Urban Water Systems in India
Typologies and Hypotheses

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Urban water and waste water management have not been relatively well understood in India. The Indian urban space has been considered in an undifferentiated manner, which ignores the specificities deriving from different stages of urban development, the sources of water, as also the diverse nature of aquifers catering for urban settlements in different parts of the country. This paper advances a series of hypotheses that can serve as an initial analytical framework and outlines a way forward for urban water systems, which could provide rich terrain for further research.

The global urban population is expected to nearly double to 6.4 billion by 2050, with about 90% of the growth in low-income countries. The predicted increase in the number of urban slum dwellers is to 2 billion in the next 30 years (Foster and Vairavamoorthy 2013). In India, the number of people living in urban areas is expected to more than double and grow to around 800 million by 2050. This will pose unprecedented challenges for water management in urban India. The demands of a rapidly industrialising economy and urbanising society come at a time when the potential for augmenting supply is limited, water tables are falling, and water quality issues have increasingly come to the fore.

As we drill deeper for water, our groundwater gets contaminated with fluoride, arsenic, mercury and even uranium in some areas. Both our rivers and our groundwater are polluted by untreated effluents and sewage dumped into them. Many urban stretches of rivers and lakes are overstrained and overburdened by industrial waste, sewage, and agricultural run-off. These waste waters are overloading rivers and lakes with toxic chemicals and wastes, consequently poisoning water resources and supplies. These toxins are finding their way into plants and animals, causing severe ecological toxicity at various trophic levels. In India, cities produce nearly 40,000 million litres of sewage every day and barely 20% of it is treated. The Central Pollution Control Board's 2011 survey states that only 2% of towns have both sewerage systems and sewage treatment plants.

Climate change poses fresh challenges with its effects on the hydrologic cycle. More extreme rates of precipitation and evapo-transpiration will exacerbate the adverse effects of floods and droughts. More intense, extreme, and variable rainfall, combined with lack of proper drainage, will mean that every spell of rain becomes an urban nightmare as roads flood and dirty water enters homes and adds to filth and disease. Conflicts across competing uses and users of water—agriculture and industry, town and country—are growing by the day. Water use efficiency in agriculture, which consumes around 80% of our water resources, continues to be among the lowest in the world. At 25% to 35%, this compares poorly with 40% to 45% in Malaysia and Morocco, 50% to 60% in Israel, Japan, China, and Taiwan. Thus, even as this paper addresses the issues surrounding urban water, it is useful to keep in mind that we face very real challenges in managing water in the economy as a whole and especially in the farm sector. The Twelfth Five Year Plan (2012–17) has proposed a paradigm shift in water management to enable a movement forward in

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This paper is based on a study done for the Indian Council for Research on International Economic Relations and Global Green Growth Institute. Many thanks are due to Isher Ahluwalia, Montek Ahluwalia, Arunabha Ghosh, Sandeep Joshi, Sayali Joshi, Rochi Khemka, Sunita Narain, and Tushaar Shah for their inputs, which have greatly enriched the paper.

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this direction (Shah 2013). Such reforms are crucial so that more water is released for rapidly growing urban India.

Figure 1: The Urban Continuum: A Schema in Four Stages

(a) Nucleus (b) Growth

(c) Expansion (d) Agglomeration

Source: Kulkarni and Mahamuni (2014).

1 Understanding the Continuum

This paper begins by deconstructing the simplistic notion of an "urban India" by presenting a picture of the very different and diverse urban settlements that go into constituting what, rather simplistically, and in an undifferentiated manner, we call urban India. We highlight the unique progression of problems faced by different-sized urban agglomerations within this continuum, as also the neglect of small towns and census towns, which appear to have fallen between the cracks of development planning so far. This neglect is also a great opportunity for innovative work from the beginning, given that these areas do not suffer from the mistakes that have already been made in the larger metros. We present a schema for India's urban continuum, which reveals shifting dependencies on sources of water in different-sized urban settlements at various stages of growth.

Tables 1 and 2 summarise census data on India's urban population from 1901 to 2011. India's urban population has grown fivefold over the last 50 years. But what is equally important to note is that urban population has grown in each of the four categories of towns and cities in Table 2, from the smallest towns with less than 1,00,000 people to the mega metros with more than five million. More than 112 million people live in these smallest towns, while over 160 million urban Indians now live in large cities with more than a million people. Thus, attending to each category is important in itself and this paper describes how each urban settlement has its own unique set of characteristics and challenges.

An indicative, diagrammatic of transitions through the four stages of nucleus, growth, expansion, and agglomeration is presented in Figure 1. The four stages in the figure broadly correspond to the classification of towns and cities in Tables 1 and 2. Thus, Stage one describes towns with a population of less than 1,00,000, Stage two corresponds to cities with population between 1,00,000 and one million, Stage three covers cities with population from one to five million, and Stage four are the mega metros with more than five million people. We believe this framework also corresponds with varying degrees of dependence on diverse sources of water in differently sized towns and cities across India's vast eco-geographic landscape.

On the basis of data that is currently available on towns and cities in India, this paper proposes the following continuum hypothesis of stages of evolution of urban settlements and their changing dependence of sources of water supply. This is proposed as a possible framework of understanding that needs

Table 1: Share of Urban Population in Cities and Towns in India, 1901–2011

Year	Population							
	5 Million and Above		1–5 Million		1,00,000–1 Million		< l,00,000	
	Cities	% of Urban Population	Cities	% of Urban Population	Cities	% of Urban Population	Towns	% of Urban Population
1901	0	0.00	0	0.00	25	26.30	1,771	73.80
1911	0	0.00	2	9.00	22	18.70	1,768	72.30
1921	0	0.00	2	11.40	28	18.60	1,887	70.00
1931	0	0.00	2	10.40	34	21.10	2,004	68.60
1941	0	0.00	2	12.20	49	26.40	2,087	61.30
1951	0	0.00	5	18.90	72	26.20	2,720	55.00
1961	1	7.70	6	15.90	100	28.30	2,223	48.10
1971	2	13.00	7	13.30	143	30.90	2,405	42.90
1981	3	15.60	9	12.10	207	33.50	3,027	38.90
1991	4	17.40	19	15.60	276	31.40	3,401	35.70
2001	6	21.10	29	16.70	359	30.80	3,984	31.40
2011	8	22.59	45	20.03	415	27.62	5,698	29.76

Source: HPEC (2011) and Census of India, various years.

Table 2: Population in Cities and Towns of India, 1901–2011

	Population (in millions)				
Year	5 Million and Above	1– 5 Million	1,00,000 – 1 Million	< 1,00,000	Total
1901	0	0	6.8	19.08	25.9
1911	0	2.34	4.85	18.76	26.0
1921	0	3.2	5.22	19.67	28.1
1931	0	3.48	7.06	22.96	33.5
1941	0	5.39	11.66	27.07	44.1
1951	0	11.8	16.36	34.34	62.5
1961	6.08	12.55	22.33	37.95	78.9
1971	14.18	14.51	33.72	46.81	109.2
1981	24.88	19.29	53.42	62.03	159.6
1991	37.86	33.95	68.33	77.68	217.8
2001	60.37	47.78	88.12	89.85	286.1
2011	85.18	75.54	104.17	112.21	377.1

Source: HPEC (2011) and Census of India, various years.

to be further tested as and when more robust data becomes available on urban India and its sources of water.

