security. It assesses the existing geographical, physical, social, and political threats using exposure, sensitivity, and adaptive capacity as the three components that determine a system's vulnerability. The paper concludes by highlighting several approaches Bangalore can utilize in adapting to climate change and addressing water challenges.

Keywords: Bangalore, Vulnerability, Urbanization, Groundwater, Cauvery River, Climate

[1] Josephine Chan (jywchan@uwaterloo.ca), Wendy Nakigudde (wsnakigu@uwaterloo.ca), Naomi Sunu (nsunu@uwaterloo.ca)

Change

I. INTRODUCTION

Bangalore, with its population of greater than 9.6 million as of 2011, is the fifth largest and one of the fastest growing cities in India (Smitha, 2016). The city of Bangalore is the hub of India's high-technology information, software, and biotechnology enterprises and a preferred destination for business-process outsourcing in the Karnataka state. Bangalore's economy is highly diversified and in addition to the Information and Communications Technologies (ICT) - based industries, the economy is also characterized by textile, aviation, machine tool, defence, service, trade, and banking industries (Sudhira & Nagendra, 2013). The economic activities of the city are characterized by the high concentration of small and medium enterprises (SMEs) in the various sectors across the economy (Sudhira & Nagendra, 2013). The city is a source of wealth with a net district income of approximately $5.8 billion USD and a per capita income greater than double the state's average per capita income (Sudhira & Nagendra, 2013). It is the district with the highest income and contributes approximately 34% to the Gross State Domestic Product (GSDP). This makes Bangalore the most preferred destination for economic migrants as close to 2 million migrants live in the city (Gopakumar, 2012). Bangalore serves as the seat of government and the administrative capital of the Karnataka state. Despite all the economic development in Bangalore, the most serious challenge it faces is the reduction in the availability and access to reliable and good quality water for its residents (Bangalore Action Plan for Sanitation and Water Infrastructure, 2014). The provision of safe and reliable water supply services is an essential overall contribution to economic development and welfare advancement (Raj, 2013).

a. Background

Bangalore receives a mean annual total rainfall of about 880 mm with about 60 precipitation days annually over the last decade (Sudhira, Ramachandra, & Subrahmanya, 2007). The winter temperatures range from 12℃ to 25℃, and 18℃ to 38℃ in the summer (Sudhira et al., 2007). The city is located at the southern edge of the Deccan Plateau at an altitude of 920 metres above sea level (masl). The ridges of the plateau delineate four watersheds: Hebbal, Koramangala, Challaghatta, and Vrishabhavathi (Sudhira et al., 2007). The urban agglomeration had an overall population of 5.7 million in 2001 and a workforce of 2.2 million (Sudhira et al., 2007). Of the total population, about 2 million were migrants, 1.2 million were from Karnataka state and mainly the rural parts, and the remaining 0.8 million from outside the state, mainly from urban areas (Sudhira et al., 2007).

Bangalore is a city that faces rapid urbanization and consequently increasing environmental pressures, and resource scarcities (Zaerpoor, 2012). Bangalore emerged as one of the fastest growing cities in India since the 1990's whose growth has been fueled by the introduction of numerous high-technology, technology enabled service industries and biotechnology- related companies. This resulted in the inflow of young, educated and middle class migrants from other urban areas in India. Despite this development spurred by the technology boom, the city is divided between high technology pockets existing adjacent to dense clusters of squatter settlements (Gopakumar, 2012). Due to infrastructure developments in Bangalore, most of the city's lakes and surface water bodies have dried up, been seriously degraded or even built upon.

Some of the water bodies and connected water channels have become abandoned or silted up as result of changes in agriculture. Historically, Bangalore has had a network of hundreds of manmade lakes and wetlands, utilized for irrigation purposes. These sources have been disrupted over the past three to four decades through activities such as reclamation of lake beds (fig. 1) (Bangalore Action Plan for Sanitation and Water Infrastructure, 2014).

