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Sustaining Urban Water Supplies in India: Increasing Role of Large Reservoirs

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Abstract Urban water demand is rapidly growing in India due to high growth in urban population and rapid industrialization. Meeting this demand is a big challenge for the urban planners in India. Incidentally, the large urban areas are experiencing faster growth in population, and most of them are in arid and semi arid regions, which are naturally water-scarce. As a result, water supplies from local water resources including aquifers are falling far short of the high and concentrated demands in most urban areas. Under such situations, these large cities have to rely on distant large reservoirs. The analysis of 302 urban centers shows that cities with larger population size have much higher level of dependence on surface water sources. Also, greater the share of surface water in the city water supplies, higher was the level of per capita water supply. Multiple regression models are estimated for Class I cities and Class II towns in India. The results show that Population Elasticity of Water Supply (PEWS) change with time and space—for Class I cities it was 1.127 in 1988, whereas that with respect to 1999 population is 1.289. It also shows that Class I cities have better water supply (PEWS is 1.127 in 1988 and 1.289 in 1999) than Class II towns (PEWS is 0.396 in 1988 and 0.675 in 1999). Given the structure and pattern of urban population

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growth, economic conditions and water demands, large reservoirs will have a much bigger role in meeting urban water supply needs.

Keywords Urban water supply · Large reservoirs · Urbanization · Population growth · India

1 Introduction

The traditional engineering approach to water management in India largely concentrated on building storages and diversions in places which provided hydrological opportunities and taking water to regions that face shortages with the aim of reducing the imbalances in demand and supplies with respect to space and time. But, large water resources projects, which can facilitate this, have begun to face fierce resistance from environmental groups across the world for the potential negative social and environmental consequences they could create (Shah and Kumar 2008). Though they have begun to propose alternative approaches, they are quite general. These approaches fail to consider two important factors that determine the effectiveness of water management approaches in a given situation. The first one is the nature of water scarcity. The second one is the type of regions which are likely to experience rapid growth in water demands.

Elaborating on the first issue, most of the solutions to India's water problems have been agriculture centric. They overlook the magnitude of water demands in urban areas; ignores the fact that a significant chunk of the growth in water demand is going to come from urban areas. Urban water demands are different from agricultural water demands. They are more or less uniform over the year, and are highly concentrated. These unique characteristics of urban water needs make it mandatory to have unique approaches and treatments.

Secondly, several of the solutions being advocated for urban water problems are based on the inherent assumption that the regions which experience water scarcity would have extra water resources naturally available for harnessing.[1] In contrast to this, most of the cities/towns experiencing fast growth in India are falling in naturally water-scarce regions and have limited water resources endowment. As a result, the amount of water that could be managed from small geographical areas within such regions is often too inadequate to cater to the very high demands resulting from rapid population growth.

The key propositions in this paper are as follows. First: in semi arid and arid areas, the urban water supply systems began to depend on local water sources such as wells, ponds and tanks. Second: with rapid growth in urban population and fast industrialization in and around urban centers, stretching these resources to meet urban water demands pose serious threat to the sustainability of the resource base itself. Third: as a result, these urban centers will have to depend on imported water from large reservoirs for ensuring sustainable water supplies, and therefore as a result, as the cities become larger, their dependence on surface water resources is

[1] They include local runoff water harvesting and groundwater recharging, urban storm water harvesting; roof water harvesting. Largely, these interventions would be effective only in high rainfall areas (Kumar et al. 2006).

likely to increase consistently. Fourth: cities depending on exogenous sources for water supplies, particularly large reservoirs, maintain higher levels of per capita water supplies as compared to those dependent on local sources.

The paper is organized as follows. The next section deals with the objective, hypothesis, methodology and data sets. The third section describes the trend of urbanization in India and their reliance on large reservoirs to meet their water needs. The subsequent sections analyze India's urban growth with special reference to the Class I cities and Class II towns; their sources and access to water, and their dependence on large reservoirs for water supply. The last section offers policy suggestions and concluding remarks.

2 Objectives

The objectives of the study are to: (a) analyze the emerging trend in urban water supplies vis-à-vis the dependence of towns and cities on local resources and large reservoirs; (b) analyze the physical, socio-economic and political factors behind the emerging trend.

The main hypothesis being tested in this paper is that beyond a threshold point, the population and economic growth of the city drive the water utilities to shift from groundwater to surface water, in hard rock regions of India. The sub-hypotheses are: (a) over time, increasing number of cities (within the same size class) depends on surface reservoirs for water supply; and (b) over time, the dependence of cities (within the same class or otherwise) on surface reservoir in volumetric terms increases.

The paper analyses the trend of urbanization and dependence of cities/towns on large reservoirs for water supply. The paper focuses on the water supply situation in Class I cities and Class II towns of India, as they are emerging as the centers of rapid population growth of the country (Mahmood and Kundu 2006), and water supply to these cities is quite challenging due to their vast population base.

3 Impact of Urbanization on Growth of Urban Water Demand

Since independence, the urban population of India has grown exponentially. Total urban population in India has increased more than ten times surpassing India's total population growth, which has increased less than five times during 1901 to 2001 (Maiti and Agrawal 2005). Currently around 27.8% (285 million in absolute terms) of India's population is living in urban areas (Government of India 2001), which, as per an estimate will continue to increase up to 40% or 550 million in 2021 (Lundqvist et al. 2003). The Government of India divides cities between Class I and Class VI, based on their population size.[2] Figure 1 describes the share of Class I cities and Class

[2]Metropolitan: with a population of more than one million people; the Class I cities are those with a population between 0.1 million and one million. The Class II towns are those having population between 50,000 and 0.1 million people; Class III towns have population in the range of 20,000 and 49,999; Class IV towns have population in the range of 10,000 and 19,999; Class V towns: between 5,000 and 9,999; and Class VI towns: with population of less than 5,000.