1.1 Stage One

Small towns in many parts of India face a major water crisis every year, even as they begin to emerge from rural hinterlands, as nuclei for urban growth (Figure 1a). Most such towns are surrounded by the rural landscape of agriculture and almost entirely depend on groundwater, which is sourced through wells and from springs in the mountains like the Himalayas. Competition around groundwater resources between rural (agricultural) and urban demand abounds. Iniquitous and uncertain water supplies force private well construction within the core area of the township. Groundwater quality concerns are seldom considered, although they are inherent to the supply system in the absence of a standardised system of water treatment, with continuous intermixing of waste water and drinking water, resulting from poor sanitation and waste disposal. Institutional mechanisms to address water supply are often poor, with virtually no capacities to address issues of aquifer depletion and contamination, resulting in worrisome public health scenarios. The positive part is that natural recharge areas, in many instances, remain undisturbed as they tend to lie largely in the rural/agricultural hinterland, as open spaces.

These are towns that tend to fall off the development map of India but as shown in Tables 1 and 2, these 4,000 towns where 100 million Indians live, comprise a substantial part of the country's urban population.[1]

1.2 Stage Two

As small towns become nuclei of growth—area- and population-wise—suburban areas and peripheral buffers with adjoining rural areas develop (Figure 1b). While the core township may continue to enjoy the privilege of an established "public water supply system," suburbs and peri-urban areas are almost entirely groundwater dependent. Private borewells in the core township area are not necessarily closed down but continue to provide supplements to public water supply, which tends to get more attention than before. Complex water transfers, often in the form of tanker markets develop both ways—from the core to the periphery and also from the rural neighbourhoods to the township areas. Groundwater quality concerns of some magnitude emerge because much of the suburban and peri-urban neighbourhoods have poor sanitation and waste disposal facilities or have poorly designed soak pits and septic tanks that interfere with aquifers providing drinking water to the growing township. However, much of this contamination goes unnoticed even as public health remains a concern, especially in the monsoon season, when the water table rises.

Groundwater, originally used for growing crops, is often transported to the town for filling the gap between growing demands and limited supplies. Some improvement in institutions may happen, but is largely confined to improvements in supply systems, piping and augmentation of water resources, rather than around water management and public health. Sewerage systems begin to develop but are generally restricted to a portion of the areas serviced by piped water supply, usually in and around the core township. Natural recharge areas begin to be encroached on primarily because of lack of capacity to recognise them as such.[2] Another generally unnoticed adverse effect is that on base flows to rivers and streams, caused by increased groundwater extraction. It is not widely recognised but river flow depletion in large parts of India is as much a consequence of groundwater extraction reducing base flows, as it is due to factors such as clogged drains and a changing climate.

These small cities, with a population less than one million, also offer great opportunities for sustainable and equitable systems of water supply and waste water treatment, with a balanced approach to surface and groundwater.

1.3 Stage Three

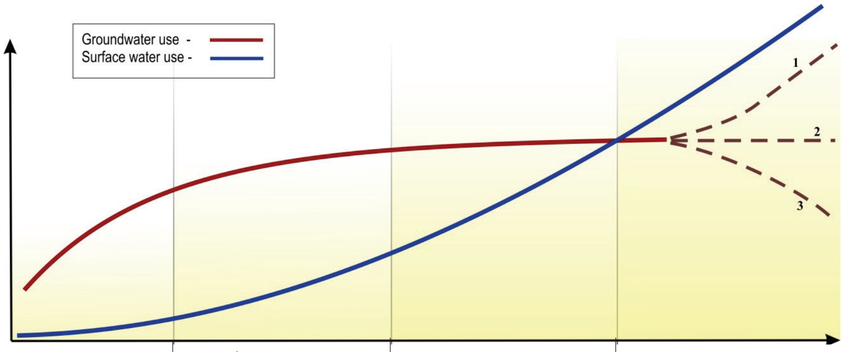
As towns expand into cities (Figure 1c), the core township remains largely undisturbed and is often labelled "old city" or "city centre." The suburbs and surrounding areas expand rapidly outwards, with an increase in population densities. Much of real estate development happens in these areas. With the formal established public water supply not holding up to the demand, deeper wells are constructed or drilled to supplement public water supply across the city. However, suburbs/peri-urban and sometimes even rural areas get into complex groundwater transfers, largely through tankers. Tanker water supply becomes an established business as water demand for various activities, including booming real estate, constantly rises. Given the incapacity of the core to treat sewage, the waste water from such growing towns and cities eventually drains off directly into rivers, lakes, and almost invariably enters groundwater. The suburbs already entirely groundwater dependent and with poor sanitation systems start showing alarming groundwater quality problems, which are magnified by the effect of added contamination from the core. With natural recharge areas already encroached on by concrete, the core looks towards recharge initiatives almost always through rooftop rainwater harvesting. These often lack a scientific base and planning, often leading to problems of waterlogging and even basement flooding in some cases.[3]

1.4 Stage Four

Many large cities in close proximity to one another often "merge" to create even larger urban agglomerations (Figure 1d). Many examples can be cited today—Mumbai and Thane, Delhi and Gurgaon, Hyderabad and Secunderabad, and Pune and Pimpri-Chinchwad. On the other hand, the sheer size of expansion in cities such as Kolkata, Bengaluru and Chennai produces the same demands on groundwater resources as that in two merging cities. While the old city or core may have a relatively small footprint (even reduced) of groundwater use, and a larger dependence on piped, surface water, the suburbs almost always witness some level of groundwater usage, although dependencies may have reduced from when the city was in Stage 3. At the same time, the physical merging of peri-urban areas, with increasing population pressures and relatively poor service provision of public water supply, implies various levels of reliance on groundwater. In Bengaluru, for instance, the south-eastern suburbs housing high-value real estate development are serviced entirely by groundwater resources—wells and tankers serviced by wells—even as many of these densely populated areas do not have sewerage and depend on "honey suckers or tankers" to take away their sewage to adjoining rural areas (personal communication, Biome Trust and ACWADAM; Kvanstrom et al 2012).[4]

Natural recharge areas are seldom protected in the absence of a clear understanding of aquifers and their boundaries, leading to a clear reduction in groundwater recharge. Even in cities claiming to be surface water-secure like Mumbai, groundwater is used quite prolifically, and even established institutions use a significant amount of groundwater from wells on their campuses with hardly any reference to groundwater quality. Non-potable needs in many such cities are often met or supplemented through groundwater resources.

Figure 2: Generalised Trends of Surface and Groundwater Use across Urban Settlements of Various Sizes in India



Small towns →	Large towns or small cities →	Large cities →	Metros
Surface water use limited to ponds/water bodies Groundwater use significant, largely through wells; sometimes through springs	Surface water use may increase as formal water supplies established Groundwater usage shifts outwards into suburbs and peri-urban areas; groundwater and surface water are transported from peri-urban/rural areas inward	Near equal share of surface water and groundwater, although much of the groundwater share 'unacknowledged' in civic water supply; Large water transports through tanker-supply; Wells are drilled into acquifers feeding springs	Large share of 'imported' formal surface water supply, with even greater share of 'unacknowledged' groundwater abstraction and transport in suburbs and peri-urban areas; uncertainly in the projected trends of groundwater use (1, 2 or 3)—possibly different in different metros. Spring-water supply almost gone/negligible

Source: Kulkarni and Mahamuni (2014).

