Groundwater Situation in Urban India: Overview, Opportunities and Challenges

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Introduction

Groundwater is a major source of water and is intensively exploited for private, domestic and industrial uses in many urban centers of the developing world. At the same time, the subsurface has also come to serve as the receptor for much of the urban and industrial wastewater and for solid waste disposal (World Bank 1998). Groundwater plays a fundamental role in shaping the economic and social health of many urban areas. However, no comprehensive statistics exist on the proportion of urban water supply world-wide derived from groundwater. It is estimated that more than 1 billion urban dwellers in Asia and 150 million in Latin America depend directly or indirectly upon well, spring and borehole sources (World Bank 1998a).

A number of factors determine the extent to which a city would depend upon groundwater to meet its water demand. The first set of factors can be called physical/ geographic—availability of sufficient groundwater either from natural recharge due to combination of good rainfall and receptive subsurface geology or from other sources such as canals, good aquifers that can store and transmit groundwater, availability of good quality groundwater that is not subject to constraints such as saline water intrusion. The second set of factors is determined by the ability of the urban area to cope with its water demand from external sources. This is driven by the economic scarcity rather than physical scarcity, or the latter may compound the former. In the event of physical scarcity, cities/ towns will still continue to grow with its buffer capacity. The available empirical evidence suggests that, by and large, cities have been able to obtain supplies, often at a greater cost than is necessary but without significantly compromising their ability to expand and prosper even in the most unhelpful locations (Molle and Berkoff 2006). Hence, water supply to any urban center is determined by its physical characteristics or economic and financial capacity. In the competition for water, cities generally win over agriculture (Molle and Berkoff 2006), but when it comes to competition between two cities or towns the dynamics are very different. Negotiation for water is more difficult for smaller urban centers that have lesser say on the water stored at distant reservoirs. In contrast, the larger urban areas[1] backed by population mass, financial capacity and political influence can attract surface water from distances of hundreds of kilometers. Newly developing urban centers (class-III to class-VI[2]) also have to depend upon their local water resources.

On the overlapping of these two sets of factors, one can arrive at the general level of dependence of urban areas on groundwater and their vulnerability at present and in the future in meeting their water demands from external sources. An accumulation of many such vulnerable urban areas within a small region or within a single river basin also implies an additional stress on water resources in the region and possible diversions of water from other uses such as irrigation or even from other regions. Therefore, one can also envisage such areas as those with high competition in the future between urban and other uses.

How would such patterns of dependence and vulnerability of urban areas to groundwater emerge? One can expect that a dominant factor driving these patterns would be the hydrogeological conditions. In India, the peninsular areas with basaltic and crystalline formations, unsuitable for groundwater exploitation, would exhibit relatively greater dependence on external surface water sources than the northern urban areas over the alluvial belt. On these would be superimposed factors such as local rainfall, location within canal commands, problems of coastal salinity, proximity to reservoirs etc. The peninsular river basins, therefore, on an average would exhibit higher proportion of urban areas depending on surface water than the northern urban areas, which have good access to local groundwater supplies from rich aquifers augmented by natural and canal recharge. But, the rich alluvial aquifers of northern India, where groundwater overexploitation has already taken place by irrigators and/or urban centers, will have to tap new water sources (surface or groundwater) in the near future.

This paper analyzes the impact and effect of 'supply-based' urban water management strategies and endeavors to identify, using some assumptions and hypothesis, the urban pockets or regions, which may face problems relating to groundwater and eventually become a black-hole for any imported water in the vicinity in India. Although there are two sets of factors - economical and physical - that mainly govern groundwater use in any urban area, the present study is restricted only to the physical aspects of it.