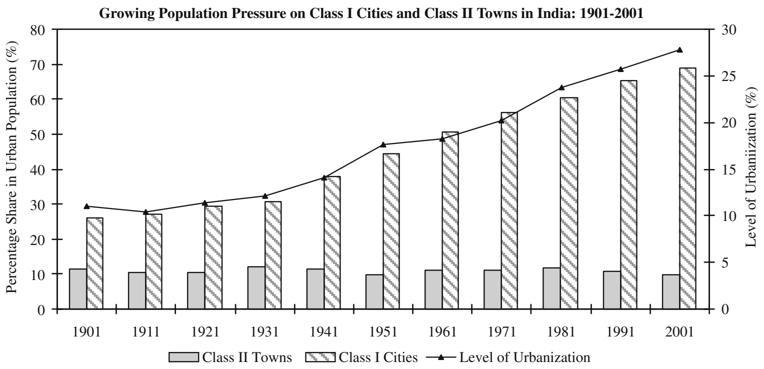

Fig. 1 Growing population pressure on class I cities and class II towns in India: 1901–2001. Source: Government of India (2001)

II towns in total urban population and the level of urbanization (urban population as a percentage of total population).

The magnitude of challenge to India's future water resources planning and management would be largely determined not so much by its population growth, but by three other factors: (1) the source of this growth, i.e., whether rural or urban; (2) where this growth is likely to occur, i.e., whether in water-scarce regions or water-rich regions; and, (3) whether the growth is going to come from increase in urban centers or faster growth of the existing urban areas. During the period from 1901 to 2001, the average annual compounded growth rate in urban population was 1.4 times higher than that of the total population in the country (Government of India 2001).

Figure 1 clearly shows that a much greater share of the urban population live in large cities today as compared to the beginning of the twentieth century. As Kundu (2006) notes, there are two reasons for the urban hierarchy becoming top heavy: (a) the growth in number of urban areas has been much lower, with not many villages transforming into towns; and (b) the larger cities have been growing at a much faster rates than the small towns. Figure 2 shows India's urban growth rate over

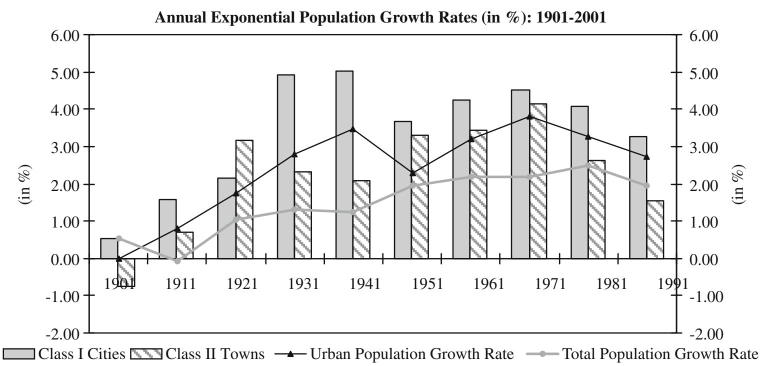

Fig. 2 Annual exponential growth rate of population across urban agglomeration in India. Source: Government of India (2001)

the decades since 1901, according to which, after 1920s, the growth rate in Class I cities has been consistently higher than that of smaller towns. Increase in number of large cities and their population pose new sets of challenges from water management perspective.

Unlike in many developed countries, India's urbanization is rapid, exponential and uncontrolled. While urbanization in developed countries drove their economic growth, which financially supported the infrastructure development in the cities (Biswas 2006a). In India, cities work as the drivers of the economy. It has been estimated that the urban areas of the developing countries, which contained about 47.2% of their total population in 2000, contribute nearly two-thirds of their total Gross National Products, and also play an equally important role in terms of social development and cultural enhancement (Biswas 2006b). In case of India the urban population accounts for one-third of the country's total population and contributes more than 50% of the country's Gross Domestic Product (GDP; Government of India 2002a). Thus, sustaining high urban growth rate would be crucial for unfolding the future growth potential of the country's economy, which has experienced high growth rate during the past one decade. Improving the performance of various urban utilities is the key to sustaining the past growth rates.

Among the many utilities, water supply is of paramount importance. In a recent study involving 145 countries shows that the improvement in water security drives economic growth of a nation through the human development route (Kumar et al. 2008a; Shah and Kumar 2008). Water supply systems would require continuous improvements to ensure high quality of services in terms of maintaining adequate level of supplies keeping pace with the growing demand in both aggregate and per capita terms; following stringent water quality norms which also change with time; ensuring equity in access to water supplies across zones and segments; and collection and safe disposal of wastewater. As population grows, a city's own local water sources could fall far short of supplies to meet the increasing demands. In such circumstances, it will have to look beyond the city limits to sustain the communities living inside and the economic activities it supports (McGranahan et al. 2001).

The National Water Policy 2002 (Government of India 2002b) has prioritized drinking water over agriculture and industrial water needs. A significant share of the water from public reservoirs is normally allocated for domestic water supplies in cities and villages in India during planning stage itself, and the sanctity of such *allocations* is maintained. Over and above, during droughts, a significant proportion of the public reservoirs get earmarked for urban and rural drinking water supply alone, sometime at the cost of irrigation and other uses. However, despite the catalytic impact that dam projects have had on the formation of modern urban landscapes, these projects have received very little attention in the emerging field of enquiry of geography of urbanization (Kaika 2006). The Sardar Sarovar reservoir built on the Narmada River in Western India, for example, is expected to make a major dent in the rural and urban drinking water needs of 9,663 villages and 137 urban centers in Saurashtra and Kachchh regions of Gujarat (Hirway and Goswami 2008). Without the large pipeline scheme, which transfers water from Sardar Sarovar main canal, the drinking water situation in these drought-prone regions would have been precarious as sustainable source of water to meet the basic requirements are absent in the region (Talati and Kumar 2005). As many cities and towns are running out of water, due to permanent depletion of local groundwater, many dams originally meant for irrigation are now supplying water for domestic consumption (Shah and Kumar 2008).