2 Changing Shares of Surface Water and Groundwater

In the absence of real-time data on groundwater use in urban India, it is difficult to predict trends in terms of how comparative shares of surface and groundwater shape up through the four-stage transition described above. However, observations across many locations in India indicate that the volumes of surface water pumped from ponds, tanks, and reservoirs, even in surface water-dependent townships, increases with time. Similar trends in groundwater use are extremely difficult to describe in the absence of reliable data. Even in a city like Pune where this has been studied extensively (Deolankar 1977; Lalwani 1993; Kulkarni et al 1997), exact quantification is difficult. However, based on evidence in National Institute of Urban Affairs (NIUA) (2005), Narain (2012), and extensive discussions with public officials, government agencies, researchers and civil society organisations across different towns and cities in India, a first-cut attempt has been made to capture the shifting significance of surface and groundwater in urban water supply over time (Figure 2). The figure summarises key elements at each stage that a single large city or metro would have gone through over a timeline of the last six decades. This is a hypothesis for future research to test further. Our conjecture is that the dependence on surface water grows over time through all four stages of urban growth. However, groundwater follows a more complex and relatively indeterminate trajectory. In particular, after the stage when the share of surface water becomes higher than that of groundwater in urban water supply, the trajectory of groundwater (given the absence of robust data on well numbers, pumping volumes, and groundwater transfers) becomes indeterminate and could move in three possible directions—(1) it follows surface water trends, (2) it remains stable, or (3) it falls considerably.

The precise trajectory, the specific path chosen, will depend on particular aquifer typologies (described in the next section) and socio-economic conditions. But understanding the precise trajectory is significant, both in terms of utility planning and management in urban India.

3 Groundwater: The Blind Spot in Urban Water Planning

India is the largest consumer of groundwater in the world. India's annual agricultural use of groundwater resources is in excess of 250 cubic kilometres, the largest in the world, leaving China way behind (Shah 2009). Moreover, 85% to 90% of rural India depends on groundwater resources for drinking water supplies (DDWS 2009; World Bank 2010). Nearly 70% of irrigated agriculture in India depends on groundwater (Ministry of Agriculture 2013). Three recent statistics point to how at least half of urban India clearly depends on groundwater for its various needs.

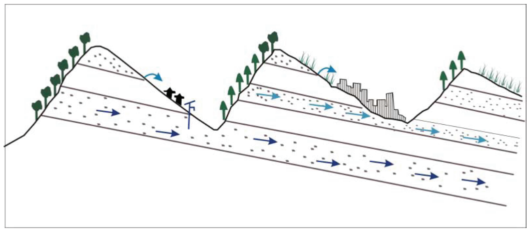
(1) Averaged for 71 cities and towns, groundwater constitutes 48% of the share in urban water supply (Narain 2012).

(2) In India, 56% of metropolitan, class I and class II cities are dependent on groundwater either fully or partially (NIUA 2005).

(3) Unaccounted water in urban areas exceeds 50%, according to the CGWB's report on the groundwater scenario in 28 Indian cities (2011).

Privately driven, individualistic pumping of groundwater in large parts of urban India has provided benefits by filling gaps in public water supply schemes. However, it has also led to problems of co-terminal depletion and contamination of aquifers. There are huge gaps in our knowledge about urban aquifers, their characteristics, the significance of their service value, and a comprehensive understanding of the competition and conflicts around groundwater resources. Sustainable management of groundwater is impossible without a much

Figure 3: Mountain Aquifer Systems



Mountain Systems

	Population	Towns/Cities
A	> 5 million	0
B	1–5 million	0
C	1,00,000–1 million	8
	Total cities (A+B+C)	8
	Total cities (% of total)	2.5
D	< 1,00,000	457
	Towns (% of total)	8
	For example, Chamba, Dharamsala, Shimla, Manali, Palampur, Kaza, Nainital, Almora, Mussoorie, Darjeeling, Gangtok, Aizawl, Shillong	

deeper understanding of the types of aquifers within which it is located.

Aquifers in large regions of India act as both sources and sinks for various loads, ranging from sullage to sewage and from industrial waste to agricultural residues such as pesticides and fertilisers. Groundwater resources in growing urban centres are therefore likely to become contaminated as much by residual contaminants from erstwhile agricultural activities and poor rural sanitation as by contamination from more current haphazard waste water disposal. Only 33% of urban Indians are connected to a piped sewer system and 13%—roughly 50 million urban Indians—still defecate in the open (Census of India 2011). Large parts of the modern cities remain unconnected to the sewage system as they live in unauthorised or illegal areas or slums, where state services do not reach (Shah 2013). Surveys of groundwater quality in many cities, therefore, reveal a large magnitude of waterborne pathogenic contamination—commonly referred to as bacteriological contamination—clear signs of groundwater contamination by sewage.[5]

4 Groundwater Resources in Urban India

A groundwater typology can be defined by hydrogeological settings, aquifer scales, and the socio-economic factors of a region (Kulkarni and Shankar 2009). Hence, the typology of groundwater decides how and how much the water stored in an aquifer changes as a consequence of groundwater recharge and extraction. The primary basis for a groundwater typology is the geology of a region, given that various geological formations host aquifers, with the characteristics of these aquifers—mainly the transmissivity, storativity, and groundwater quality—determining the groundwater flow and stocks in the region. Kulkarni and Mahamuni (2014) divide variously sized towns and cities into six categories (Figure 3, Figures 4, 5, 6, 7 and 8, pp 63–65).[6] This was attempted using a geographic information systems (GIS) framework of overlays on the fourfold urban classification described above. This classification is probably a first of its kind and is evolving as the GIS analysis is sharpened. However, it provides a useful indicative typology of groundwater resources in urban India.

4.1 Himalayan Mountain Systems

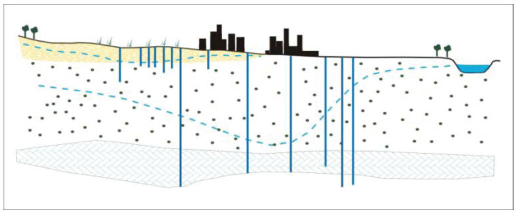
Even though only 3% of the larger cities and 8% of smaller towns are located in the Himalayan mountain regions, the uniqueness of its hydrogeology and ecosystems warrants a separate category under urban groundwater typology. To begin with, the hydrogeology is represented by numerous local aquifers, at many locations and altitudes in this expansive region. These aquifers feed springs that form the primary means of water supply to both rural and urban habitations and also contribute significantly to base flows in streams and rivers of the Indo-Gangetic river basins. Even by gross, conservative estimates, there are more than a million perennial springs in the Indian Himalayan region alone (personal communication ACWADAM). Given the structural complexity of rock formations in the Himalayas, these aquifers, although local, are often fed by recharge from distant locations.

The single largest problem surrounding groundwater and urbanisation in the region is that the sinking of wells interferes with spring discharges. Second, in many instances, aquifer continuity across villages and towns presents the potential of contamination from on-site sanitation and waste disposal sites. Third, in the absence of a protocol of including hydrogeology in urban planning, the concept of "protecting" recharge areas is largely missing, although recent initiatives have provided promising approaches to spring water management and "springshed development" activity (Tambe et al 2011; Mahamuni and Upasani 2011). Moreover, tourism has pushed rapid infrastructure development in many of these townships. The town of Leh, in Ladakh District of Jammu and Kashmir, for instance, which largely depended on spring-water to meet its household needs is increasingly turning into a town of borewells as tourism pressure and urbanisation builds up rapidly. With such pressures, not only are borewells and springs competing for groundwater from "common" aquifers, water that was allocated to agriculture in the peri-urban pockets of Leh is also affected, with infrastructure interfering with natural recharge zones (ACWADAM, personal communication). The situation is similar in many Himalayan towns, Shimla, Manali, Palampur, Almora, and Gangtok, to name a few. While agriculture has remained largely rain-fed, there are trends of shifting to irrigation at scale, building another layer of competition around fragile and low-storage aquifers, particularly in the peri-urban areas of small and large townships.