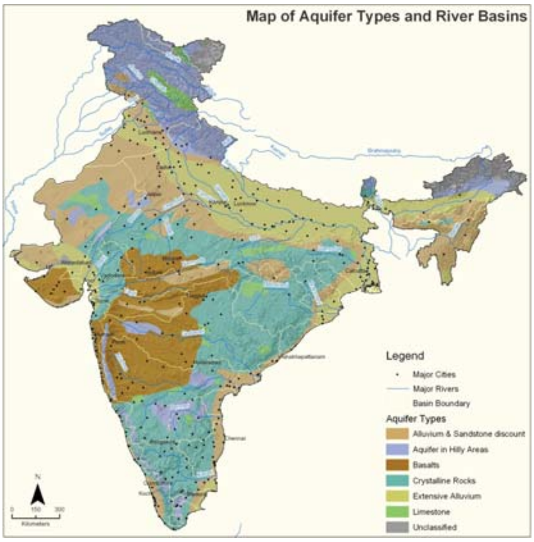
[1] The census of 1961 adopted a two-fold categorization to identify urban centers. First, the settlements that were given urban civic status like corporation, municipality and cantonment by state governments were identified as statutory towns. Second, three demographic criteria were applied to identify the census towns. These were (a) population size of 5,000 or more, (b) density of at least 400 persons per square kilometer, and (c) at least 75 % of the male workers to be engaged outside agriculture (Sivaramakrishnan, Kundu and Singh 2005).

[2] According to the census of India, urban areas are classified into six classes based on population. Class-I = 100,000 and above; Class-II = 50,000 – 99,999; Class-III = 20,000 – 49,999; Class-IV = 10,000 – 19,999; Class-V = 5,000 – 9,999; Class-VI = less than 5,000.

Hypothesis

This paper seeks to enquire a causal relationship between the physical environment and urban groundwater use through a spatial analysis. It is aimed to identify cities already undergoing, or may face in the near future, the physical scarcity of groundwater for use. This physical scarcity of the cities can be determined based on the geographical factors i.e., rainfall and recharge rate, hydrogeology, water deficit or rich river basin, population size, present groundwater utilization within city and its surroundings etc.

Figure 1. Location of urban centers (taken for the study) on the aquifer and basin map of India.



Methodology

The study is based on secondary data. The main data used here for the analysis is from a recent study conducted by the National Institute of Urban Affairs (NIUA), Government of India, which gives the status of water supply and sewerage in more than 300 cities consisting of metropolitan areas, class-I and class-II cities across different states (NIUA 2005). In addition to this, information on urban water for many cities and towns was obtained from various individuals: NGOs' and previous IWMI's studies i.e., total urban water supply, groundwater and surface water supply etc; reports of the Central Ground Water Board (CGWB), Central Water Commission (CWC) and National Commission on Integrated Water Resources Development (NCIWRD). The census of India and irrigation census have also been used as auxiliary information.

About NIUA Study

A questionnaire-based survey of 304 cities and the urban authorities was conducted by the National Institute of Urban Affairs, Union Ministry of Urban Development (NIUA 2005) during 1999 to 2002 and the report was published in 2006. The study encompassed 22 mega-cities, 164 class-I cities and 117 class-II cities. The data collected pertains to the quantum of water supply, groundwater and surface water supply, sources of water supply, standards adopted by urban water supply, water supply duration, demand-supply and deficit etc. The data of urban centers was superimposed on GIS layers of river basins, aquifers, district groundwater situation (CGWB 2004) etc. (Figure 1).

Findings and Discussion

Hydrogeology

Subsurface geology beneath the urban areas plays a key role for the dependence on groundwater. The alluvium plains bestowed with water-rich aquifers and/or with high groundwater recharge either naturally owing to good rainfall or from canals, support urban centers through high groundwater potential. Urban centers situated above crystalline rock or basalt will not be able to support groundwater development, due to its subsurface storage limitations. For example, urban centers in southern peninsular India are heavily dependent upon surface water, as scope for groundwater development is limited owing to hydrogeological conditions.