3.1 Changing Urban Water Demand and Supply Scenarios

Urban water demand comes both from (a) the concentration of human populations, who need water to survive; and (b) urban economic activity (Meinzen-Dick and Appasamy 2002). Cities are characterized by concentration of population as well as various kinds of economic activities including manufacturing. The factors that determine its water supply potential and level of scarcity can be geo-hydrological; hydrological; technological, managerial, economic and political. At early stages of development, the water needs of a city are generally met through development of local groundwater resources, and diversion of water from lakes, ponds, rivers and tanks.

Soon, scope of such options became limited as water demand increases as a result of increasing population pressure (vertical expansion) and expanding city boundaries (horizontal expansion), economic growth, and improved standard of living. The problem of inadequate supply is compounded by groundwater depletion, reduced inflows into surface reservoirs due to catchment degradation, and deterioration of their water quality due to indiscriminate disposal of industrial effluents and municipal wastewater. Under such situations, cities have to look beyond their boundaries to meet their water needs. Long-distance transfer of water to the growing urban system has already become a necessity in many countries (Lundqvist et al. 2003). Mexico City, Cairo and Beijing in the developing world and San Diego, Los Angeles, El Paso in USA are some of the examples where the city's water demands have been met through large reservoirs. In India, Yamuna River is the major source of water supply for Delhi. Its future water supply plan includes drawing water from Tehri reservoir. Delhi's groundwater potential and flows in the Yamuna are not adequate to support its population and economic activities without imported water. Similarly, the growth of Jodhpur city in the arid regions of Rajasthan can be duly acknowledged to the water supplied from Sutlej River through the Yamuna canal.

3.2 Economics of Urban Water Supply

The investment decisions in the water sector are largely taken on economic and political grounds. The past efforts for transfer of water from large reservoirs to cities faced severe criticism on the following grounds: first: cities take away water from farms (Lundqvist et al. 2003; Saravanan and Appasamy 1999); second: the cost of water transfer from far away places is enormously high (SANDRP 1999); and third: the environmental impacts of dam construction and water transfer are always negative and irreversible (D'Souza 2002; McCully 1996; Fitzhugh and Richter 2004). On the other hand, all social, economic and political considerations favour transfer of water from agriculture to domestic sector. First, water for drinking is a social good, and meeting drinking water requirements is the first and foremost priority according to the National Water Policy - 2002 (Government of India 2002b). Second: urban dwellers generally enjoy more political clouts as compared to their rural counterparts. Third: urban areas are growth centers, and any reduction in supply of water to urban areas could cause much higher economic losses than the losses in rural areas with the same level of reduction to agricultural water supplies. In spite of the fact that domestic sector, including that in rural areas, accounts for only 3% to 5% of the total water consumed in India (Bansil 2004), this seems to be a daunting task.

The direct and indirect social and economic outcomes of regular water supply in urban areas would justify a city's decisions to obtain supplies often at costs higher than what is necessary, but without significantly compromising their ability to expand and prosper even in the most unhelpful locations (Molle and Berkoff 2006). When urban areas house large manufacturing units, the opportunity cost of not providing adequate amount of water would become prohibitively high in terms of negative consequences for the economic activities that urban areas support, and survival of the communities living there.

Also, from macro economic perspective, the contribution from agricultural sector to the country's GDP has been decreasing over the years (from 38% in 1980 to 22.7% in 2001), while the contribution from domestic (service) and industrial sectors to the same has been increasing (Ministry of Agriculture 2002—as cited in Amarasinghe et al. 2005). This had forced water resource bureaucracies to reallocate water from agriculture to non-agricultural uses including urban and industrial uses in the past. But due to the growing water scarcity in rural areas including that for drinking and domestic uses, these agencies would be increasingly under pressure to look for new sources of water (Mukherjee 2008a). This can lead to planning of new schemes that involve transfer of water from abundant regions to water-scarce regions where urban centers are located.[3] The underlying premise in this new approach is that while the negative environmental impacts of construction of large dams and water transfer can be controlled with good science and technology, the opportunity cost of delaying or stopping dam construction could often be severe (UNDP 2006; Shah and Kumar 2008).

4 How Does Water Supply Scenario Change with Urban Growth?

At early stages of growth a city may rely on its own local water resources such as groundwater, and lakes and ponds to meet its water requirement. In most cases cities exploit their groundwater resource, which is easily accessible since it is within the boundaries of urban centers, and cost effective in terms of initial investment. For a long time since Independence, Chennai city depended on the tanks which are located in the periphery of the city for municipal water supplies. Similarly, Ahmedabad city depended on water from Sabarmati River and the groundwater resources for meeting water supply needs of the city.

But urban growth changes it's water demand patterns altogether. The reason for this is that both the rise in population and economic growth, which are integral

[3]The drinking water supply schemes in large number of cities in Gujarat including Ahmedabad, based on water from Sardar Sarovar reservoir is one of the most recent examples of such an approach. While earlier, Ahmedabad city depended on water from Dharoi reservoir, the increasing pressure on this scheme to get water for rural drinking had reduced its ability to meet Ahmedabad's annual demands.

part of urban growth, increase the water demands exponentially. The cumulative effect of urban economic growth and population growth on urban water demand can be explained this way. The population growth itself increase per capita water supply needs from the municipal side due to the increasing need for sewage disposal. The economic growth increases the per capita water demand for domestic uses (Rosegrant and Ringler 1998). Also, urban growth, which comes with heavy industrialization, would increase the water supply needs for commercial activities and manufacturing units. Amarasinghe et al. (2007) shows that economic growth and urbanization influence the per capita water demand in urban centers. Their analysis shows that a 1% increase in per capita gross domestic product would have a 0.17% increase in the per capita domestic water demand. A similar increase in urbanization would result in a 0.68% increase in per capita domestic water demand.