4.2 Extensive Alluvial Systems

The two main regions of large-scale groundwater extraction coincide with the two largest hydrogeological settings within the typology—the extensive alluvial systems and the crystalline (basement) system, described later. In a reference to the ever-increasing trends of groundwater pumping in these two regions, Postel (1999) suggested that two-thirds of the annual overdraft of global groundwater to the extent of 200 km^3 (supporting 10% of the global food production) was taking place in western and peninsular India, corresponding to these two regions.

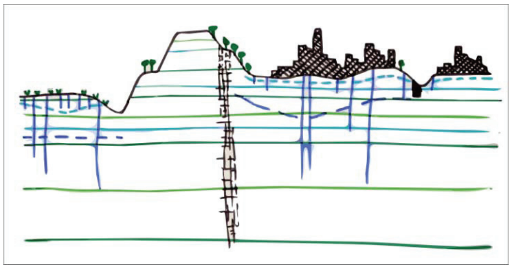
Figure 4: Alluvial Aquifer Systems



Alluvial

	Population	Towns/Cities
A	> 5 million	5
B	1–5 million	19
C	1,00,000–1 million	118
	Total cities (A+B+C)	142
	Total cities (% of total)	46
D	< 1,00,000	1,847
	Total towns (% of total)	32
	For example, Amritsar, Chandigarh, Ludhiana, Patiala, Meerut, Delhi, Bareilly, Lucknow, Allahabad, Varanasi, Patna, Kolkata, Cuttack, Guwahati, Jorhat, Dibrugarh, Bhubaneshwar	

Figure 5: Basalt Aquifer



Volcanic (Basalt)

	Population	Towns/Cities
A	> 5 million	2
B	1–5 million	6
C	1,00,000 to 1 million	24
	Total cities (A+B+C)	32
	Total cities %	10.5
D	< 1,00,000	391
	Total towns %	7
	Mumbai, Nagpur, Pune, Nashik, Aurangabad, Akola, Nanded, Solapur, Buldhana, Indore, Dewas, Ujjain, Bidar, Bijapur	

The vast region of groundwater exploitation in the North-West regions of the country is from alluvial aquifers, largely in the form of unconsolidated sediments deposited to form the vast plains of the Indus and Ganga River Basins, lying in Punjab, Haryana, part of Rajasthan, and Western Uttar Pradesh (UP). Further east, this region grades into the flood-prone areas of Eastern Uttar Pradesh, Bihar, parts of West Bengal and Assam (Brahmaputra river basin).

Some 46% of large cities and 32% of small towns in India are situated within the alluvial aquifer setting. While the western part of the region has witnessed groundwater depletion, parts of the eastern plains face a constant threat from flooding and are waterlogged. Chandigarh, Delhi, Lucknow, Allahabad, Varanasi, and Patna are some examples of large cities located within this setting. In multiple, overlying aquifers with virtually infinite lateral boundaries competition appears through a race to drill deeper and pump more (Kulkarni and Vijay Shankar 2014). Even as well numbers grow, some users with larger pump capacities can capture extra water, although the relative share of water available to each may progressively decline as water levels across the aquifer drop over the long term. But once the aquifers are depleted, it requires a major effort to revive them, since groundwater recharge has to take place at a regional scale, with large volumes of water.

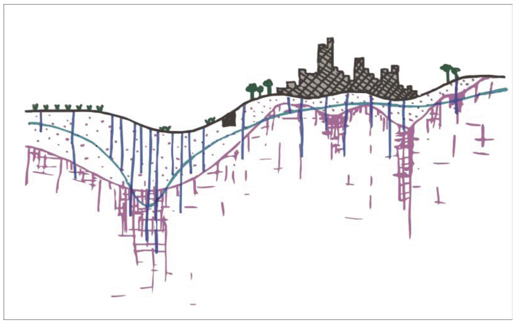
Despite the presence of large rivers—mostly the tributaries and main channels of the Indus and Ganga—there is great dependence of domestic water and water for agriculture on groundwater resources, with many industrial zones depending on groundwater as well. Moreover, groundwater quality across this setting is a major concern with arsenic dominating many areas. Other contaminants cannot be ruled out from areas where agriculture has prospered with heavy inputs of irrigation, fertiliser application, and pesticide/insecticide usage. Complex groundwater markets are emerging in both the drier western parts of the basin as well as in the eastern (flood-prone) region in the form of what is labelled "collusive opportunism" by Shah (2009) in his description of India's groundwater anarchy. As cities grow in the region, the most alarming question will be that of groundwater quality, a factor that changes with space, time, and depth. Hence, expanding urban space, competition with rural water supplies, and the constant potential of hitting a groundwater contaminant zone are the emerging challenges for the region.

4.3 Volcanic (Basalt)

The basalt rocks of Western and Central India represent voluminous outpouring of lava that solidified and gave rise to an extensive (more than half a million square kilometres) and thick pile (hundreds of metres) of "lava flows," Basalt aquifers also constitute a layered system and exhibit a high degree of variation that leads to a range of aquifer properties (Deolankar 1980; Kulkarni et al 2000). Basalt aquifers are heterogeneous in nature with limited storage and are pumped heavily for irrigation in some pockets. Their limited areal extent and thickness implies that groundwater in such aquifers occurs only on a local scale, unlike in alluvial aquifers. A city or even a town often taps multiple basalt aquifers, with a layered system of weathered and fractured rock, giving rise to aquifers at different depths or disconnected, shallow aquifers defined by zones of rock-weathering.

Most towns and cities in Western and Central Maharashtra, South Gujarat, parts of Saurashtra, large parts of Western and Central Madhya Pradesh, and portions of North Karnataka and North-western Andhra Pradesh fall under this category. Competition around drilling deeper is quite intense, both during severe water cuts in a town or city, say during a drought in the region or when agriculture-driven groundwater over-exploitation sets in.[7] Large urban agglomerations like Mumbai, Pune, Pimpri-Chinchwad, and Kolhapur are located in the "dam-dominant" region of India. Unacknowledged use of groundwater, especially in suburbs and peri-urban areas of even these large cities, is significant and measurement of

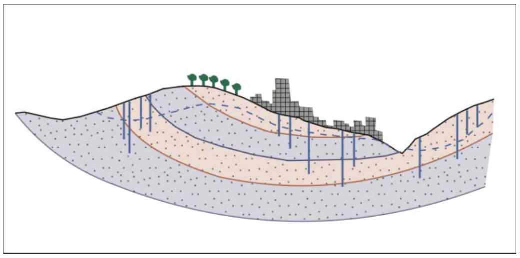
Figure 6: Crystalline Aquifer Systems



Crystallines

	Population	Towns/Cities
A	> 5 million	4
B	1–5 million	21
C	1,00,000 to 1 million	89
	Total cities (A+B+C)	114
	Total cities %	35.5
D	< 1,00,000	1,773
	Total towns %	31
	For example, Bhilwara, Bengaluru, Bolangir, Kalahandi, Hyderabad, Ranchi, Coimbatore, Nalgonda, Tumkur, Mysore, Vellore, Salem, Dindigul, Kottayam, Thrissur	

Figure 7: Consolidated Sedimentary Formations



Sedimentary Systems

	Population	Towns/Cities
A	> 5 million	0
B	1-5 million	1
C	1,00,000 to 1 million	12
	Total cities (A+B+C)	13
	Total cities (% of total)	4.0
D	< 1,00,000	172
	Towns (% of total)	3.0
	For example, Dhanbad, Hazaribagh, Adilabad, Chandrapur, Raipur, Rewa, Cuddapah, Kota, Bundi	

groundwater usage outside that in formal public supply would be higher than the 10% mentioned for basalt in NIUA (2005).