Bangalore has at least three sources of water to meet their water needs namely: ground water, reservoirs, and river water. Groundwater is the most widely used form of water even though it is largely non-formalized. Residents use groundwater to supplement the highly inadequate piped water supply by pumping water from wells and boreholes located in their backyards (Gopakumar, 2012). The second source of water supply is through reservoirs, as Bangalore is dotted with hundreds of small, large and usually interconnected reservoirs that are rainfed and were traditionally set up for irrigation purposes. Many of the small reservoirs have disappeared as result of encroachment and urbanization whilst the large reservoirs have also become sinks for urban waste and unfit for use as potable water (Gopakumar, 2012). Rivers are the third source of water for Bangalore even though no major river flows through Bangalore. The

Arkavathy River was the main source of water for Bangalore but can no longer meet water demands because it has gradually been encroached on by urbanization. The BWSSB has therefore focused on supplying Bangalore with water from the Cauvery River which is 100km away and 600 meters below the city's altitude (Gopakumar, 2012).

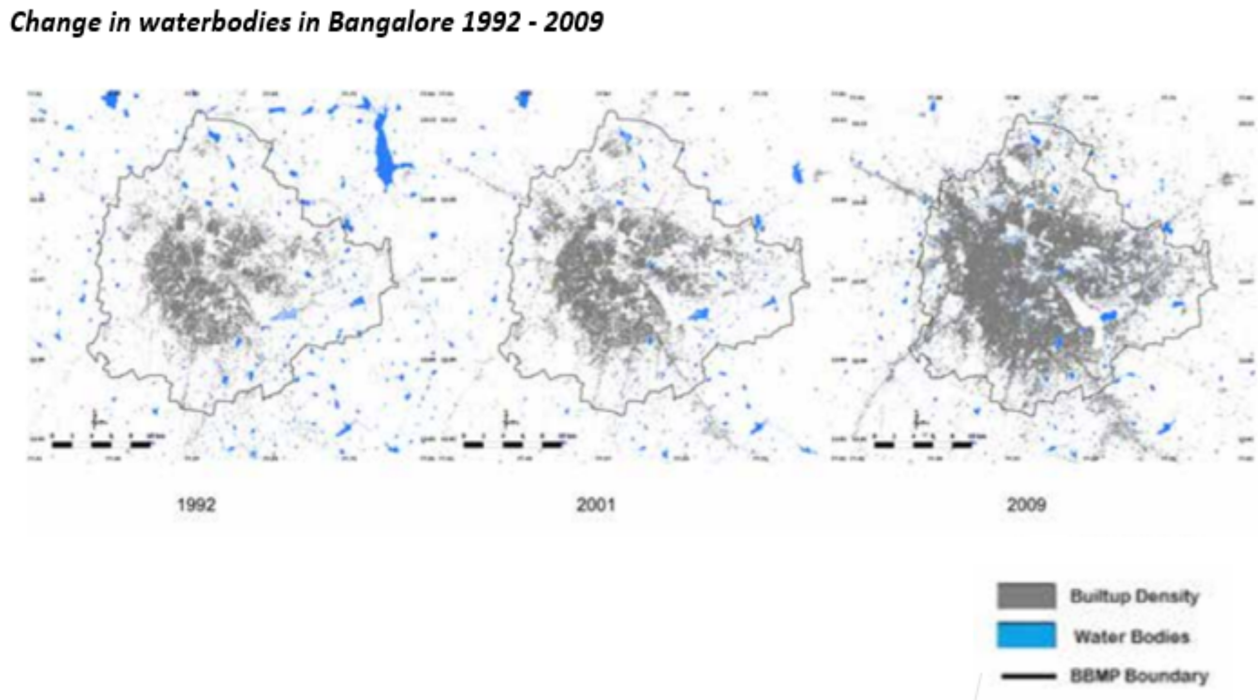


Fig 1: Source : (Bangalore Action Plan for Sanitation and Water Infrastructure, 2014).

b. Institutional layout of water resource management and governance in Bangalore

The primary actors in water management and governance include Bangalore Water Supply and Sewerage Board (BWSSB), Karnataka Urban Water Supply and Drainage Board (KUWSDB), small town municipalities, Gram Panchayats (GP), and the Karnataka State Pollution Board[1] (Lele, Srinivasan, Jamwal, Thomas, & Eswar, 2013; Bijani, 2012).

1. KUWSDB governs the following for small towns: supply quantity of domestic and industry water, sewage quantity domestic and industry sectors, quality of surface water, sustainability of groundwater and surface water, and the allocation of water on the micro-scale. GP is a municipality of a small town that governs: the domestic supply quantity of water and sewage, the quality of surface water, the sustainability of groundwater and surface water, and the allocation of water on the micro-scale. (Lele et al.,

2013).