Out of the total water supply, the proportion of surface water (SW) in the urban centers above hard rock geology such as basalt, crystalline rocks and limestone, was 92 %, 79 %and 95 %, respectively (Table 1). These three regions cover 15 %, 30 % and 3 %, respectively of total geographical area of the country. The total available storage of groundwater bodies in hard-rock aquifers is strictly limited by their weathering characteristics and water-bearing properties. These aquifer systems (which comprise principally such formations as the weathered granitic basement complex and the Deccan Trap Basalts and occur largely outside the major irrigation canal commands) are the worst affected in terms of resource depletion (Foster and Garduño 2007). Such subsurface can barely support smaller towns (class IV to VI) with its groundwater resources. Hence, larger the city in such a region the more would be the dependence on surface water. Interestingly, basaltic hard-rock region has the highest urban population. Any additional urban growth will have to be supported by reallocating the irrigation

Table 1. Relationship between aquifer and surface water supply.

Aquifers	No. of sample cities	Average of % of SW supply in urban centers	% Urban population **
Alluvium and Sandstone discourse	78	55.90	27.50 %
Aquifer in Hilly Areas	19	52.66	28.28 %
Basalt	43	91.77	39.56 %
Crystalline Rocks	70	78.90	28.22 %
Extensive Alluvium	84	25.16	21.93 %
Limestone	2	94.89	23.70 %
Overall	296	57.88	27.33 %

Source: Based on NIUA, 2005 data; ** Based on Census of India 2001 water. This means that SW irrigation will be under constant pressure from the urban growth which and irrigation in these regions will have to improve water use efficiency.

River Basins

River basin wise water utilization in agriculture, domestic and industrial uses as well as rural drinking water has been analyzed in Amarasinghe et al. 2005. We have used CGWB 2004 data for the analysis (Table 2).

Table 2. Basin-wise groundwater (GW) supply in a percentage.

Basin	No. of sample cities	Ave. % of GW supply in cities	% Urban population **
Barak	5	11.34	Not available
Brahmani_Baitarn	3	66.67	13.73 %
Brahmaputra	5	21.82	14.38 %
Cauvery	17	7.35	38.08 %
EFR1	7	22.02	20.96 %
EFR2	18	22.20	46.57 %
Ganga	109	66.94	22.48 %
Godavari	18	5.37	25.66 %
Indus	21	66.46	28.48 %
Krishna	26	14.39	33.07 %
Luni	16	35.83	31.42 %
Mahanadi	5	27.55	20.29 %
Mahi	4	50.74	18.25 %
Narmada	5	28.21	28.94 %
Pennar	8	47.62	23.92 %
Sabarmati	3	40.93	36.37 %
Tapi	5	0.00	34.12 %
WFR	21	19.05	47.17 %
Total	296	41.10	27.33 %

Source: Based on NIUA, 2005 data; ** Based on Census of India, 2001

Note: EFR1: Easterly flowing rivers between Mahanadi and Pennar; EFR2: Easterly flowing rivers between Pennar and Kannyakumari; WFR: all westerly flowing rivers i.e., Kutch, Saurashtra, between Tapi and Tadri, Tadri and Kannyakumari

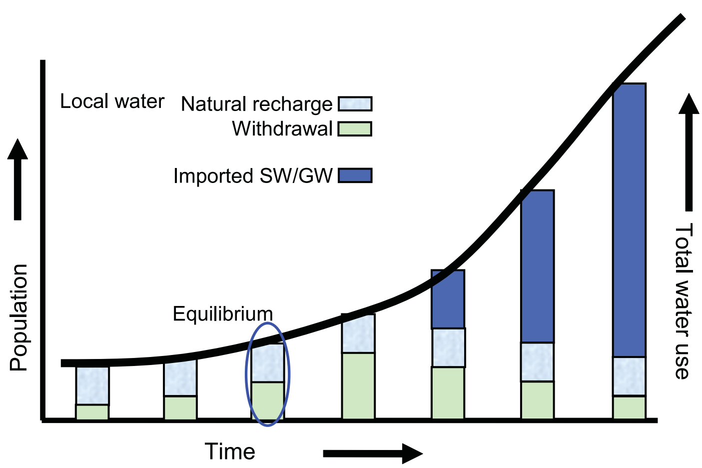
Looking at the basin-wise GW supply of the urban centers, Ganga, Brahmani-Baitarn and Indus have the highest proportion of GW supply - more than 66 %. Among sample cities, Tapi River basin has no GW supply, while, Mahi, Pennar and Sabarmati also have GW supply above 40 %. Groundwater supply also depends on the aquifer. Several river basins such as Krishna, Godavari, Cauvery and EFR2, in which major part of urban water supply comes from surface water, also have relatively high urbanization. Sabarmati and Luni have high urbanization and also high dependence on groundwater.