Thus, when the cities grow, the dependability of local water resources to provide adequate supplies to the consumers on a sustainable basis reduces. More importantly, most fast growing urban centers in India are located in semi arid and arid areas experiencing high variability in rainfall conditions and mostly with poor aquifer conditions, making the supplies from local water bodies such as tanks, and ponds and wells unreliable. Examples are Pune, Jaipur, Jodhpur, Nagpur, Ahmedabad, Hyderabad, Chennai, Delhi, Rajkot, Hyderabad and Bangalore (based on data provided in Kumar et al. 2008b). There are very few fast growing large cities such as Kolkata and Mumbai that are located in water-abundant regions. In a semi arid or arid region, if the urban centre taps water for municipal uses from underground sources, the chances of aquifers getting depleted due to excessive pumping are very high as the pumping takes place within small geographical areas creating *cones of depression*. This is a phenomenon found in many urban areas around the world including those located in humid climates.[4] Examples are Beijing, Bangkok, Delhi and Ahmedabad. Moreover, in many cities increasing urbanization leads to encroachment of tank catchments for building activities and peri urban agriculture, adversely affecting the inflows from the catchments.

If one compares the water supply potential of the tanks around Chennai against the city's water demands, it could be seen that the supply potential of these sources is far too short of the city's water demands. Obviously, Chennai now has to depend on water from Srisailam reservoir on Krishna river in Andhra Pradesh to meet most of its water requirements. On a different account, over-draft of groundwater for municipal uses has led to mining of aquifers underlying Ahmedabad city; with serious water quality problems in terms of high levels of TDS (Total Dissolved Solids) and fluoride in groundwater beyond permissible levels. Whereas, Sabarmati River as a source of water for municipal uses ceased to exist due to excessive diversion of water from the upstream reservoir in Dharoi for rural drinking and irrigation. Hence, Ahmedabad city depends on water from Sardar Sarovar reservoir. A similar phenomenon was found in Hyderabad. Earlier, the city used to depend on the lakes for its water supply needs. Today, with a population of nearly 4 million people, the Hyderabad Municipal Water Supply and Sewerage Board depend heavily on water from the Krishna River to ensure good quality supplies.

[4] In Kolkata (formerly Calcutta), which falls under humid region, similar conical depression has been observed (Srinivasan 2004).

An analysis of the water supply sources of 302 urban centers representing various classes of cities shows that the dependence on surface reservoirs for water supplies increases with increase in size of the city (Fig. 3).

4.1 Urban Water Supply from River Basin perspective

The total land of India can be largely divided into 19 major drainage basins. Table 1 provides estimates of per capita renewable water resources and population composition of major river basins in India. It can be seen that the renewable water resources in per capita terms and percentage of population living in urban areas varies remarkably across the basins. Hence, an analysis of urban water supply challenges based on aggregate figures of renewable water availability, and urban population would be highly misleading. Hence, we have looked at urban water supply data basin-wise. Rivers have played a significant role in the history of civilizations. So is their role in the social, cultural, economic and spiritual life in India.

Except for the Brahmaputra, Meghna, Mahanadi, Narmada and WFR2 basin, annual per capita renewable water resource is lower than 2,000 kl for all other basins. A comparison of annual per capita renewable water resource (in kiloliter) and percentage of urban population in total population across the river basins shows that, except for the above five basins, there is a negative relationship between them. Across the basins, level of urbanization is the highest in Sabarmati basin (46%) with per capita renewable water resource of 635 kl. No wonder that a large chunk of total water harvested in Dharoi dam on Sabarmati River was supplied to cities including Ahmedabad (which is the largest urban centre in Sabarmati basin) until they started receiving the benefits of Narmada water through Sardar Sarovar Project. Incidentally, all river basins with relatively higher degree of urbanization such as Sabarmati, Tapi, Cauvery and EFR2 are also characterized by arid or semi-arid climate with extremely low renewable water availability, and therefore cannot support high degree of urbanization unless water is drawn from sources outside the basin.

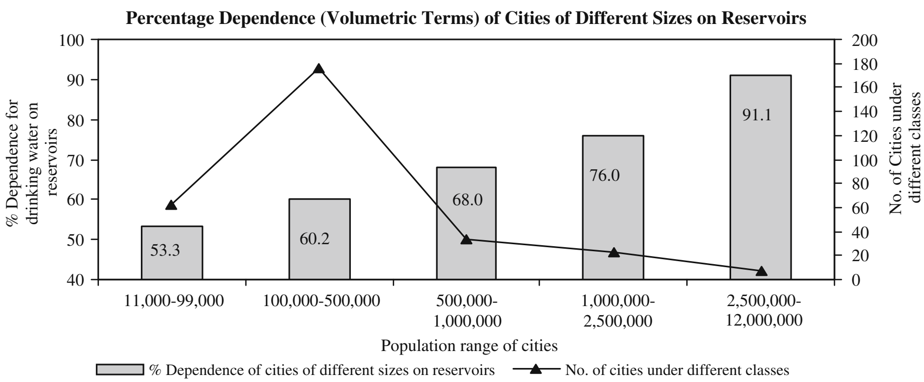

Fig. 3 Percentage dependence (in Volumetric Terms) of cities of different sizes on reservoirs. Source: NIUA (2005)

Table 1 Area and population served by the River Basins in India, 1999

	River basin	Catchment area (km^2)	Population: Total population (million)	Population: Urban population (% of total)	Renewable water resource (km^3/Year)	Annual per capita renewable water resource (kiloliter)
Basins of the westerly flowing rivers	Indus	321	48.8	29	73.3	1,502.3
	Mahi	35	6.7	23	11.0	1,644.8
	Narmada	99	17.9	21	45.6	2,549.7
	Sabarmati	22	6.0	46	3.8	635.0
	Tapi	65	17.9	37	14.9	831.3
	WFR1	56	58.9	28	15.1	256.4
	WFR2	378	51.9	43	200.9	3,871.7
Basins of the easterly flowing rivers	Brahmani and Baitarani	52	16.7	13	28.5	1,705.4
	Cauvery	81	32.6	30	21.4	655.2
	EFR1	87	19.2	26	22.5	1,172.9
	EFR2	100	39.0	40	16.5	422.1
	Ganga	861	370.2	25	525.0	1,418.2
	Godavari	313	76.7	15	110.5	1,441.2
	Krishna	259	68.9	32	69.8	1,013.2
	Mahanadi	142	27.2	20	66.9	2,458.8
	Pennar	55	14.3	22	6.3	442.0
	Subarnarekha	29	15.0	24	12.4	824.7
	Brahmaputra	194	33.2	14	629.1	18,947.3
	Meghna	42	10.0	18	48.4	4,836.0
	All basins	3,191	932.0	26	1,921.9	2,062.1