4.4 Crystalline (Igneous and Metamorphic Rock) Aquifers

The other region where groundwater exploitation has emerged as a large-scale challenge is in peninsular India within the crystalline aquifers in the Godavari, Krishna, and Kaveri River basins of peninsular India. This setting is the second largest hydrogeological setting in India, after the alluvial system described before. Some 31% of small towns and 36% of larger cities are located in this hydrogeological setting.

Aquifer conditions that govern storage and flow of groundwater in crystalline formations change even over very short distances, similar to those in basalt. However, the degree of heterogeneity of aquifer conditions is not as stark in crystalline rocks as that in basalt, although the highly variable well yields and consequently groundwater pumping patterns are of a similar nature in both. Where regional weathering and fracture patterns have developed in crystalline rock formations, the groundwater conditions are almost akin to those in a shallow alluvial aquifer. Such variability leads to fundamentally diverse recharge and discharge conditions in these aquifers, a fact that is seldom understood during groundwater development and management. Crystalline aquifer systems tend to be depleted rapidly when intensive development occurs. Owing to low storage generally, water levels fall rapidly and shallow wells go out of service as water contained in the upper weathered and fractured zone is pumped out. Further, as water is confined to the near-surface weathered zone, groundwater availability in hard rock regions also tends to be much more sensitive to recent precipitation, and also vulnerable to surface-related contamination. One of the most significant factors that affects these aquifers as part of the urbanisation process is that much of the local aquifer storage in a shallow, unconfined (or phreatic) crystalline aquifer may be "lost" when deep foundations for infrastructure such as housing are excavated and concreted.

Urban centres in Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Odisha, Jharkhand and Chhattisgarh, along with large parts of the Bundelkhand region of Madhya Pradesh and Uttar Pradesh, are underlain by crystalline rock aquifers. In Bengaluru, the local river Arkavathi is now dry on account of base flow depletion from groundwater over-exploitation, especially through deep borewells.

4.5 Consolidated Sedimentary Formations

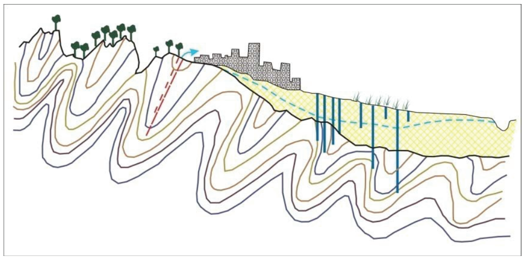
Only about 3% of small towns and 4% of the larger cities are underlain by these formations, which host local to quite regional-scale aquifers and aquifer systems. Some of these rocks may hold groundwater recharged over longer time frames of decades, and maybe hundreds of years. Many of these formations also host some mineral deposits that are obtained through quarries and mines. Hence, towns and cities that have interface with mining activities are likely to have interference of mining over potential groundwater stocks. Townships in the coal belt of East-Central India, such as Dhanbad and Hazaribagh in Jharkhand and Chandrapur in Maharashtra or Adilabad in Telangana, are a few examples. Many of these areas not only show private access to groundwater from high-yielding aquifers (generally high storage and quick transmission), but also have a significant proportion of public water supply dependent on groundwater from these aquifers.

Many of the mines in the adjoining areas of such townships dewater underground aquifers as part of the "dewatering" of mines without the townships being aware of such effects. Similarly, groundwater quality in such areas is always questionable and random testing of wells for iron, fluoride and arsenic has yielded fairly high levels of contamination from some of these chemical constituents.

4.6 Transition Zones

The best examples of transition zones are towns and cities located at the interface of mountain/hill ranges and the plain areas, although other transitions are also possible (between

Figure 8: Zones of Aquifer Setting Transition



Mixed

	Population	Towns/Cities
A	> 5 million	0
B	1-5 million	0
C	1,00,000 to 1 million	0
	Total cities (A+B+C)	0
	Total cities (% of total)	0
D	Towns	1,142
	Towns (% of total)	20
	For example, Gurgaon, Bagdogra, Haldwani, Kalka, Bhopal, Bhuj	

two or even three of the preceding "types"). Hence, we have illustrated here, as an example, the transition between the foothill portions of the Himalayan system and the adjoining alluvial region. Commonly called the "terai," this region shows a sudden break in the mountain slope along with the significant change in porosities and permeabilities of the two aquifer settings. Many springs emerge at this interface. There are reports of arsenic pockets in these transition zones, which have a mix of spring water in the uplands and shallow tube wells fitted with handpumps on the other.

Townships like Bagdogra in West Bengal, Haldwani in Uttarakhand and Kalka in Himachal Pradesh are some examples. Other examples are the small and large towns that are situated at the interface of Aravalli ranges and the adjoining alluvial plains, including the growing city of Gurgaon.

It should be apparent from the above description why it is so important to understand the specific nature of the aquifer(s) present in each location to be able to undertake sustainable and equitable management of groundwater.

5 India's Urban Areas in a 6×4 Matrix

We now propose the classification of all of India's urban settlements into a 6×4 matrix, which captures both the stage of urban expansion (four stages) and the aquifer type they belong to (six types). The strategy to address the problem of urban water would need to be different in each of the 24 cells of this matrix. The first step in devising these strategies would be to appropriately locate each of India's towns and cities in these cells. An initial illustrative classification of 150 towns and cities is provided in Table 3. It is important to note that towns and cities will move towards the right in each row of the matrix as they grow in size. Hence, solutions need to be formulated in a deeply dynamic manner. Which is why it makes most sense to focus on those towns where precipitate errors have not been made and there is still scope for fresh, innovative work from the beginning of the kind described later in this paper.

6 Solutions: Seven Elements of a Paradigm Shift

In proposing possible solutions to India's urban water challenge, the attempt we have made is to not only learn from the mistakes of the past, but to also build on the innovations that appear most promising in providing cost-effective, sustainable