Groundwater Dependence Versus Population of the City

The size of the city is a strong indicator of how much surface water it can import or how much it has to rely on local sources of water. Urban centers with a larger population have more negotiating power for the quantity of water needed. In India, 56 % of metropolitan, class-I and class-II cities are dependant on groundwater either fully or partially (NIUA 2005). Towns smaller than this mostly do not have access to imported water (mostly surface water from the nearby reservoirs). Hence, overall dependence on groundwater for urban water supply in India is very high. Larger urban spots (million plus cities) on the Indian map are growing rapidly. But, many small spots (class-I and class-II cities) are emerging on the map, at a rate much faster than the million plus cities (Mahmood and Kundu 2004). Day by day, the dependence of urban authorities on groundwater within the city limits and from surrounding areas has been on the rise (Londhe et al. 2004; Phansalkar et al. 2005). There has been a rise in private tubewells within the city as well as tankers supplying drinking water to urban areas.

If we plot population growth with time and urban water supply of any city, it can be seen that, initially, there will be higher dependence on local water resources i.e., water bodies, tapping shallow aquifers using dug wells etc. As population grows, local water resources may no longer be able to fulfill the needs and hence, as a result, chase for declining groundwater levels increases using bore-wells and tubewells. That is where the city crosses the equilibrium (column three from left to right in Figure 2). As urban centers continue to grow, the volume and proportion of imported water increases and water supplies that were originally obtained from shallow unconfined aquifers may no longer be sufficient, because (a) the city outgrows the supply capacity of the local aquifer; (b) often quality, especially of GW deteriorates. Hence, if the local water sources are insufficient in quantity and/or quality for urban domestic use, the city needs to import water from beyond its urban limits (World Bank 1998a; World Bank 2003). Once a city manages to get assured water supply from external sources, it gradually abandons or reduces the local water resources. Eventually, city's claim for external sources becomes stronger and larger (last three columns in Figure 2).

Figure 2. Hypothetical plot—population growth with time versus water supply.

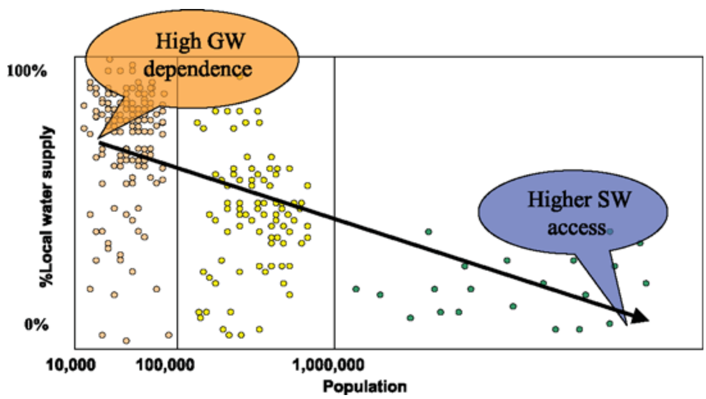


Thus, importing of water becomes inevitable for any city if it continues to grow. The time may vary from city to city depending upon the availability of local water resources in terms of quality and quantity. If this does not happen, then the city's development may get smothered. For instance, Ahmedabad had started importing water since 1980 and it has kept on increasing; Kolkatta is a classic example. Perennial Hugli River is a continuous source for groundwater recharge. Hence, theoretically, using GW for urban water supply seems to be the most practical option. According to CGWB (Rainwater Harvesting Dossiers, CSE, Undated), due to GW mining[3] Kolkatta is on a 'highway' to disaster. Total groundwater extraction is 1,123 MLD against the safe yield of 204 MLD, which has resulted in land subsidence in many parts of the city. Hence, the city is now forced to import water (SW or GW) beyond its urban limits.

