Anthropology of changing paradigms of urban water systems

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Abstract

The dynamic interaction between society and nature is influenced by the prevailing normative, cognitive, and regulative societal systems, which guide the relationships between society and nature or ecology. Therefore, mature cities with increasinglycomplex urban interactions must shift from the simple agenda of demand-supply to multi-criterion modelsthat takes into account factors like impacts of climate change, variation in settlement patterns, humanvulnerability, and resource optimization to balance the society–ecology relationship. However, rapidly growing megacities have failed to balance their development andassociatedsocietal goals. This paper presentsan assessment of the paradigm shift in the relationship between people and water as a resource, or thehydro-social construct,along a temporal gradient from about AD 1206 to the present for an ancient Asian city, namely Delhi. The city struggles at present with many challenges, including demographic fluctuations, increasing geographic spread, economic restructuring, changes in landuse and settlement patterns, and, most relevant here,the transition from a water-sensitive city to a water-scarce city. The study identifies the causes of shifts in the water–society relationships and areas of interventions,that takes into account the physical, economic, and social characteristics of the city's water resource to ensure that water, a basic human need, must be accessible to all inhabitants of the city.

Keywords: Hydro-Social Construct; UrbanWater; Society; Sustainability; Governance

Introduction

The relationship between society and nature is dynamic and is directed not only by the balance between natural resource endowment and their demand but is also governed by drivers asthe societal systems with their three pillars, namelythe normative, cognitive, and regulative systems (Brown et al. 2009). Cities are centres of major developmental activities and therefore subject to continual socio-economic restructuring; at the same time, cities strive to optimize their resources and to provide utility services to their inhabitants sustainably (Weisz 2011). Therefore, the current understanding of theassociation between people and nature needs to incorporate a contemporary angle to the classical module of sustainability to balance a city's growth withits societal goals (Andries et al. 2004), andthe transformations of the city's physical, institutional, and governance structures are prime towards the balance (Brown et al. 2009).

The present study assesses the paradigm shift in the relationships between people and water as a resource, or thehydro-social construct,along a temporal gradient from about AD 1206 to the present for an ancient Asian city, namely Delhi.Such a study can help to understand the changes in the society–water relationship for other cities as well.Hydro-social constructs have been studied forseveral cities (Kim et al. 2001; Onodera et al. 2008; Weisz 2011; Mehta et al. 2013).However, this paper traces the evolution of the society–water relationship with its drivers and its impact on the city's growth. Initially, water was the only factor that governed Delhi's socio-economic development; later on, socio-cultural and economic changes became the governing factors for the city's hydrological profile (Hardiman 2002; Mann 2007). This pattern of evolution, in which water and its management playeda key role in the city's socio-cultural changes, make Delhiparticularly suitable to study the interaction between society and water. Historically, the water management systems have been reformed from a distinctly decentralized, community-driven, and state-patronized system to a completely state-managed public system. Information on the water management in the past was collected from the archives of the Delhi government and through interactions with key informants, andinformation on the present-day urban water system was obtained by interviewing officials of water utility agencies and from documents published by the state and central governments in India.

The new institutionalism (Hall and Taylor 1996) was used as an analytical approach to understand the evolving urban hydro-social construct becausethe institutionalism focuses on developing a sociological view of institutions to comprehend the way a hydro-social system interacts and affects society. These institutions comprise three mutually reinforcing pillars: (1) cognitive: dominant knowledge, thinking, and skills; (2) normative: values and leadership; and (3) regulative: administration, rules, and systems.These three pillars together shapethe patterns of practice. Moreover, the new institutionalism provides insights into institutions outside of the traditional views of economics by explaining why and how institutions emerge in a certain way within a given context and, if they change, the pattern of that change or transition. Besides, the ‘cumulative socio-political drivers’ of the transition must reflect shifts in the normative and regulative dimensions and include the impact of‘service delivery functions’ (Brown et al. 2009) on the cognitive dimension of the hydro-social construct. However, for institutions to remain stable or to be able to withstand changes, a mutually reinforcing shift is mandatory within each pillar.