Table 3: 150 Towns and Cities by Stage of Development and Aquifer Type

Stage of Urban Development / Aquifer Type	Nucleus	Growth	Expansion	Agglomeration
Mountain systems, mainly Himalaya	Banihal (J&K), Kaza (HP), Bhimtal (UK), Namchi (Sikkim), Jowai (Meghalaya)	Leh (J&K), Palampur, Hamirpur (HP), Nainital, Almora, Mussoorie (UP)	Anantnag (J&K), Nainital (UP), Darjeeling (WB), Itanagar (Arunachal Pradesh), Aizawl (Mizoram)	Jammu, Srinagar (J&K), Shimla (HP), Shillong (Meghalaya), Gangtok (Sikkim)
Extensive alluvial systems, largely within the Indo-Gangetic and Brahmaputra flood plains	Fazilka, Abohar, Sangrur (Punjab), Kaithal (Haryana), Raebareli, Fatehpur (UP), Sitamarhi, Bettiah (Bihar), Nabadwip (WB)	Barmer (Rajasthan), Ferozepur, Bhatinda (Punjab), Jaunpur, Meerut (UP), Hissar, Kurukshetra (Haryana), Saharsa, Madhubani (Bihar), Burdwan (WB), Dibrugarh (Assam)	Jodhpur (Rajasthan), Kanpur, Gorakhpur, Moradabad, Bareilly (UP), Ludhiana, Amritsar (Punjab), Darbhanga (Bihar)	Chandigarh, New Delhi, Allahabad, Varanasi, Lucknow (UP), Ahmedabad (Gujarat), Patna (Bihar), Kolkata (WB), Guwahati (Assam), Bhubaneshwar (Odisha)
Deccan volcanic, forming the plateau uplands of West–Central India	Palghar, Paud, Saswad, Bhor, Chiplun (Maharashtra), Bagli, Karnavad (MP)	Lonavala, Ratnagiri, Beed (Maharashtra), Pithampur, Dewas (MP)	Satara, Wardha, Amravati, Kolhapur, Latur, Nanded, Baramati (Maharashtra), Ujjain (MP)	Mumbai, Thane, Pune-Pimpri-Chinchwad, Aurangabad, Nagpur, Nashik, Solapur (Maharashtra), Indore (MP)
Geologically ancient crystalline rock formations of peninsular, Eastern and North-western India	Chalakudy (Kerala), Sivakasi (TN), Kunigal (Karnataka), Kosigi, Daulatabad (Telangana), Khunti, Lohardaga (Jharkhand)	Palakkad (Kerala), Madanapalle (AP), Chitradurga, Gadag, Davangere (Karnataka), Karimnagar, Nalgonda (Telangana), Purulia (West Bengal), Jhansi (Jharkhand)	Thrissur (Kerala), Coimbatore, Thiruvannamalai, Madurai (TN), Jamshedpur (Jharkhand)	Bengaluru, Mysore (Karnataka), Hyderabad (Telangana), Thirupati, Visakhapatnam (AP), Ranchi (Jharkhand), Ernakulam, Thiruvananthapuram (Kerala)
Sedimentary rock formations from various parts of India	Karaikudy, Ariyalur (TN), Tadipatri (AP), Badami (Karnataka)	Tiruchirapalli (TN), Kadapa (AP), Shahbad (Karnataka), Satna (MP)	Kurnool (AP), Chandrapur (Maharashtra), Bilaspur (CG), Bhuj (Gujarat), Jabalpur (MP)	Raipur (CG)
Transition zones at the interface of two or more of the above formations	Jaisalmer, Neemrana (Rajasthan) Sangamner (Maharashtra), Hazaribagh, Dhanbad (Jharkhand), Shahdol (MP)	Gwalior (MP), Siliguri (West Bengal)	Vadodara (Gujarat), Dehradun (UP), Agartala (Tripura), Nagpur (Maharashtra)	

AP: Andhra Pradesh; CG: Chhattisgarh; HP: Himachal Pradesh; J&K: Jammu and Kashmir; MP: Madhya Pradesh; TN: Tamil Nadu; UK: Uttarakhand; WB: West Bengal.

solutions. The aim is also to suggest mid-course corrections that could help chart a better future for India's urban areas. What we describe now are some of the common elements that would need to characterise solutions across our 6×4 matrix, which would need to be implemented in a location-specific manner within each urban settlement.

6.1 Sustainable Groundwater Management

Developing an understanding about groundwater resources is as much a function of the diversity of aquifers as it is of the nature and extent of groundwater use. The aquifer mapping and management programme, one of the highlights of India's Twelfth Five Year Plan, could be used as an instrument to begin this process. The following key steps could form the building blocks of an urban aquifer management programme in India.

(a) Identifying status of existing groundwater resources in cities through participatory mechanisms, involving citizens, educational institutions and urban utilities.

(b) Assessing groundwater resources through a participatory "aquifer mapping" approach coupled with systematic studies by institutions with appropriate capacities to identify natural recharge areas, groundwater discharging zones, and quantification of aquifer characteristics, namely transmissivities, storativities, and groundwater quality.

(c) Profiling stakeholders, including users, tanker operators, and drilling agencies, and developing mechanisms for registering water sources.

(d) Ascertaining quantitative and quality-related groundwater security, including groundwater recharge, which is allied to the protection, conservation, and upkeep of waterbodies.

(e) Considering hydrogeology during waste disposal, sewage and sullage management, and design of sewerage and sewage treatment.

(f) Developing a framework of regulatory norms around urban groundwater use and protection of urban aquifers by preserving natural recharge areas.

(g) Understanding changes in river flows and quality, and the precise relationship between aquifers, aquifer systems and the river flowing through a town or city.

(h) Finally, developing an institutional structure required for mapping aquifers, and initiating groundwater management as an integral part of urban governance.

6.2 Focus on Recycling and Reuse of Waste Water

As argued in the Twelfth Plan document, perhaps the most important lesson from urban water works in India is the need to tackle water and waste water together, with primacy being given to the treatment of sewage. Sewage invariably goes into streams, ponds, lakes and rivers or groundwater, causing pollution that compromises health. No Indian city is in a position to boast of a complete sewerage system, which can keep up with the sanitation and pollution challenge. In fact, most Indian cities have a massive backlog of incomplete sewage systems or systems in serious need for refurbishment and repair. Currently, according to estimates of the Central Pollution Control Board, the country has installed capacity to treat roughly 30% of the excreta it generates. Just two cities, Delhi and Mumbai, which generate around 17% of the country's sewage, have nearly 40% of the country's installed capacity. What is worse, some of these plants do not function because of high recurring costs—electricity and chemicals and others—because they do not have enough sewage to treat. In most cities, only a small (unestimated) proportion of sewage is transported for treatment. And if the treated sewage—transported in official drains—is allowed to be mixed with the untreated sewage—transported in unofficial and open drains—then the net result is pollution.

The most advanced city is Bengaluru with 3,610 km of sewage lines and 14 sewage treatment plants. The rough estimation is that the city generates 800–1,000 million litres per day (mld) of sewage and the installed capacity to treat is roughly equivalent—some 721 mld. It also has high tariff; 100% metered supply, high recovery of its dues; 100% water supply, and substantial investment in sewage infrastructure. However, there is a significant underutilisation of treatment capacity because Bengaluru's sewage treatment plants only receive some 300 mld of sewage. In other words, less than half the sewage is trapped and half is treated. It is no wonder then that its waterways—rivers and lakes—remain polluted and nitrate levels in groundwater are increasing, which is dangerous for health.

Large parts of the modern cities remain unconnected to the sewage system as they live in unauthorised or illegal areas or slums, where the state services do not reach. Moreover, there are also zones within the growth pockets of a large city where even authorised housing remains unconnected to both water supply and sewage systems, at least for a certain period of time. If sewage systems are not comprehensive—spread across the city to collect, convey, and intercept the waste of all—then pollution will not be under control. The added problem is that the location of the hardware—the sewage treatment plant—is not designed to dispose of the treated effluent so that it actually cleans the waterbody. Most cities build a sewage treatment plant where there is land. The treated sewage is then disposed off, as conveniently as possible, invariably into a drain. But as this drain collects the untreated waste of large numbers of people, the end result is pollution. In most cities, settlements have grown without underground sewerage infrastructure. "Fitting" in sewage lines into already built, crowded and congested, and haphazard construction is a difficult task. This challenge is compounded by that even where sewerage lines exist, they are buried, broken or choked. Worse, nobody really knows the state of disrepair.

Decentralised waste water management systems can overcome many of these problems in the following ways:

(i) Catering to the unserved areas and minimising the pressure of transporting to a single location.

(ii) Reducing the cost of treatment and operation and maintenance (O&M) costs.

(iii) Adopting site-specific treatment technologies based on land use.

(iv) Minimising the land required for treatment.

What is more, with basic level treatment of sewage, the water can be reutilised in industries and power plants. The water sludge after treatment can also be used as manure in agriculture; this measure may result in revenue generation to urban local bodies (ULB). It is in the interest of the city to find ways to find buyers and users for its sewage. In this way it can work out the effluent profile of its treated effluent and segregate its waste to meet the needs of the end user.