Now, if we plot many urban centers, based on the population size and source of water supply, we find that larger the population size of urban centers the lesser would be the dependence on local water supplies. As towns transform into cities and mega-cities dependence on external sources of water increases.

Figure 3 shows the hypothetical lay out of the population size of urban centers versus dependence on local water resources. Based on this hypothesis we plotted around 315 cities (based on NIUA 2005 and other individual studies) and the result is shown in Figure 4. Among higher groundwater dependent million plus cities, Jaipur fetches nearly 90 % of its total urban water supply from a groundwater reservoir that is around 100 kilometers away. Ludhiana in Punjab receives all its urban water supply from the groundwater reserves. The city, at present is sustaining on its economic capacity. District level groundwater development is 144 % (CGWB 2004).

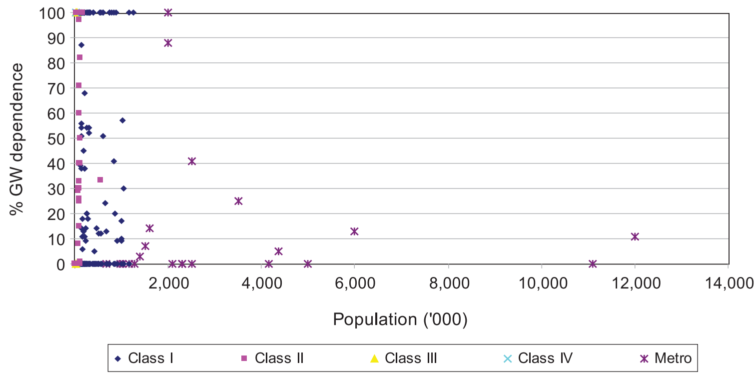
Figure 3. Hypothetical plot - population size versus dependence on local water resources.



Correlation between the size of city and its dependence on groundwater is indicated in Table 3. Average dependence of the urban centers on groundwater covered under NIUA 2005 study shows that it increases from 12 % to 36 % to 49 % with the decrease in city size from mega-cities (one million plus) to class I cities to class II towns.

[3] GW mining – when groundwater withdrawal increases the recharge.

Figure 4. Groundwater dependence versus city/town's population.



Source: Based on NIUA study (2005) and other individual studies

Table 3. Percentage water drawn from surface and ground sources – 1999.

Size class of urban centers	%Water drawn from	
	Surface source	Ground source
Metropolitan cities	88	12
Class I cities	64	36
Class II towns	52	49
Total no. of cities/towns	78	22

Source: Based on NIUA study 2005

It should be noted that, these figures are for the water supplied by urban authorities and not the actual use. Proportion of informal water supply is higher in smaller towns than in the bigger cities (NIUA 2005 and personal observation during IWMI's field work). The coverage of urban water supply system was found to be 98 %, 91 % and 89 % in million plus cities, class-I and class-II, respectively. It is a commonly observed phenomenon that population not covered in the formal water supply system often depends upon groundwater i.e., individual dug-wells, borewells, tubewells, hand-pumps, tankers from peri-urban areas etc. For instance, in the year 2004, Chennai wastewater generation was three to four times the piped water production, and in May of the same year, when the Metro Water Board could not distribute piped water at all, 11,000 tankers were crisscrossing the city to provide minimum quantities of water to households and businesses. These coping strategies have obvious physical and environmental limits, as the water is supplied from a large aquifer outside the city (World Bank 2006). For larger cities, such cases are documented but for the smaller towns it is a routine. Hence, dependence on groundwater would be much higher than the plot shows. Similarly, coverage of water supply does not necessarily mean adequate water supply. According to NIUA 2005, average water supply was found to be 182 liters per capita per day (LPCD), 124 LPCD and 83 LPCD in million plus cities, class-I and class-II towns. Thus, undersupplied quantity of water is managed from the groundwater sources (Table 4).