The institutional layout with respect to the city of Bangalore is complex due to the different institutional layout with respect to the city of Bangalore is complex due to the different actors and the disparities between urban and rural settings, which results in further difficulties due to collaboration between many competing interests.

The BWSSB is the state owned public utility that supplies drinking water and provides sanitation services to the residents of Bangalore. It is also primarily responsible for water management in Bangalore (Lele et al., 2013). The board is staffed with predominantly technical personnel and has heavily invested in series of construction projects over the past years to supply water to Bangalore from great distances. Although the BWSSB is the biggest supplier, it is the least dependent on local sources (Lele et al., 2013). The BWSSB is represented by lower-ranked engineers in the field who act as assistant executive engineers, assistant engineers, water inspectors, and valve men who see to the distribution of water. The board also partners with the Social Development Unit (SDU) and non- governmental organizations (NGOs) to ensure supply of water and sanitation in slum communities in Bangalore. The SDU acts like the intermediary between the BWSSB and the NGOs whilst the NGOs act as intermediaries between the BWSSB and the slum communities (Gopakumar, 2012).

II. VULNERABILITIES OF BANGALORE'S WATER SYSTEM

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability through three components: exposure, sensitivity, and adaptive capacity. The vulnerability of Bangalore will be determined by their exposure to climatic variabilities, the degree to which they will be affected (sensitivity), and their potential to adjust to the climatic variabilities based on the resources they have (adaptive capacity) (Ludeña & Yoon, 2015). We discuss each of these aspects in turn.

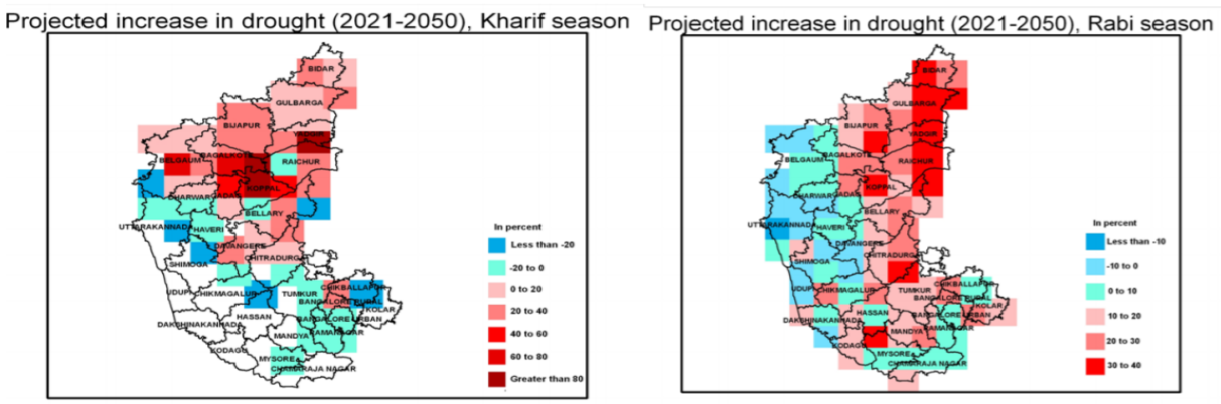
a. EXPOSURE

Climate exposure indicators include: temperature rise, heavy rain, drought, and sea level rise. The IPCC predicts that the impact of global warming will continue as the probability of severe heat waves, heavy rain, drought, tropical depression, and sea level rise increases over time. Exposure also relates to the degree of climate stress upon a system, including the frequency and magnitude of extreme events (Ludeña & Yoon, 2015).

i. Impact of climate change on water resources

Studies have shown significant increases in frequency of rainfall days and one day of extreme rainfall event over the last century in Bangalore. However, according to the Karnataka Climate Action Plan, estimates for the years 2021 – 2050 compared to the baseline years of 1961 – 1990, Bangalore will experience a percentage decline in monsoon and post-monsoon precipitation of 10% and 20% respectively. There is the possibility of increased drought instances for areas in Bangalore by 30% according to the estimations. The severity of estimated droughts can be increased by high temperatures, high winds and low humidity. Annual average minimum and maximum temperatures over Bangalore have been 19^0C and 29^0C respectively. A mean annual temperature increase of between 2^0C to 2.5^0C has been recorded over the last decade due to urban heat island effect and early climate signals. Bangalore primarily relies on a single source of water, i.e. the Cauvery River in the Karnataka State, which is shared with three other boundary states. This lack of diversity in water sources puts the city of Bangalore at risk of water shortages as average water yield decreases are expected in the Cauvery basin by 2050 in comparison to the baseline; this will affect the amount of water allocated to Bangalore for withdrawal. Bangalore also experiences flooding and will be prone to more flooding in the future, especially in slums that have become established in floodplains of rivers and drainage channels (Karnataka Climate Action Plan, 2011 and Bangalore Action Plan for Sanitation and Water Infrastructure, 2014).