Source: Figures derived based on data available in Amarasinghe et al. (2005) and NCIWRD (1999)
WFR1 westerly flowing rivers—Group 1: the westerly flowing rivers in the Kutch and Saurashtra regions of the state of Gujarat, and the Luni river; *WFR2* westerly flowing rivers—Group 2: the westerly flowing rivers south of the Tapi basin; *EFR1* easterly flowing rivers—Group 1: the easterly flowing small and medium-sized rivers between the Mahanadi and Pennar basins; *EFR2* easterly flowing rivers—Group 2: the easterly flowing small and medium-sized rivers between the Pennar basin and Kanyakumari at the southern tip of India

Tables 2 and 3 provide basin-wise total water supply to Class I cities and Class II towns, respectively, showing the relative contribution of surface water and groundwater to the city water supply.

The data shows that Class I cities rely more on surface water sources to meet their demand. The trend in Class II towns shows that these urban agglomerations still have some reliance on groundwater sources. The inadequacy of water supplies in Class II towns can be attributed to its smaller population base, and limited economic and political power to draw water from surface sources located outside their municipal boundaries. The subsequent section would deal with this aspect of water supply in Class II towns in further detail.

4.2 Water Supply Scenario in Class I Cities and Class II Towns

Table 4 shows the changing composition of water supply in cities and towns of India falling under different categories, over time. It clearly brings out two important facts:

Table 2 Basin-wise water supply in class I cities: 1999–2000

Major river basin	No. of cities	Population	Ground source (mld)	Surface source (mld)	Combined source (mld)	Total water supply (mld)	Per capita water supply (lpcd)
Brahamani	1	398,864		21.6 (100.0)		21.6	54.1
Brahmaputra	7	1,415,601	10.7 (7.3)	30.4 (20.9)	104.4 (71.8)	145.5	102.8
Cauvery	16	8,212,863	12.9 (1.4)	232.0 (25.2)	675.5 (73.4)	920.4	112.1
Ganga	103	49,478,976	732.9 (8.2)	1,344.0 (15.1)	6,809.9 (76.6)	8,886.9	179.6
Godavari	25	6,919,320		623.4 (80.8)	147.9 (19.2)	771.4	111.5
Indus	15	4,192,909	282.8 (37.3)	212.8 (28.1)	262.3 (34.6)	757.9	180.7
Krish	27	12,659,457	4.8 (0.3)	864.9 (50.3)	850.0 (49.4)	1,719.7	135.8
Mahadi	9	2,476,450	114.4 (29.0)	221.8 (56.3)	58.2 (14.7)	394.4	159.2
Mahi	3	1,311,534			206.2 (100.0)	206.2	157.2
Narmada	4	1,183,593		13.6 (8.5)	147.0 (91.5)	160.7	135.7
Penr	6	971,371		50.9 (63.5)	29.2 (36.5)	80.1	82.5
Sabarmati	7	3,678,921	22.0 (3.3)	24.5 (3.7)	613.6 (93.0)	660.2	179.4
Subarrekha	2	1,059,883		358.5 (100.0)		358.5	338.3
Tapi	8	3,444,041		180.2 (50.6)	176.0 (49.4)	356.2	103.4
Sub total	233	97,403,783	1,180.5 (7.6)	4,178.6 (27.1)	10,080.4 (65.3)	15,439.4	158.5
coastal	29	23,275,720	63.0 (1.5)	3,428.9 (84.2)	579.4 (14.2)	4,071.3	174.9
Non-major basin, non coastal	37	7,434,362	298.8 (27.2)	528.4 (48.2)	269.4 (24.6)	1,096.6	147.5
Grand total	299	128,113,586	1,542.2 (7.5)	8,135.9 (39.5)	10,929.1 (53.0)	20,607.2	160.9

Figure in the parenthesis shows the percentage share in total water supply. Source: CPCB (2000a)

Table 3 Basin-wise per capita water supply in class-II towns: 1999–2000

Major river basin	No. of town	Population	Ground source (mld)	Surface source (mld)	Combined source (mld)	Total water supply (mld)	Per capita water supply (lpcd)
Brahmani	1	41,202	4.0 (100.0)			4	97.1
Brahmaputra	9	611,617	17.5 (33.0)		35.6 (67.0)	53.1	86.8
Cauvery	18	1,155,954	21.1 (41.1)	7.6 (14.8)	22.6 (44.1)	51.3	44.4
Ganga	119	7,903,938	331.0 (42.7)	119.1 (15.4)	325.3 (42.0)	775.4	98.1
Godavari	37	2,405,618	13.2 (8.3)	47.2 (29.7)	98.3 (61.9)	158.7	66.0
Indus	20	1,336,496	106.4 (61.3)		67.3 (38.7)	173.7	130.0
Krish	22	1,464,861	22.3 (18.7)	27.6 (23.2)	69.3 (58.1)	119.2	81.4
Mahadi	9	548,883	4.7 (14.2)	19.6 (59.0)	8.9 (26.8)	33.2	60.5
Mahi	4	238,770	4.0 (15.4)		22 (84.6)	26	108.9
Narmada	5	330,307	18.9 (56.3)	10.7 (31.8)	4 (11.9)	33.6	101.7
Penr	5	338,500	0.0	0.0	19.2 (100.0)	19.2	56.7
Sabarmati	6	342,993	35.0 (88.6)	4.5 (11.4)		39.5	115.2
Subarrekha	2	133,164	4.1 (45.1)	5.0 (54.9)		9.1	68.3
Tapi	5	371,292	23.1 (100.0)			23.1	62.2
Sub total	262	17,223,595	605.3 (39.8)	241.3 (15.9)	672.5 (44.3)	1,519.1	88.2
Coastal	16	966,375	13.4 (25.2)	12.5 (23.5)	27.2 (51.2)	53.1	54.9
No major basin	67	4,185,618	219.1 (60.2)	53.5 (14.7)	91.4 (25.1)	364	87.0
Grand total	345	22,375,588	837.8 (43.3)	307.3 (15.9)	791.1 (40.9)	1,936.2	86.5