6.3 Reducing Industrial Water Footprint

A rapidly emerging element of urban water, which requires much greater focus on recycling and reuse, is industrial water. Indian industry is currently excessively dependent on freshwater and tends to dump its untreated waste into rivers and groundwater. Overall, the water footprint of Indian industry is too high, which is bringing industry into conflict with other parts of the economy and society. There is huge scope for reducing the industrial water footprint, and this can be done through technologies and investments, which have a very short payback period.

A study by Prayas Energy Group (2011) suggests that coal-based thermal power plants (TPP) need massive amounts of water, both for cooling and ash disposal. In case of coastal power plants, the water requirement is normally met from the sea, but for inland TPPs water is a far more critical issue. Out of the 1,92,804 MW with environmental clearance, about 1,38,000 MW or 72% are inland. The Energy and Resources Institute (TERI) has estimated that in 1999–2001, out of about 83,000 mld of water discharged by all the industries in India, about 66,700 mld (~80%) is cooling water discharged from TPPs. The Centre for Science and Environment (CSE) puts the figure closer to 90%. During the same period, it was estimated that for every megawatt of power produced, Indian TPPs consumed about eight times more water than those in developed nations. This is mainly attributed to the once-through cooling system (open loop system). Cooling towers and ash handling are the major water consuming areas and account for about 70% of the water use within a plant. Comprehensive water audits conducted by TERI at some of India's largest TPPs revealed immense scope of water savings in the cooling towers and ash handling systems. Once-through systems are becoming uncommon in the world. However, in India, many plants still operate the once-through cooling system. A rough estimate suggests that by converting all the TPPs in India to closed-cycle cooling systems, about 65,000 mld of freshwater can be saved.

The payback period for the proposed waste water treatment and recycling system is less than three years. From a national perspective, where a large number of power plants, other than National Thermal Power Corporation (NTPC) ones, still function on the once-through cooling system, there is considerable scope to improve water-use efficiency and conserve water resources.

The first step in this direction will be to make comprehensive water audits a recurring feature of industrial activity so that we know what is being used by the industrial sector at present, so that changes can be monitored and the most cost-effective basket of water-efficiency technologies and processes designed and implemented to reduce water demand and increase industrial value added per unit of water consumed. We must make it mandatory for companies to include details of their water footprint for the year in their annual report. Simultaneously, we must develop benchmarks for specific water use in different industries and would ensure their application in the grant of clearances for industrial projects.

The second step would be to examine the measures to levy charges for water use and incentives for water conservation. Currently, the Water (Prevention and Control of Pollution) Cess Act 1977 is the only instrument to impose cess on discharge of effluent water from industrial units. This charge is based on the quantum of discharge from the industry and is used to augment the resources of the central and state pollution control boards. The charges imposed through the water cess are not enough of a disincentive for industries to reduce their water footprint. It is important to examine this act and other provisions and options to substantially increase the charges imposed on water use and effluents. This is particularly important where industries use groundwater and do not pay municipalities, water utilities, or even irrigation departments for water use. The importance of water pricing as an instrument for change is critical.

The third step would be to publicly validate the water audit of industries so that this builds experience and confidence on the best practices. This water reduction commitment of each industry will be tracked for compliance and enforcement through environmental regulatory institutions. The water audit would also help identify training requirements and the best way of achieving behavioural change within the business. The maximum water saving will be delivered when both behavioural change and hard measures are successfully adopted by the end user.

6.4 Protect and Prioritise Local Waterbodies

The first priority for cities when planning water supply should be the protection, restoration and recharge of their traditional waterbodies. Under the Jawaharlal Nehru National Urban Renewal Mission (JNNURM), cities must get funds for water projects only when they have accounted for the water supply from local waterbodies. This would reduce costs of supply from a distance and also preserve the ecology of the city. The CSE reports that of about 1,012 waterbodies in Delhi, about 70 are under partial encroachment and about 98 under total encroachment. Encroachments severely reduce the water holding capacity of natural reservoirs. This results in outflow of water during monsoon, leading to widespread floods.

There is no specific legislation in India to protect waterbodies—urban or rural. In December 2010, the Union Ministry of Environment and Forests issued the Wetlands (Conservation and Management) Rules, 2010. Under the rules, wetlands have been classified into different categories based on location and size. In addition, the Central Wetland Regulatory Authority has been set up for regulation. But these rules, important as they are, still leave out most urban waterbodies from the ambit of protection. These lakes and water systems, which at one time even gave names of the localities and people, are in desperate need of recognition and protection.

Today, cities have grown over the water body and its functional parts—its drains and its catchment. Guwahati is the one city racked by incessant flooding, which has decided to legislate the protection of its key water structures. It has identified the land holding the water and recorded the area of the catchment in its Waterbodies Preservation and Conservation Bill 2008. But it is finding protection difficult. The catchment over years has been legally handed over to buildings. It has also been taken over by the city's poor for their settlements. This scenario is not unique to Guwahati. What makes matters worse is that in many instances, waterbodies have been truncated to suit disjointed bureaucracies and policies. In most cases either the waterbody itself has been divided—the waterhead is owned by one agency and the waterbody by another. Or there are many agencies that "own" different waterbodies of the city and so planning, policing, and protecting is difficult. Jammu and Kashmir is one state that has mandated its Lakes and Waterways Development Authority the right to manage not just the lake but also the catchment. Clearly, this is the model for other cities as well.

On 6 September 2014, the Madurai bench of the Madras High Court gave a landmark ruling directing the government not to grant layout approval or building plan permission on lands located on waterbodies. It was responding to a public interest litigation (PIL) on the subject. This historic judgment is not only a wake-up call for Tamil Nadu, but for other states as well where a significant number of small waterbodies are dying. Earlier, in 2013, the Supreme Court directed authorities in Kanpur Dehat District to check encroachments on waterbodies in their jurisdiction. The Rajasthan High Court in 2012 also came down heavily on the state government over illegal allotments and encroachments in the catchment area of waterbodies.

6.5 Shift Focus to Management and Distribution

The much more acute problem in urban India is not the quantum of water to be supplied, but its management and equitable supply to all. In most cities, water supply is sourced from long distances. In this system of bringing water from far and distributing it within the city, the length of the pipeline increases, as does the cost of infrastructure and its maintenance. In the current water supply system, there are enormous inefficiencies—losses in the distribution system because of leakages and bad management, not to mention the quality of water supplied within and across towns and cities. But equally, there are huge challenges, for water is divided very unequally within cities. As per the National Sample Survey (NSS) 65th round, only 47% urban households have individual water connections.

Currently, cities estimate that as much as 40% to 50% of the water is "lost" in the distribution system. Even this is a guesstimate, as most cities do not have real accounts for the water that is actually supplied to consumers. Nagpur is an exception in this regard. The city has prepared a water-loss balance sheet. According to this calculation, of the 765 mld the city sources from the Pench forest and tiger reserve—some 40 km away—it finally collects money for a mere 200 mld, or 32% of what is sourced. The city loses as much as 140 mld, a quarter, in bringing water from the reserve. The revenue loss because of this leakage wipes out its entire budget.

Data suggests that most cities spend anywhere between 30% and 50% of their water supply accounts for electricity to pump water. As the distance increases, the cost of building and then maintaining the water pipeline and its distribution network increases. And if the network is not maintained, water losses increase. All this means that there is less to supply and more to pay. The end result is that the cost of water increases and the government finds it impossible to subsidise the supply of water to all. The situation is worse in the case of the poor, who often have to spend a great deal of time and money to obtain water since they do not have house connections.