Figure 2



Graph showing projected increase in drought incidences in the future compared to the baseline (1961-1990). The percentage increases in drought incidences in Kharif and Rabi[1] season are shown. The blue colors indicate that drought instances are projected to decrease, while the red colors indicate that such instances may increase. *Source: (Karnataka Climate Change Action Plan, 2011)*

ii. Drainage systems

Unplanned urbanization has drastically altered the drainage characteristics of natural catchments (Gupta & Nair, 2011). This has resulted in an increase of surface runoff (Gupta & Nair, 2011). Furthermore, flooding in Bangalore has intensified due to encroachment of wetland and floodplains that act as natural drainage systems. Flooding in general, results from a variety and often a combination of things such as the overflow of land areas due to the increase in impermeable or hardened surfaces, temporary backwater effects in local drainage channels and sewers, rise of groundwater coincident with increased stream flow.

A secondary effect of flooding is the creation of unsanitary conditions (Grupta & Nair, 2011). The intensified flooding in Bangalore also impacts the disposal of solid waste which subsequently interferes with water drainage (Gupta & Nair, 2011). Even with the appropriate infrastructure in place, the heavy rains, together with the silt and garbage, cause blockage that

1. Kharif refers to the wet season in Bangalore from April to October, Rabi refers to the dry season in Bangalore from November to March (Alauddin & Sharma, 2013).

renders the stormwater drainage system of Bangalore ineffective (Gupta & Nair, 2011).

b. SENSITIVITY

A system's sensitivity to climate change in measured through geographic and socio-economic factors such as population and infrastructure (Ludeña & Yoon, 2015). The indicators of sensitivity include geographical conditions, land use, demographic characteristics, and industrial structure such as dependency on agriculture and extent of industrial diversification (Ludeña & Yoon, 2015).

i. Urbanization and Biodiversity

There has been rapid population growth with an increase in population from 163 091 to 8 499 399 from 1901 to 2011 respectively (Sudhira & Nagendra, 2013). Urban sprawl and landscape fragmentation has occurred due to migration, population growth, increase in economic activity, and the availability of land for expansion (Sudhira & Nagendra, 2013). The city has experienced encroachment and pollution of bodies of water, and large scale conversion of open areas into industrial, commercial, and residential settlements (Sudhira & Nagendra, 2013). The pattern of urban growth is complex and irregular because urban growth is less directed by colonial legacies and state policies (Sudhira & Nagendra, 2013). There are accelerated and fragmented processes of change in the periphery and reduced urbanization in the city core (Sudhira & Nagendra, 2013). The city core is rich in vegetation species, but it is less dense compared to other cities. This biodiversity is at risk as climate change adversely impacts and exacerbates changes in temperature (Sudhira & Nagendra, 2013). With the increase in population, transportation has also become a major contributing factor to environmental issues in Bangalore as there is a vehicle population of about 3.8 million (Sudhira & Nagendra, 2013). This vehicle-to-person ratio is much higher than other Indian cities and is due to the lack of sufficient public transport (Sudhira & Nagendra, 2013).

There is generally an emphasis on economic development at the cost of environmental degradation in Bangalore (Sudhira & Nagendra, 2013). Historically, there were thousands of reservoirs surrounding Bangalore that were used for agriculture, fishing, and domestic uses, and they were managed by village communities. Today, they are managed by multiple government departments with overlapping responsibilities and jurisdictions (Sudhira & Nagendra, 2013). Green spaces and lakes are embedded within multiple land use categories and are governed by multiple institutions with often uncoordinated jurisdictional responsibilities (Sudhira & Nagendra, 2013). Such practices, conditions and contexts have resulted in the widespread degradation of these important resources. In response, in addition to formal institutions and structures, civil society, NGOs, and community based organizations have begun to take a larger role in environmental issues and might be important actors in the future (Sudhira & Nagendra, 2013).