Figure in the parenthesis shows the percentage share in total water supply. Source: CPCB (2000b)

Table 4 Decadal trend of water supply in class I cities and class II towns in India (1978–79 to 1994–95)

Parameters	Class I cities			Class II towns		
	1978–1979	1988–1989	1994–1995	1978–1979	1988–1989	1994–1995
Number	142	212	299	190	241	345
Population (millions)	60.16	102.85	128.03	12.76	20.70	23.62
Distribution of cities and towns according to catchment area (number)						
Major river basins	112	170	233	135	168	262
Coastal	17	23	29	13	20	16
Non-basin, non coastal	13	19	37	42	53	67
Distribution population of cities and towns according to catchment area (millions)						
Major river basins	42.7 (71.0%)	74.4 (72.3%)	97.4 (76.1%)	9.2 (72.1%)	14.7 (71.0%)	17.2 (72.8%)
Coastal	12.8 (21.3%)	20.6 (20.0%)	23.2 (18.1%)	0.8 (6.3%)	1.7 (8.2%)	2.2 (9.4%)
Non-basin, non coastal	4.7 (7.7%)	7.8 (7.6%)	7.4 (5.8%)	2.7 (21.6%)	4.3 (20.8%)	4.2 (17.7%)
Total water supply (million liter per day)	8,638	15,191	20,607	1,533	1,622	1,936
Ground water (million liter daily)	784 (9.1%)	3528 (23.2%)	1542 (7.5%)	499 (31.5%)	700 (43.2%)	838 (43.3%)
Surface water (million liter daily)	5261 (61.0%)	11132 (73.3%)	8136 (39.5%)	1018 (64.3%)	814 (50.2%)	307 (15.9%)
Combined ground and surface source (million liter daily)	2,582 (29.9%)	531 (3.5%)	10,929 (53.0%)	66 (4.2%)	108 (6.7%)	791 (40.9%)
Per capita water supply (liter per capita per day)	144	149	161	120	78	82

Source: Compiled from CPCB (2002), CPCB (1978–1979a, b), CPCB (1990a, b) and CPCB (2000a, b)

Table 5 Factors influencing total water supply (LNWSTOT) in cities and towns of India: 1988–89

	Class I cities: 1988 Coefficient	Class II towns: 1988 Coefficient	Class I cities & class II towns: 1988 Coefficient
Constant	−12.4023[a] (0.8214)	−3.6558[c] (2.1301)	−12.1822[a] (0.6272)
LNPOP1988	1.1266[a] (0.0565)	0.3963[b] (0.1842)	1.1297[a] (0.0506)
WSCOV	0.0193[a] (0.0051)	0.0139[a] (0.0022)	0.0166[a] (0.0027)
ARID	−0.1242 (0.1028)	−0.4274[a] (0.0905)	−0.2998[a] (0.0698)
No. of observations	209	239	447
Adj. R^2	0.7106	0.1839	0.7037
D-W Stat	1.5485	1.7905	1.6138
F-Stat	171.2545	18.8768	354.1578

Figure in the parenthesis shows the white heteroskedasticity-consistent standard error for the estimated coefficient

LNWSTOT natural logarithm of total water supply in 1988, *LNPOP1988* natural logarithm of 1988 population (estimated), *WSCOV* percentage of population covered under organized water supply, *ARID* whether the city/town falls under arid and semi-arid zone or otherwise (1, 0)

[a]Estimated coefficient is significant at 0.01 level

[b]Estimated coefficient is significant at 0.05 level

[c]Estimated coefficient is significant at 0.10 level

(a) the level of dependence of larger cities on surface water is much higher than of smaller cities; and (b) the larger cities have higher average per capita water supplies. Further, over the years, the percentage dependence of Class I cities, which only relied on surface water sources for municipal water supplies, on this resource had increased (from 1971 to 1981). Thereafter, it actually declined. At the same time, the percentage contribution of "*cities with combined sources*" to overall city water supply had increased substantially from 1981 to 1991. It is quite likely that their water withdrawal from surface sources had actually increased in those cities. Also, some of the cities, which were only using surface water earlier, might have started using well water as well, and in the process, have fallen in the third category of cities with combined sources. Nevertheless, some improvements in per capita supplies are also seen. Contrary to this, in the case of Class II towns, the percentage dependence of water utilities, which depend on only groundwater for municipal supplies, on

Table 6 Factors influencing total water supply (LNWSTOT) in cities and towns of India: 1999

	Class I cities:1999 Coefficient	Class II towns:1999 Coefficient	Class I cities & class II towns: 1999 Coefficient
Constant	−3.9738[a] (0.4039)	−1.4009 (0.8489)	−3.7564[a] (0.2451)
LNPOP1999	1.2893[a] (0.0666)	0.6750[a] (0.1905)	1.2331[a] (0.0424)
ARID	−0.0066 (0.1023)	0.3316[a] (0.1189)	0.1253 (0.0819)
No. of obs	163	111	274
Adj. R^2	0.6984	0.1617	0.7383
D-W Stat:	1.7615	1.4982	1.6237
F-Stat	188.5594	11.6096	386.1231