Accordingly, the present paper presents the shifts in the *pattern* and in the *institutions* related to water management over time to contribute to the present-day debate on urban hydro-social constructs. The debate, which revolves round a question, namely ‘How did the water–society relationship in Delhi change from the pre-Colonial to the post-Colonial period?’, is to be seen in the light of many other suppositions, including the following: 1) water is a finite resource without substitutes (MoEF 2010); 2) the horizontal urban growth of Delhi (Ghosh andKansal 2014) pushes human settlements away from the natural sources of surface water (Sohail et al. 2013); 3) water demands of an urban area, in most cases, outstrip its renewable stocks (MoEF 2010; CGWB 2013); and 4) high population density and economic restructuring of the city (Bhagat 2011; Census of India 2011) have a tendency to alter the character of the water from ‘blue’ to ‘grey’, endangering the environment.

Delhi and its water resources: current status

Delhi, also known as the National Capital Territory of Delhi (NCTD), extends from 28°24′17″ N to 28°53′00″N and from 76°50′24″ E to 77°20′37″ E and is spread over 1483 km² (GNCTD 2015). In 2011,Delhi had a population of more than 16.78 million (Bhagat 2011). The territory has nine districts and shares its borders with six states, namely Himachal Pradesh, Haryana, Punjab, Uttar Pradesh, Uttarakhand, and Rajasthan (Sohail et al. 2013).

Historically, Delhi’s urban growth has been horizontal, starting from the walled city during the pre-Colonial period and expanding in concentric circles, engulfing the smaller surrounding villages, and merging with New Delhi (Hardiman 2002; Mann 2007; GNCTD 2015). The concentric growth of the city is the result of its two ring roads. The inner ring road was developed following the first master plan for Delhi and the outer ring road, which girdles the city, was developed following the second master plandrawn up by theDelhi Development Authority (DDA 2010). Thus, the urban form of Delhi has been largely influenced by the planning process(DDA 2010). The territory is part of the Yamuna floodplain and lies at the foot of the Aravali hills. Geographically, Delhi is a conurbation (Fig. 1) surrounded by its satellite towns (Faridabad, Ghaziabad, Gurgaon, andNoida), which are under different political administrations and share the region's natural resources with Delhi (GNCTD 2015).

Delhi receives water from three main sources: surface water, groundwater, and rainwater. Major sources of surface water in Delhi are Yamuna, Bhakra, and Ganga reservoirs(GNCTD 2010; Sharma and Kansal 2011). Apart from Yamuna, the main river in the city, water is supplied to Delhi through different interstate arrangements, andthe sources also include such subsurface sources as Ranney wells (RW) and tube wells (TW) (CGWB 2013; Ghosh et al. 2016). The net annual availability of groundwater in the NCTD is 0.29 billion cubic meters (BCM), the annual estimated extraction is 0.39 BCM, and the stage of development is 137% (CGWB 2013). However, annual groundwater draft for all the purposes to net annual availability in different zones of Delhi shows a significant decline except in a few areas (Table 1). The annual rate of decline is as high as 1.7–2 m in some areas (South and South-West districts) (Shekhar et al. 2006) with the depth varying from 6 m (floodplains) to 60 m (the southern ridge) (GNCTD 2010).

Figure 1

Table 1

Figure 1 shows changes in land use in Delhi over the past four decades(1973–2013). Similar to the pattern of urbanization experienced by other emerging economies, Delhi too has witnessed a tremendous increase in built-up area and a commensurate decrease in farmland. Although the extent of Delhi's forested area (which comes under the jurisdiction of the state administration and the defence services) has remained unchanged, natural vegetation has increased considerably, which includes parks in residential and institutional areas, roadside greenery, and other recreational areas. A reduction in fallow land and wasteland shows that land is increasingly used for settlements and recreation at the cost of farming: today, farmland in Delhi is only about 50% of that in 1973. Figure 1 also shows a marginal decrease in the area occupied by water bodies. However, many of the water bodies today comprise pools of untreated sewage resulting from lack of adequate drainage and sewerage systems (Sharma and Kansal 2011). This pattern of growth has implications for groundwater recharge and urban flooding.