ii. Groundwater Exploitation

Groundwater is the primary source of household, industrial and irrigation water in many areas of Greater Bangalore. According to Central Ground Water board (2013), groundwater contributes to about eighty percent of the drinking water requirements in the rural areas, fifty percent of the urban water requirements and more than fifty percent of the irrigation requirements of the nation. Out of the net irrigated area of 66,375 ha in Bangalore, 10,752 ha is irrigated as per Minor irrigation census of 2006-07. The dependence on groundwater as a source for all types of irrigation remains high in agrarian states like Karnataka. In Bangalore district, groundwater is mainly developed through dug wells, dug-cum-borewells, borewells for irrigation, industrial and domestic purposes. Climate change and variability is exacerbating problems that relate to the flow of water and the monsoon season, reinforcing the desire to overuse groundwater (Ackermann, 2012). This has resulted in depletion of ground water levels & over exploitation of the groundwater resources in the district.

In recent years, the increase in migration of people to work in Bangalore has also resulted in an attraction to water and rivers. Rapid urbanization in Bangalore has led to large scale land use changes which have led to an increase in paved surfaces. As a consequence this has not only led to the intensification of urban floods, destruction of ecosystems such as wetlands but also a decline in water infiltration (Gupta & Nair, 2011). Many residents living in the peripheral areas of Bangalore are currently faced with the issue of rapid groundwater depletion. The inadequacy of the BWSSB infrastructure, combined with the high cost of bottled and tanker water, means that the city augments nearly half of its domestic water needs with groundwater (Zaerpoor, 2012). Recent studies have shown that Bangalore recharges approximately 3,290 hectare metres[2] of groundwater per annum. This is due to the built up areas which amounts to 560 sq km with

[2] One hectare metre = 10,000 cubic metres

only 240 sq km left for water to seep in. The city therefore uses three times more water than it can recharge. According to a hydrologist and expert of the Karnataka Groundwater Authority, the built up areas of Bangalore are made of concrete and mosaic surfaces which reduce aquifer recharge. The ground has a capacity of infiltration of up to 300m. Beyond this point there are only hard rocky surfaces. Nonetheless, borewells have been dug in several peripheral areas beyond 280 metres which means that 20 metres reserve of water left in the ground is being depleted and yet it could have been accumulated for years. Bangalore was expanded to include surrounding villages in city limits; however, many peripheral areas are not formally connected to the city's water and sewerage network hence the heavy reliance on groundwater. Initially borewells were drilled 30-40 metres and mostly fitted with taps which restricted the amount of water that could be extracted (Zaerpoor, 2012). The introduction of high speed drills in the 1970s led to rapid increase in groundwater extraction (Zaerpoor, 2012).

iii. Pavement and urban centres

The city of Bangalore was constructed on hard rocks namely; granite (igneous rock) and gneiss (metamorphic rock) (Zaerpoor, 2012). Granite is very common in the Western part of the city while gneiss rock formations are dominant throughout the city (Zaerpoor, 2012). These rocks are crystalline structures that have little space in between making it difficult for water to seep into the ground (Zaerpoor, 2012). According to Zaerpoor (2012: 25), any form of penetration would occur through cracks, faults or fractures. Beyond 280-290 metres is a massive hard rock that remains impermeable to water allowing the buildup of an underground water table (Zaerpoor, 2012). In many parts of the city borewells cannot expect to get access to water beyond 280 metres (Zaerpoor, 2012). The physical build up of the city as well as its geology make groundwater extraction difficult (Zaerpoor, 2012).

c. ADAPTIVE CAPACITY

The adaptive capacity to climate change depends on physical resources, access to technology and information, varieties of infrastructure, institutional capability, and the distribution of resources. The ability of Bangalore's system to adjust to climate variabilities in order to limit their risk to water insecurities will define their adaptive capacity (Ludeña & Yoon, 2015). The indicators for adaptive capacity encompass their political, institutional, infrastructural developments.

i. Institutional

The BWSSB, the main agency for ensuring supply of water in Bangalore has been beset by administrative challenges as well as the physical and economic scarcity of water. Inefficient recovery of capital, operational and maintenance costs as well inability to deal with water thefts has resulted in inadequate financial resources to improve upon water treatment and supply infrastructure. This situation has been blamed on the state government's lack of prioritization of water pricing policies to ensure sustainable water production and distribution. Dependence on Cauvery River as their only surface water, combined with falling a groundwater table, drying up of lakes and improper sewage treatment, impacts the physical availability of water in Bangalore. At the same time, the BWSSB lacks the staff strength to operate effectively as their current staff strength is 5.2 workers to 1000 connections (Raj, 2013).