Thus, we must shift the exclusive focus on augmentation of water supply to managing the supply for all and managing to supply clean water. We will have to spend less in bringing water to our houses. In other words, cut the length of the pipeline to reduce electricity and pumping costs and the resultant "leakage." This means that we will have to revive local waterbodies and recharge groundwater, so that we can source water from as close as possible. We must again cut the costs and transportation of sewage—use decentralised networks and use a variety of technologies to treat sewage as locally as possible.

6.6 Eco-restorative, Low-cost Technologies[8]

The High Powered Expert Committee Report on Indian Urban Infrastructure and Services (HPEC 2011) estimates that water supply and sewerage treatment will cost the nation around Rs 5,60,000 crore over the next 20 years. Conventional technologies, normally employed to treat the pollution from point sources, are also not that effective against non-point sources of pollution. It has been estimated that Pune city will need about 3,000 MW electricity per day to run its sewage treatment plants based on conventional energy-intensive technologies. Energy is also required for the disposal of huge sludge from the conventional engineering waste water treatment technologies.[9] To generate that much electricity daily, 3,000 tonnes of carbon dioxide will be released into the environment.[10] Applying the same logic nationwide, it will be 1,20,000 tonnes each day. On the other hand, untreated wastes left in the waterbodies will lead to an increase of greenhouse gases (GHG) mostly due to generation of methane in enormous quantities.

Thus, there is an urgent need to consider alternative technology options, which have now been tested on the ground. Vertical eco-filtration techniques were developed in the 1990s to treat waste waters from domestic and industrial sources. These innovations helped industry reduce operational costs substantially by reducing electricity consumption, chemical, and manpower requirements. Over time, the vertical eco-filtration technique was converted into the horizontal eco-filtration technique or the green bridge system. This has now been successfully tested out at several locations across the country—College of Military Engineering (CME), Pune in 2003 (treating waste waters without electricity or chemicals); Udaipur's Ahar River in 2010 (increased dissolved oxygen from 0 to 8 mg/l in just 60 days; poor fishermen and farmers benefited due to alleviation of pollution in the river and Udaisagar lake downstream); restoration of the Buddha Stream of Sutlej River receiving waste water from Ludhiana's urban and industrial areas; restoration of the five-stream Rasoolabad Ghat Complex in Allahabad, Ganga (flow ranging from 0.5 mld to 10 mld) in 2011.

A series of treatment units comprising anaerobic, microaerophilic, and aerobic process is powerful for organic pollution treatment along with nitrate and phosphorus removal. All these processes, occurring in different treatment units separately, create a cumulative effect in the soil-scape process for point source pollution or green bridge system for non-point source pollution.

7 Capacity Building of Urban Local Bodies

Indian cities desperately need to build capacity to take managerial and technological decisions an essential public services and to implement and deliver these services to all. This internal capacity is even more important in a situation where many elements of the urban services are to be contracted to private companies. Although one of the key goals of JNNURM was to incentivise building of ULB capacity, it is not clear this architecture has actually led to major changes on the ground. Devolution of powers to ULBs as per the Constitution (74th Amendment) Act, 1992 faces the most critical bottleneck of lack of professional human resource capacities among ULBs. Policymaking, service provision, and regulation still rely heavily on the state government bureaucracy.

Currently, water supply and sewerage services in cities are run by a complex institutional set-up with overlapping jurisdictions and fragmented roles and responsibilities. The responsibilities for these services are shared by ULBs for O&M and para-statals for investing in capital infrastructure. In a few metro cities, services are provided by an independent authority. Institutional fragmentation with regard to policymaking, financing, regulation, and service delivery has also contributed to the poor state of urban water service delivery (IIR 2011).

Water charges levied by ULBs are very low and fee collection is poor so that even recovery of O&M proves difficult. Water boards in India are able to recover only 30% to 35% of the O&M cost (HPEC 2011). There is no systematic planning, resource allocation, or skill enhancement programmes. An overall organisational development strategy, both at the state and ULB levels, is missing. One of the major underlying reasons for the poor performance of water utilities is lack of dedicated cadre. There is evidence that well-established municipal cadre in a few states (Karnataka, Maharashtra and Tamil Nadu) had a positive impact on governance, reforms initiatives, attracting external funding and technological innovation. Other states without the requisite municipal cadre lagged far behind in each of these respects (GoI 2014). Global experiences of successive waterbodies/utilities in institutional reforms focus on key principles—decentralisation of responsibilities to local governments; building autonomous utilities with tariff rationalisation; dynamic leadership and human resource development; and community participation. In 2010, the Government of Maharashtra launched Sujal Nirmal Abhiyan, a state-led integrated water and sanitation programme aimed at reforming the performance of ULBs. The programme incentivises reform by making the release of grants entirely performance-based. It offers an example for other states to emulate.

Conclusions

This paper presents an overview of the problems of water and waste water in urban India. It suggests a novel approach based on a differentiated understanding of the urban space, which distinguishes urban settlements on the basis of stages of urban development, the relative roles of different sources of water and underlying aquifer systems. We propose a series of hypotheses, which need to be investigated more deeply in each of the major urban settings. On the one hand, we propose seven elements of a common approach that needs to mark a departure from the earlier top-down, technology-driven, capital-intensive framework. This includes special and closer attention to groundwater, as also local water resources and alternative, eco-friendly, low-cost, decentralised technologies of waste water treatment. On the other hand, we propose a 6×4 matrix into which we could divide each Indian urban settlement to devise strategies more specifically appropriate to each cell in this matrix. Thus, the paper proposes a new framework for understanding water in urban India, as also a series of hypotheses that constitute a rich agenda for further research.

NOTES

1 The heartening part of their predicament is that they have not reached a point of no return and their problems are readily amenable to solutions, with high elements of sustainability and equity and urban local bodies (ULB) capacities built into them, if only India's policymakers were to pay due attention. Bagli town in Dewas District, part of the groundwater over-exploited Malwa plateau region in Madhya Pradesh, is a typical case in point, well researched in Samaj Pragati Sahayog (2002), which provides one of the first, and perhaps only, comprehensive plan for addressing water supply and solid and liquid waste management in small towns in India.

2 Gorakhpur city in Uttar Pradesh could be considered a case here, as much of its water supply is groundwater dependent even as the city faces repeated flooding and water-logging risks (TERI 2012b).

3 A large sprawling housing colony alone, spread over 360 hectares of land in suburban Pune, was drawing half a million cubic metres of groundwater every year by pumping groundwater from basalt aquifers through 150-odd borewells in the mid-1990s (Kulkarni et al 1997) during Stage 2 of Pune's urban trajectory without any focus whatsoever on groundwater recharge.

4 Biome Trust, Bengaluru and Advanced Centre for Water Resources Development and Management, Pune are currently involved in a participatory urban groundwater management initiative in South-eastern Bengaluru. The initiative is being partnered and supported by WIPRO.

5 In the city of Lucknow, during the period of its initial urban growth, nitrate concentrations ranged between 25 and 50 mg N/l, indicating that about 20% of the nitrogen was being leached to the water table (Morris et al 1994).

6 Sketches are not to scale.

7 The well-documented case of Dewas city in Madhya Pradesh illustrates the emergence of a water crisis by competitive drilling and pumping of groundwater in and around the growing city, even as far back as the early 1990s (Samaj Pragati Sahayog 1994).

8 This section draws heavily on the pioneering work of Sandeep Joshi and his organisation Shrishti Eco-Research Institute.

9 Natural systems do not generate sludge at all. Therefore, there is no requirement of energy for sludge disposal.

10 Based on the data generated by the US Department of Energy, in association with the Environment Protection Agency.

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