Table 4. Share of ground and surface water source – 1999 (no. of cities/towns).

Size class of urban centers	Only SW		Only GW		SW and GW				Data not available		Total	
					SW <50 %		SW>50 %					
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Metros	12	55	1	4	2	9	7	32	0	0	22	100
Class I	69	42	54	33	10	6	30	18	1	1	164	100
Class II	49	43	48	42	4	3	13	11	1	1	115	100
Total	130	43	103	34	16	5	50	17	2	1	301	100

Source: NIUA study 2005

Notes: SW = Surface Water, GW = Groundwater

However, the overall dependence of these urban areas on groundwater for their water needs as compared with surface water sources shows wide variation across the country. Which type of cities shows greater dependence on groundwater? On a general basis, larger cities have easier access to surface water sources from lakes or from reservoirs located possibly far away from the city limits e.g., New Delhi, Ahmedabad, Mumbai, Bangalore. However, this is not true for the smaller cities which have high to full dependence on groundwater resources unless they have nearby sources of surface water e.g., Anand, Kolar, Barabanki (Anand et al. 2005; Raju et al. 2004). As mentioned, these smaller towns (class-I and class-II) in India are showing maximum growth in population as compared with both million plus cities and the new smaller towns (class-IV to class-VI). The degree of vulnerability of these high-groundwater dependant cities varies with geographical and hydrologic factors, on the nature of local groundwater resources available and alternative use for that. In the regions where there is already a high level of groundwater development from irrigation, groundwater-starved cities will/are pose(ing) competition in respect of irrigation, for example northern and western Rajasthan, North Gujarat etc. High competition can impose a limit on growth on both irrigation and urban development in these areas unless there is better management of the local groundwater resources. In addition to this, many of these locations are surrounded by high industrial polluting units, which degrade the quality of groundwater apart from existing contaminants. In the context of possible interbasin transfer of waters, these high-groundwater starved urban centers would claim their strong candidature on the arriving water. There is a potential question of allocation of imported surface water between the highly groundwater exploited agricultural areas and developing urban centers. This aspect of urban dependence on groundwater and increasing need for further water is an important aspect to be kept in mind before developing water management at the basin level.

Groundwater Quality and Degree of Development

Groundwater quality can easily be deteriorated by industrial effluents, urban wastewater, overuse of pesticides by irrigators, and seawater intrusion either directly from casual disposal or indirectly as seepage from treatment lagoons or infiltration from surface watercourses or canals. Another potential water quality threat is sedimentary formation, from which water is tapped, which varies over a wide range depending on adjacent rock types and mineral compositions of rocks. Often overexploitation of groundwater magnifies inherent salts i.e., TDS, fluorides and chlorides. Such factors greatly influence groundwater use. For example, in many cities/towns of north, central and south Gujarat (due to inherent salinity) and coastal Saurashtra (due to seawater intrusion and also inherent salinity) many households have installed water treatment plants at individual or community level for drinking water use. For those who cannot afford/manage to install have negative health impacts. (Indu, Sunderrajan and Shah 2006).