All waters users are supposed to enjoy subsidies, however, low income consumers tend to be excluded from the BWSSB water supply network; poorer households end up in the same water networks of richer consumers and become marginalized (Raj, 2013). BWSSB needs to have proper and more efficient management practices such as appropriate user charges, while users should be responsible in becoming more aware of the economic justification, urgency and inevitability of increasing water tariffs (Raj, 2013). Moreover, the institutions in charge of water management are lacking in clear policies for water users. Moreover, these policies should be more transparent and accessible to all.

The investment of the BWSSB in drawing water from the Cauvery River includes hundreds of kilometers of massive pipelines, three booster pumping stations, a balancing reservoir, treatment facilities and a host of control and maintenance stations. Additionally, there is a dispatch station at Cauvery and a receiving station at Bangalore. Energy requirements for the pumping of a substantial fraction of Bangalore's water supply uphill, over long distances, creates a heavy financial burden for the board (Gopakumar, 2012). The Cauvery Water Disputes Tribunal was set up to address water resource allocation between boundary communities of the Cauvery to prevent disputes. Bangalore's share was capped at 14.52 thousand million cubic feet (TMC) with that assumption that 80% of lifted water will return to Cauvery as a return flow. The Tribunal however does not have mechanisms in place to measure how much water is being returned to the Cauvery and does not have plans for water sharing due to shortages in drought years, despite the fact that more drought years have been predicted (Lele *et al.*, 2013 and Raj, 2013).

ii. Political

Political interferences in the running of the BWSSB has hindered the operationalization of financial measures that will make water supply sustainable. Despite the increasing water demands, poor metering systems and poor recovery of operational and maintenance costs ensure that the BWSSB does not generate sufficient funds to cover their operational costs and so relies on the state government for funding. Increasing costs from rising electricity charges and unwillingness of decision makers to increase water tariffs has resulted in poor water delivery. BWSSB water tariff was Rs 5 for every 1000 litres of water supplied whilst actual cost of supply was Rs 40 per 1000 litres. Since the last upward adjustment of water tariffs in 2005, tariffs were only increased again in 2014. The BWSSB spends 65% of its total revenue on electricity used in the supply of water to Bangalore. This forms a huge part of their production and operational costs which continually increases as demand increases (BWSSB, 2014 and Raj, 2013).

iii. Leakages and Unaccounted For Water

As described above, groundwater and surface water is used in meeting the domestic, agricultural, commercial and industrial water needs of people in Bangalore. Water quality has reduced due to poor maintenance of infrastructure as potable water distribution lines get mixed with sewage water. Bangalore experiences huge distribution losses as 48% of water distributed is unaccounted for (See fig:3) due to water leakages at the distribution mains, service pipes and valves, and water pilferage (Lele et al., 2013 and Raj, 2013).