Figure in the parenthesis shows the white heteroskedasticity-consistent standard error for the estimated coefficient

LNWSTOT natural logarithm of total water supply in 1999, *LNPOP1999* natural logarithm of 1999 Population (estimated), *ARID* whether the city/town falls under arid and semi-arid zone or otherwise (1, 0)

[a]Estimated coefficient is significant at 0.01 level

Table 7 Factors influencing share of surface water source(s) in total water supply in cities/towns (SHARESW) (in percentage) in India: 1988–1989

	Class I cities: 1988 Coefficient	Class II towns: 1988 Coefficient	Class I cities and class II towns: 1988 Coefficient
Constant	−90.4427[b] (39.7691)	−205.4805[a] (72.5397)	−60.8334[b] (25.4934)
LNPOP1988	8.4855[b] (3.2723)	18.9130[a] (6.3873)	6.0773[a] (2.1655)
WSCOV	0.4110[b] (0.1729)	0.4159[a] (0.1516)	0.4205[a] (0.1133)
ARID	14.0732[b] (6.3384)	21.6391[a] (6.1973)	18.2597[a] (4.4215)
No. of obs.	190	240	415
Adj. R^2	0.0786	0.0919	0.0839
D-W Stat	1.1556	1.2453	1.2348
F-Stat	6.3737	8.5560	13.6303

Figure in the parenthesis shows the white heteroskedasticity-consistent standard error for the estimated coefficient

SHARESW share of surface water in total water supply in cities/towns

[a]Estimated coefficient is significant at 0.01 level

[b]Estimated coefficient is significant at 0.05 level

[c]Estimated coefficient is significant at 0.10 level

this resource had increased over time, and some reduction in per capita supplies is observed.

We have estimated multiple regression models based on the available information on urban water supply for 209 Class I cities and 239 Class II towns in India. The results, presented in Table 5, show that Population Elasticity of Water Supply (PEWS) change with time and space. For example, for Class I cities PEWS with reference to 1988 population is 1.127, whereas that with respect to 1999 population is 1.289 (Tables 5 and 6). The results show that water supply grows at a faster rate than the population growth rates. The results also show that Class I cities have better water supply (PEWS is 1.127 in 1988 and 1.289 in 1999) than Class II towns (PEWS is 0.396 in 1988 and 0.675 in 1999). For Class I cities and Class II towns together, PEWS is 1.129 with respect to 1988 population and 1.233 with respect to 1999 population. However, due to data unavailability we cannot extend our analysis beyond 1990s.

Table 8 Factors influencing share of surface water source(s) in total water supply in cities/towns (SHARESW) (in percentage) in India: 1999

	Class I cities: 1999 Coefficient	Class II cities: 1999 Coefficient	Class I cities & class II towns: 1999 Coefficient
Constant	−1.5442 (30.208)	136.8331 (69.5703)	12.1360 (18.2851)
LNPOP1999	7.8721 (5.4118)	−23.7506 (15.3756)	5.0105 (3.5157)
ARID	24.7819[a] (7.3318)	33.0973[a] (8.5866)	27.7156[a] (5.6632)
No. of obs	163	111	274
Adj. R^2	0.0768	0.1105	0.0899
D-W Stat	1.3055	1.5253	1.3909
F-Stat	7.7423	7.8315	14.4862

Figure in the parenthesis shows the white heteroskedasticity-consistent standard error for the estimated coefficient

[a]Estimated coefficient is significant at 0.01 level

[b]Estimated coefficient is significant at 0.05 level

[a]Estimated coefficient is significant at 0.10 level

Table 9 Factors influencing per capita water supply (LPCD)

	Class I cities: 1988 Coefficient	Class I cities: 1988 Coefficient	Class II towns: 1988 Coefficient	Class I cities: 1999 Coefficient	Class II towns:1999
Constant	65.8493[a] (20.9084)	70.2356[a] (25.4632)	121.7716[a] (20.0214)	120.2845[a] (12.8119)	107.1745[c] (20.3485)
ARID	−21.4331[c] (11.0566)	−19.5516[c] (10.964)	−38.1568[a] (10.13465)	−17.5583 (13.1079)	−35.5910 (20.2721)
WSCOV	0.9600[a] (0.2785)	0.9892[a] (0.2712)	0.0349 (0.2749)		
SHARESW	0.0829 (0.1166)				0.0841 (0.1451)
SHAREGW		−0.0914 (0.1133)			
DIST				0.1386[c] (0.0725)	0.0550 (0.1208)
No. of observations	190	190	239	109	60
Adj. R^2	0.0712	0.0721	0.0645	0.0440	0.1065
D-W Stat	1.5725	1.5805	1.7207	1.2781	0.9136
F-stat	5.8304	5.9494	8.1419	2.4390	2.2246

Figure in the parenthesis shows the white heteroskedasticity-consistent standard error for the estimated coefficient
SHAREGW share of groundwater in total water supply in cities/towns, *DIST* distance between water supply source (surface water) and the city/town
[a]Estimated coefficient is significant at 0.01 level
[b]Estimated coefficient is significant at 0.05 level
[c]Estimated coefficient is significant at 0.10 level

In order to understand the factors influencing the share of surface water source(s) in total water supply, multiple regression models were estimated separately for 190 Class I cities and 240 Class II towns. Tables 7 and 8 show that when population increases share of surface water in municipal water supplies increases. Urban agglomerations located in arid and semi-arid regions, yet having better water supply coverage are those which are dependent more on surface water sources. These sources are large surface reservoirs located at far off places. The regression analysis reinforces the fact that with growing urban population, it is necessary to augment the supply from exogenous sources for providing better access and coverage. The existing local supply potential is not enough to achieve full coverage; while access to water supply is also meager in many urban centers. In arid and semi-arid parts of India, urban water supply systems are under stress and to cope up with population pressure, there is need to look for surface water sources to augment water supply.