Water transition in Delhi: a historical account

Delhi's history as it relates to water can be divided into three periods: 1) Pre-Colonial, which itself can be divided further into three sub-periods (Pre-Sultanate, Sultanate, and Mughal), 2) Colonial (during the British rule in India), and 3) Post-Colonial (Spear et al. 1994; Cherian 2004). During the Pre-Colonial period, the pattern was mostly decentralized, with groundwater and water-harvesting structures such as*hauz*es (lakes),*baoli*s (stepwells), and*nahar*s (streams). From the Colonial era and particularly after 1857, water as a resource began to be centralized in administrative terms to meet the health and hygiene concerns of the ruling elite. The old structures were either dismantled or abandoned during this period. The post-Colonial period begins after India gained independence, in 1947. This period can be further divided into three, namely 1947–1956, 1957–1991, and 1992–2015, based on major shifts in the administrative structure of Delhi (Delhi Municipal Corporation (DMC) Act, 1957). Despite all the differences in methods and structures of water management, the role of power relations was vital in the society–water relationship.

Until the beginning of the 19th century, the river Yamuna was never a major source of water for Delhi's population, which depended mainly on groundwater and stored water (Cherian 2004). It was only after the introduction of piped water supply that the Yamuna became a major source of water. The tree-covered ridge, the alluvial plain, and the bed of the river Yamuna have played a major role in making Delhi a very habitable location (Fig. 2). The drainage basin of the Delhi region was formed by many small streams. However, the river Yamuna, shifting eastwards, was one of the deciding factorsthat changed the settlement pattern in the region. The city at present is a water-deficit region: small streams and lakes have disappeared, and water storage structures are scarce or missing altogether. The river Yamuna, after crossing the city's boundary, runs dry for nearly eight months in a year (MoUD 2012); a significant percentage of water supply comes from a source a few hundred kilometres away, and groundwater development is 137% (CGWB 2013), which is critical and significantly constrained for access to water resources.

Figure 2

Pre-Sultanate Period (before AD 1206)

Hauz Rani, Lal Kottal [*tal* is Hindi for a lake], Anangtal, and Mahipalpur dam are the prime water storage structures attributed to the pre-Sultanate period. Large lakes such asSurajkund [*kund* is Hindi for a pond] and Anangtal are fine examples of water harvesting from this period. Smaller streams of the river Yamuna were tapped to feed these large lakes. The supply was augmented by wells, which collected run-off during the rainy season and recharged the groundwater through wetland seepage and percolation through fissures in rocks (Agarwal and Narain 1997). The complex geology and subterranean flows also allowed a hierarchy of wells (Spear et al. 1994; Cherian 2004).

Sultanate Period (1206–1526)

Several cities were built in the region of the Aravali hills with a wide variety of water-harvesting systems during the Sultanate period. Large tanks such as Hauz-i-Sultani and a network of stepwells including Gandhakkibaoli, Rajaonkibaoli, and Hauz-i-Shamsi are examples of water structures from this period (Spear et al. 1994). All new forts and the capital city itself were constructed in coordination with the eastward-flowing river Yamuna and its underground streams. Storage structures near the river were filled by underground movement of water and those at a distance were filled by run-off that recharged groundwater during the monsoon (Shah, 2009; Bottrall, 1992). The *baoli*s were non-spiritual structures constructed mainly for the public, irrespective of religion, for access to safe water for all. Silting of one tank or well had no effect on the structures elsewhere, a feature of the decentralized nature of the water system. The *baoli*s were maintained by the locals, and larger structures such as lakes, tanks, and bunds were under the jurisdiction and the responsibility of the central authority, namelythe ruling king (Cherian 2004).

Mughal Period (1527–1540; 1555–1857)

Water management during the Mughal period relied on the existing *baoli*s and wells. However, improvements in these structures and technological standardization made Delhi rich in hydrologic terms (Habib 1982). The embankment along the river Yamuna, arresting its shift, and a network of canals through the city are the most important contributions of the Mughal period (Bottrall 1992;Shah 2009). Band-i-Akbari and Band-i-Shahjehani are examples of bunds that continue to save Delhi from flooding even now. The Hisar–Firuza canal, built earlier, was repaired and became a permanent structure in the city ofShahjahanabad (the walled city of Old Delhi, which was the capital of the Mughal empire until the British took over the country) and was referred to as Nahar-i-Faiz or Nahar-i-Behist. In the main city, the canal recharged the *dighi*s (square or circular reservoirs) and wells, and the job of *kahar*s (palanquin bearers and appointed especially to draw water) was to draw water from the *dighi*s. Most houses had their own wells and *dighi*s, which served as a stand-by if water supply to the city through the canal failed. In 1843, Shahjahanabad had 607 wells, of which 52 provided particularly sweet water.