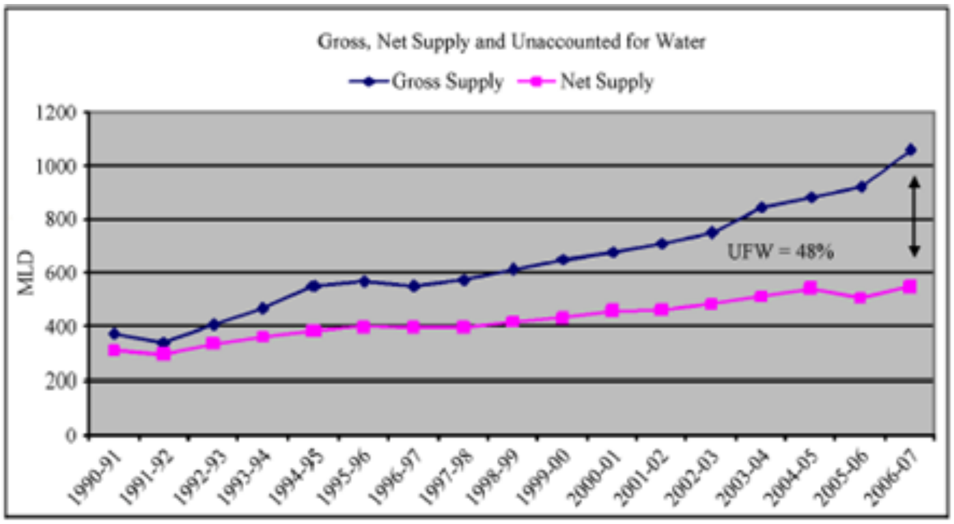


Fig 3: Gross, net supply and un-accounted for water in Bangalore city. Source: (Raj, 2013)

iv. Technology: Wastewater treatment

Wastewater reuse and wastewater treatment plants are highly debated between several analysts, as effective adaptation approaches to meet Bangalore's water needs (Jamwal et al., 2014). BWSSB manages 14 centralized Sewage Treatment Plants (STPs) and 612 decentralized STPs are privately managed. Despite this investment, the lack of an underground drainage system in many parts prevents the STP's from receiving adequate water for treatment. An estimated 64% of Bangalore's untreated wastewater still flows into river systems indicating under-utilization of the STPs. In spite of this, the BWSSB has begun investment and proposes to generate more than 300 MLD of treated water across their treatment plants. The disadvantage of investing in more wastewater treatment plants is that transportation of the treated water through pipes is attributable to the consumer costs as much as water treatment resulting in expensive treated water. Thus even treated water currently available does not have an avid market. Also, if urban consumers recycle and reuse their water effectively, farmers downstream who rely on the effluent water for crop irrigation will encounter reduced flows and concentrated industrial contaminants in effluents. This will affect their agricultural profits as well as negatively impact their health (Jamwal et al., 2014).

III. PROPOSED SOLUTIONS

a. Monitoring of groundwater extraction process

The State of Karnataka enacted a Groundwater Act in 2011 to regulate the overexploitation of groundwater in the state (Ministry of Water Resources). It also set up the Karnataka Groundwater Authority to implement the act and rules in the state (Ministry of Water Resources). Some ways in which ground water extraction can be regulated is by enforcing strict penalties on excessive ground-water extraction (Raj, 2013). There is also no formal and systematic monitoring of groundwater extraction in urban areas, despite the need for it. Lele et al (2013) argue that, for sustainable water resources management to occur, there must be some sort of formal system implemented and enforced to monitor and collect data. It is also important to enact the Karnataka Ground Water Bill which seeks to register borewells, install meters and establish user-pay fees (Zaerpoor, 2012). Regulatory reforms must include the establishment of required drilling depths, distance between wells and cropping systems that do not require over-withdrawal of the water resource (Bangalore Action Plan for Sanitation and Water Infrastructure, 2014). Artificial recharge to groundwater through structures such as dug well recharge, watershed treatment, recharge trenches, percolation tanks, check dams, subsurface dykes, point recharge structures should be implemented based on site specific scientific investigation (Ministry of Water Resources). Such structures can be taken up in all the over-exploited blocks of the district (Ministry of Water Resources).

b. Increasing infiltration and rainwater harvesting techniques

New design approaches which explicitly design roads to act as drains, can radically reduce the duration of flooding. It is also possible to design city pavements to allow for infiltration (Gupta & Nair, 2011). Better handling of solid waste and litter to prevent systems from becoming rapidly blocked with debris is also a reasonable step to be taken in terms of sustainable water resources management (Gupta & Nair, 2011).

Artificial lakes in Bangalore were created to regulate floods, as well as to recharge and maintain the groundwater table (Ministry of Water Resources). They also act as sediment traps, prevent clogging up of natural valleys, and reduce erosion by regulating run-off (Ministry of

Water Resources). However, due to unplanned urbanization, several waterbodies have been wiped off the map (Ministry of Water Resources). Measures to rejuvenate tanks and lakes in Karnataka are critical in building up ground water resources (Ministry of Water Resources).