Water footprint of urban centers in India is growing up and it is mostly away from the urban centers (Kampman 2007). However, due to growing dependence on distant sources protection and maintenance of local sources is often neglected (Mukherjee 2008b). As a result the major challenges that water supply sector in India is facing today are not only to meet the large investment requirement to augment the water supply, but also additional investment burden to tackle the water quality related problems.

In order to analyze the impact of organized water supply (in terms of percentage coverage of population under organized water supply), the composition of water supply (percentage contribution of surface water and groundwater to the total water supplied), and the climate on per capita water consumption in cities, multiple regressions were run by considering per capita water supply (*lpcd*) as dependent variable and *wscov, arid* and *sharesw* or *sharegw* as independent variables. The results show that per capita water supply (in lpcd) goes up as *wscov* improves and in arid regions *lpcd* is low (Table 9). However, *sharesw* or *sharegw* do not have significant impact on water use. Regression analysis for Class I cities based on the sample survey carried out by NIUA (2005) shows that as distance (*dist*) between

Table 10 Factors influencing distance between surface water source and cities/ towns (LNDIST) in India: 1999

	Class I cities: 1999 Coefficient	Class I cities and class II towns: 1999 Coefficient
Constant	1.6972[a] (0.5302)	1.8039[a] (0.3528)
SHAREGW	−0.0132[b] (0.0056)	−0.0056 (0.0049)
LNWSTOT	0.2559[c] (0.1488)	0.2079[c] (0.1147)
No. of observations	109	170
Adj. R^2	0.0528	0.0176
D-W Stat	1.3788	1.4004
F-Stat	4.0093	2.5165

Figure in the parenthesis shows the white heteroskedasticity-consistent standard error for the estimated coefficient

SHAREGW share of groundwater in total water supply in cities/towns, *LNDIST* natural logarithm of distance between water supply source (surface water) and the city/town 6. Sustaining Urban Water Supplies in India: Increasing Role of Large Reservoirs

[a]Estimated coefficient is significant at 0.01 level

[b]Estimated coefficient is significant at 0.05 level

[c]Estimated coefficient is significant at 0.10 level

drinking water source and urban centers increases water use (as measured by lpcd) increases.

Table 10 shows that distance between urban centre and water supply source increase with the growing water supply. The inference which can be drawn from this result is that the only way for cities to augment their water supplies is to depend on exogenous sources.

5 Conclusion and Policy Suggestions

Large dams have played significant role in achieving national food security, rural employment, hydro power generation and flood control. Enactment of National Water Policy-2002 (Government of India 2002b) has increased the importance of large reservoirs in domestic and industrial water supply too. The reason is that earmarking water from aquifers for high priority uses like drinking is still not possible through administrative measures, in the absence of well-defined property rights in groundwater. The future population growth, economic development and urbanization would demand further increase in water supplies for domestic and industrial sectors. The spin-off effects of these developments would be on the demand for water for food production and hydropower generation. In nutshell, the role of large dams is going to be more critical in the years to come.

As per some projections, by 2050 around 45% of India's population would be living in urban areas (Kundu 2006). In India, the water demand for urban and rural drinking water is expected to increase up to 67 BCM by 2050 from the current level of 25 BCM (Government of India 1999). Moreover, the water supply coverage in urban areas is steadily improving. In 2000 around 69% of total households were covered under water supply system, which has increased at a growth rate of 2% annually during the past two decades (Government of India 2004—as cited in Amarasinghe et al. 2007). Amarasinghe et al. (2007) project that most of the urban population in India would be covered by adequate drinking water supplies by 2050. This would increase per capita water consumption even in poor households. Looking at this increasing demand for domestic water supply, it would not be an exaggeration to say that cities would not be able to cope up with their water demands without relying on large reservoirs.

This view has been challenged by a few scholars. Their contention is that the local water resources including lakes, ponds and groundwater were exploited in an uncontrolled manner in the process of urbanization owing to poor planning, which resulted in their depletion and pollution (SANDRP 1999). The same scholars argue for rainwater harvesting and groundwater recharge as options for augmenting water supplies in urban areas. Ironically, such arguments are largely based on anecdotal evidences about the effectiveness of such interventions. Whereas there is substantial body of scientific literature now available in India which shows that most of these local solutions offer extremely limited scope in augmenting water supplies in naturally water-scarce regions. For instance, Kumar (2004) shows that roof water harvesting systems would not only be hydrologically and economically unviable in urban areas in most parts of India,[5] but also would lead to inequity in access to urban

[5]Except in high rainfall, hilly and mountainous regions.

water supplies, if they are subsidized. It points out the negligibly small per capita roof area available for urban dwellers and the pattern of occurrence of rainfall against water demand pattern as the major reasons. Other works (Kumar et al. 2006, 2008a) show that rainwater harvesting and groundwater recharge offer extremely limited potential in the naturally water-scarce arid and semi arid regions from the point of view of hydrological opportunity and economic viability.

Notably, institutional and policy reforms are needed to encourage demand management in the water sector, including establishment of well-defined property rights in water, introduction of pollution tax, and pricing of water in agriculture and domestic sector and electricity in the farm sector that reflect their actual consumption (Kumar 2003). These can encourage wastewater treatment, use of water efficient technologies in production, and efficient water use technologies in domestic and irrigation sectors (Postel 1992; Brown 2008; Kumar 2003). In fact, these are a must to achieve equity and environmental sustainability in the long term. These interventions would certainly have positive impacts on water demands of the cities. But, in India, they can certainly not guarantee non-reliance of cities on large reservoirs. The reasons are many. First, India has a large population base, and so urban population growth would remain high in actual terms even if the percentage growth rate becomes very low. Second: not necessarily all Class I cities and Class II towns would have enough financial resources and political clout to implement such interventions successfully. Third: many of the large cities in the country are located in arid and semi arid regions, and their growth cannot sustain without water supplied from large water reservoirs distantly located. Cities such as Ahmedabad, Chennai, Jodhpur, Rajkot and Bhuj would have collapsed long ago, had water from other areas had not been made available.

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