Hydro-social construct and urban water transition for Pre-Colonial period

Attributes

NormativeDuring the pre-Colonial period, water was considered a social service, andthere is little evidence that power relations influenced access to water. Water structures were part of the community life.

Cognitive The local masonry and hydraulic skills of the Sultanate and Mughal periods formed the cognitive basis of water management in these times. This amalgamation brought standardization in old practices and improvements in structures.

Regulative The management of water was decentralized. Cleaning and maintenance werecarried out through public participation:only the large structures were under the control of the central authority.

Hydro-social construct

The hydro-social constructs during the pre-Sultanate, Sultanate, and Mughal periods were influenced by the natural constraints of the landscape and waterscape of those times. Places for settlements were chosen with due consideration to the availability of water and of an affordable technology to tap that water. The dependence on storm water and wells ensured that water was availablenot only during the rainy season but also round the year. Thus, there is no evidence to show that water was used by the rulers to exercise their authority or that there was any biophysical scarcity of water.

Colonial period (1857–1947)

The state in the British era sought total ownership of water resources and established a centralized system to control water supply. The existing structures were considered primitive and were dismantled, and a distinct proprietary element was introduced(Bottrall 1992). Water was taxed at all levels, and charges for water were made a part of the land-tax system (Hardiman 2002). The elite and the well-to-do, mostly the British and few rich Indian landlords, were the only beneficiaries of this system of financing new water infrastructure (Willcocks 1984), consisting of an electrically powered and pumped water system, to supply water to the public. As the population kept increasing and driven by health concerns, the British ruling India at that time lived mostly in civil lines and cantonment areas, and the planning of sanitation systems serving these areas was separated from the rest. In 1931, the newly established capital city of British India, called New Delhi, was formally inaugurated and thereafter, all municipal works remained focused on this part of Delhi; the 'old' Delhi was neglected totally (Mann 2007). Table 2 provides details of the water works undertaken during this period. The villages surrounding Delhi,which are now part of modern Delhi as urban villages (Sohail et al. 2013), had *johad*s (village ponds) as a source of water for the commoners; these ponds were an integral part of the communal life and were regularly cleaned and maintained by the vicinal community (Sengupta 1985).

Table 2

Hydro-social construct and urban water transition for Colonial period

Attributes

NormativeThe ruling elite, who believedthatadvanced technology was invariably superior and that they knew more about providing public services, discarded the old decentralized methods of water management and thus destroyed the surrounding communal life. The normative sense of the Britishelite favoured centralized water systems with focus on central management and vigilance for better sanitation, hygiene, and health.

Cognitive The Colonial period saw advances in testing chemical parameters of water, long-distance pumping of water through electric pumps, and recognition of waterborne diseases.

Regulative The authorities wereunidimensional in perception and hence regulation of water created a new privileged class of those who could afford to pay taxes. This excluded a large section of the population living outside the city boundaries. Thus, the sources of water supply were centralized under the ownership of British state rule.

Hydro-social construct

The Colonial period marks the advent of anthropogenic changes in hydrology to suit human settlement. Delhi saw a strong centralized control over water resources, wherein water was supplied based on political considerations and to those who could afford to pay taxes (Hardiman 2002). This period saw a paradigm shift in the hydro-social construct and a total disconnect with the previous arrangements (Mann 2007). The hydro-social construct during the Colonial period promised water supply and hygiene to the British and the local elite through a centralized public water supply and distribution system. Community institutions were pulled down, thereby excluding the larger population, which remained confined to the old and densely populated settlements.Moreover, the British taxation system changed the approach of water provisioning from a ‘social service’ to a ‘get as you pay’ service, dividing the society into the privileged, who had access to piped water, and the non-privileged, who did not.