In Bangalore city, there are more than 200 parks and also large institutions, industries, public, and semi-public areas that can be utilized for rainwater harvesting (Ministry of Water Resources). Additional water bodies in barren catchments of various campuses should be developed on a large scale to prevent wastage of run-off and to help augment ground water recharge (Ministry of Water Resources).

c. Basin, stakeholders, knowledge

An integrated water monitoring component has been suggested to improve upon the existing integrated water resource management (IWRM) concept which has challenges in recognizing and accommodating the link between groundwater and surface water resources in planning and management. The new approach requires a holistic consideration of the water cycle from the whole river basin perspective. It also requires the promotion of integrated knowledge and understanding from an interdisciplinary approach and multidisciplinary leadership (Lele and Srinivisan, 2016). People who can best manage the water resource are those who are closest to it and not agencies who visit periodically. There is also evidence that the creation of smaller administrative units could bode well for public service delivery and better overall governance (Sridhar, 2016). Through the use of participatory groundwater management techniques, local organizations, civil society, private sector and government can ensure the sustainable management of groundwater. The participatory groundwater management approach requires community capacity building through formal and non-formal education to impart knowledge to community members in the fields of hydrology, agriculture and institution management. This approach is highly relevant in putting groundwater management into the hands of many rural communities because around 50% of irrigated agriculture and 85% of rural drinking water comes from groundwater and they are the most at risk of water shortages. Components of participatory groundwater management include well irrigation systems, participatory hydrological monitoring, farmer data water management and artificial groundwater recharge and community based institutions (Govardhan Das and Burke, 2013)

d. Reforms in water supply operations and management

As a result of poor governance and political interference, the induction of knowledge, experience and technology use in water management in the city has been inhibited. The governance structure needs to undergo reformation that will result in increased accountability, coordination and devolution of some powers to user groups. Water users will generally not welcome increased tariffs unless BWSSB educates stakeholders about the urgency, economic justification and inevitability of increasing water tariffs (Raj, 2013). Satisfactory revenue collection should charge the rich higher tariffs for their non-drinking water consumptive uses that will be used in subsidizing the cost of services to poor consumers. The use of economic instruments, for example increasing of water tariffs, can be used in rationalizing the consumption behavior of water users, ensure equitable water allocation within similar users and help the BWSSB maintain water supply infrastructure. The inadequate use of such instruments due to the lack of political will by the policymakers has contributed to the current water situation in Bangalore (BWSSB, 2014 and Raj, 2013).

e. Computerization of data, tapping leakages

Water supply is currently not sufficient to meet demand in Bangalore. With and estimated 35% to 48% of total water supplied unaccounted for due to leakages, wastage errors in meter readings and unauthorized consumption, there is great potential for creating 'more water' through attention to this problem. Water management is currently controlled by hundreds of valve men and engineers turning valves on and off at specified times. There is improper data recording of supplied water and no mechanism that can monitor and provide feedback on work done by the valve men. Water management software and digital instruments capable of measuring and storing data in digital form can be used to manage water flow in Bangalore, with real time reporting on a rich geospatial visual. Alarm systems can be incorporated that will be triggered when some sections of aging pipe systems break down or malfunction. Similar systems may assist with computations to monitor and provide data on water losses to enable repairs (Merchant *et al*., 2014).

f. Educating water users

One way of creating awareness on proper water use amongst the public is through mass media communication (Raj, 2013). Awareness campaigns can be done in several local languages to reach a diverse population (Raj, 2013). These campaigns need to emphasize the need to save the precious resource and highlight its potential impact due to climate change (Raj, 2013). This may be operationalized by allocating a higher budget for information, education and communication (IEC) on water management (Raj, 2013).

g. Climate Action Plan

Bangalore must have their own climate action plan that will provide the guidelines for action and define the various organizations and stakeholders who can work together in its implementation. Implementation of the action plan will build the resilience of the city to the impacts of climate change.

IV. CONCLUSIONS

Bangalore can only increase their adaptive capacity to climate change impacts if the current political, institutional, and technical problems are resolved, without overlooking the increasing population and subsequently the heightening demand for water. There exists a multitude of diverse issues that span from urban sprawl, to institutional setbacks that reveal the vulnerabilities of the currently established water resource management system. Left unattended, these will only be exacerbated by climate change in the forthcoming years; in turn, they will exacerbate the negative impacts of climate change and variability. Solutions require interdisciplinary thinking and knowledge as well as the collaboration of all relevant stakeholders who are willing to work towards the common goal of equitable access to safe drinking water and creating more resilient solutions as it pertains to climate change. If urgency is not attached to the solving of these current and anticipated challenges, Bangalore's present economic growth and prosperity will come to a standstill.

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