Importance of Wastewater and Storm Water in Urban Areas

According to the World Bank 1998, out of the new water any water supply project introduced in the urban areas, around 90 % subsequently becomes wastewater, which must be collected, treated and disposed of in an environmentally sound manner. It has become apparent that common wastewater handling and reuse practices (which are frequently uncontrolled and unplanned) generate high rates of infiltration to underlying aquifers, especially in sandy alluvium. Thus, for smaller towns, where reliance on groundwater is higher, incidental infiltration of wastewater often gives volumetrically the most significant quantities for local 'reuse' which is rarely planned and may not even be recognized (Foster et al. 2006). You can potentially improve wastewater quality and store it for future use or else it can also pollute aquifers used for potable water supply. For example, cities' subsurface with sandy alluvium (Gujarat, Rajasthan, Haryana, Punjab etc.,) where the water table is very deep, on-site sewerage (dry-toilet, composting toilet, cesspool, septic tank and subsurface infiltration, soak pits/wells/ponds, treatment/recharge lagoons etc.,) or sewerage pipes with perforation can be a good option for (a) groundwater recharge and (b) reducing the cost of wastewater disposal and treatment, for example, Kolkata wetland management (KMC). On the contrary, cities in alluvium of Gangetic Basin i.e., UP, Bihar, West Bengal etc., with very shallow water levels should have good a sewerage system with ideally no leakage to avoid any GW contamination. Hence, a better sewerage system is a prerequisite for the sustainable use of GW in the cities of these regions. For cities with lined sewerage network, properly treated urban wastewater can be reused for irrigation and/or by industries as well, as it can become a very good source for aquifer recharge. Hence, wastewater, could then serve as a 'new' source of water (Biswas 2006).

Similarly, storm water drainage arrangement in conjunction with the ground conditions and rainfall regime provides a good source of recharge. Where the subsoil infiltration capacity is adequate, the ground is the most economical receptor for urban runoff, thereby avoiding the need for costly surface drainage measures (World Bank 1998a).

This area has major implications in terms of future approaches to groundwater and wastewater management in many rapidly-developing urban centers (World Bank 2003). Provision of urban water supply, even if it becomes universal by 2015 as per the Millennium Development Goals, will not be sustainable by itself unless adequate arrangements are made for wastewater collection, treatment and disposal (Biswas 2006).

Urbanization and Water Management

Urbanization in India

It should also be noted that, it is not only that urbanization is taking place in great magnitude in class-I cities[4], but, the urban centers are also increasing in terms of absolute numbers. Strategically for the water sector, these towns are important for the investment point of view. Most of the class-I and class-II cities face day-to-day problems of financial crunch, low returns on investments, inadequate operating and maintenance expertise and poor civic and infrastructure facilities. Such urban authorities also need reform (World Bank 1998b). Per capita water demand for class-I cities increases dramatically by almost 1.5 times compared with other smaller class cities from 150 LPCD to 220 LPCD (NCIWRD 1999).

Urban Agglomeration

Another important stand-out in urbanization is the increasing trend of 'megalopolis' or 'sub-urbanism'. The cities tend to sprawl. The second cadres of the cities are coming up around the mega-cities. The reason is high prices in the urban core and traditional suburbs drive people to distant suburbs. This pattern owes largely to the preference of middle and the working classes for privacy and space, while elites crave for better living environment which encourages urban sprawl. For corporates, it is taxes that force to keep their godowns and other commercial activities outside municipal limits. In fact, the new sub-urbanism seeks not to fight market forces, but to address the problems. These are not mere bedroom communities with malls, but boast well-developed business parks, town centers and in many cases notably, large amount of well-preserved or developed natural open spaces. Majority of these sprawls are now turning into 'garden cities'. For instance, around Delhi there are peripheral cities emerging to solve all the requirements of the big cities. One key that becomes crucial in this regard is the excellent transportation, which is also argued by Faroohar 2006. Burgeoning IT hubs outside Delhi like Gurgaon, Noida and Gaziabad serve as new bedroom communities and all sit on good roads into the capital. More examples are Virar, Vashi (Navi Mumbai), Pune for Mumbai, Bopal, Vejalpur, Science city for Ahmedabad. Most of these peripheral or second cities depend heavily on groundwater. These cities are normally not covered under municipal corporations, especially for the provision of water supply and sewerage infrastructure. That is why it is very important that these second cities or urban agglomerations need to be covered under urban water supply schemes. Recent amendment in Jawaharlal Nehru National Urban Renewal Mission (GOI 2006) for inclusion of city's peri-urban areas, out growths and urban corridors and other peripheral areas is a step towards addressing the issue.

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[4] Proportion of total urban population of class-1 has increased from 22 % % in 1901 to 60 % % in 2001 (*Source:* Registrar General and Census Commissioner 1993; Indiastat.com 2006; Mahemood and Kundu 2005).

Linkage Between Urbanization, Infrastructure Development, Tourism and Water

With the increase in urbanization and with better infrastructure facilities i.e., roads, electricity, communication etc., tourism activities shoot up. New trend of buying properties for the vacations and holidays in near by hill-stations, lake side etc., is emerging among urban elites. For, example, domestic tourists from Delhi visiting Mussourie, Shimla, Haridwar increase during weekends; Similarly mountains Abu and Udaipur for Ahmedabad; Lonawala, Khandala for Mumbai and Pune elites. Such tourist destinations are increasing in number. Many of such tourist towns are witnessing unexpected growth and unable to cope with water demand from their local water resources. Often tourist destinations are located in geographically adverse conditions. In spite of that, such towns can become black-holes to attract water from distant sources.

Future Work and Conclusion

Methodology for Vulnerability Analysis

What we have presented in this paper is the current status and potential threat of groundwater use in urban centers of India and our conceptual picture of how different geographical factors contribute to vulnerability in terms of urban groundwater. In this section, we outline a proposed procedure to evaluate this vulnerability based on various factors. This methodology utilizes data that is mostly available, but some need to be generated as well. The important factors are: (a) level of current dependence on groundwater for overall urban water use; (b) level of groundwater development in surrounding block/district; (c) average distance to external sources of water; (d) level of development of river basin; and (e) hydrogeological factors e.g., specific yield. A combination of these factors will enable us to identify the current hotspots and future attractors of excess or imported water in any river basin. Some examples follow:

1. Bharuch is a class-I city in Gujarat which uses 90 % of surface water since the local groundwater is overexploited and contains a high concentration of saline. In the surrounding districts groundwater development is around 50 % (source: 2004 Groundwater statistics of CGWB), but it lies within Narmada and Mahi river basins which still have water available for supply to the city. In that case, the city is not under further high stress as far as groundwater vulnerability is concerned.

2. Ludhiana is a metropolitan city in Punjab, which completely relies on groundwater sources. The district level groundwater development is 144 % and it lies within the Indus River basin that is almost closed and highly exploited. The groundwater in this city is highly vulnerable to further exploitation and is already suffering from severe pollution from industries.

3. Barielly is a class-I city in Uttar Pradesh, which receives 100 % of its supplies from groundwater. The district level groundwater development is 86 % and it lies within the Ganges Basin. In this case, even though there is a high dependence on groundwater and high degree of groundwater development, perpetual recharge from

canal system that contributes 40 % of the groundwater recharge in this area (source: 2004 Groundwater Statistics of CGWB), means that there is no current high vulnerability of groundwater exploitation in this town.

On a macro-scale we conclude that the level of dependence on groundwater is greater for smaller sized towns, which have lesser power to demand and have lesser economic strength to pay for water sources that are located at distant places. Though, smaller towns with all the adverse conditions would eventually win over other uses for urban water supply. Rajasthan's Indira Gandhi Nahar (IGNP) Canal is a case in point. The proportion of drinking water has increased over time and will continue so. Gradually all the cities, towns as well as villages in northern and western Rajasthan are being covered by IGNP water. We also see a marked difference spatially in dependence on groundwater with the northern urban areas, which are located on rich alluvial aquifers and get good recharge from canals, highly dependant on local groundwater for their overall water usage. On the other hand, peninsular towns in hard-rock regions have lesser opportunity to develop groundwater resources. To sustain the growth they have to depend on external sources. In case of nonavailability of such external sources of water, this can impose a limit to overall growth of the urban areas. Integration of all the factors such as hydrogeological, within or outside canal command area, rainfall and recharge, population size, proximity to water bodies, urban out-growths, and utilization of wastewater would help planners in designing better and sustainable urban water supply and sanitation systems.

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