Post-Colonial period (1947–1956, 1957–1991, and 1992–2015)

The DMC Act, 1957, and The Constitution (69th Amendment) Act, 1991, were the turning points in modern Delhi’s administrative structure. The Delhi Joint Water and Sewerage Board, constituted in 1926, was amalgamated with the DMC (DMC Act, 1957), and the corporation formed the Delhi Water Supply and Sewerage Disposal Committee. In 1991, Delhi was accorded the status of a state (with certain exceptions) and later, in 1998, water supply, drainage, and sewerage were transferred to an autonomous managing authority, namely the Delhi Jal Board (DJB) (*jal* is Hindi for water) (DJB 1998).

The post-Colonial period adopted the so-called ‘management’ of water provisioning with respect to clean drinking water to citizens and proper discharge of wastewater. Drinking water was supplied by sharing water from large dams and by exploiting groundwater, and the city’s wastewater was discharged by using natural drains, ponds, and wetlands and by discharging it into the river Yamuna—polluting these sources and destroying their ecology.These attemptsat water and wastewater management could not be sustainedin the face of rapid socio-economic changesin Delhi and their impact on water provisioning.

Even now, the ways to augment future water supplies remain unchanged and include centralized appropriation of water by building dams several kilometres away (for example, the Renuka, Kishau, and LakhwarVyasi dams). Although such eco-friendly options as recycling, controlling losses, and rainwater harvesting have been considered in recent decades, they have not been implemented on the required scale. Universal coverage of the water supply network and sewerage connections and equitable supply of water are said to be the DJB’s mission, but the results are yet to be seen.

Hydro-social construct and urban water transitionfor Post-Colonial period

Attributes

Normative After India attained independence, the main concern of people was to get clean and potable water. It is only recently that citizens have started paying attention to pollution of the river

Yamuna and drying up of other water bodies. However, the understanding of environmental limits is not widespread yet, and technology transfer is often misconstrued as the solution to all water-related challenges. Seasonal water shortages and the vulnerability of the sources of supply to political disturbances aggravate the problem. At present, a large number of people do not have access to piped supply of treated water, and the pressure to provide such access is expected to increase. Sewage connections serve less than 50% of the population—all of which point to a progressive deterioration of water bodies. Therefore, it is difficult to imagine any major shift in values until basic water services are delivered to all.

Cognitive Hydraulic engineering and urban hydrology have advanced greatly during the past three decades. Environmentalism has gathered increasing momentum with the concern for sustainable development since Bruntland Commission's report and that for climate change since the 1990s. However, urban planners in Delhi are aware of technical advancementsand such concepts as sustainable city development and have tried to incorporate them into government policies (as claimed by officials during our interactions with them, although no evidence exists to support these claims). Using information and communication technology (ICT) for managing water treatment plants and geographic information system (GIS) for mapping the flow of water through a network of pipelines are some recent developments. Water accounting and measures to check water losses and to make waterworks more energy efficient are also being implemented.

Regulative Centralized supervision has continued to manage Delhi's water resources and water as a utility during the post-Colonial period, although the control of this utility shifted from the central government to the state government in 1991. This shift has brought greater accountability into the system, and services have improved since. However, the functioning and the focus have largely remained the same. The methods of collecting water taxes and managing revenue have recently been modified and improved.

Hydro-social construct

It is noteworthy that during the post-Colonial period, Delhi has become increasingly dependent on external sources of water, some of which are even a few hundred kilometres away. This has reduced water to a mere commodity instead of being a natural resource. Catering to the water demand of the city was the sole focus of this period: the rapidly growing population and the expanding city simply did not offer anyscope to set priorities.

Changes in hydro-social constructs

The hydro-social construct and the transitions in water metabolism (Newman et al. 1999) of Delhi have variedover the years and are completely different today from what they were a few centuries ago. Identifying the factors that led to such transitions required a good understanding of water movement within the city and its associated drivers and limitations, and that understanding can be usedin developing water management schemes for a sustainable city. Although problems related to water supply have been reported earlier,the discrete and sectoral approaches that were adopted to deal with the problems could not be sustained. Therefore, the present study recommends a multi-dimensional approach for a ‘smart’ water city.

From the analysis of the paradigms of Delhi’s water management schemes in the past, it is apparent that pre-Sultanate, Sultanate, and Mughal Delhi had more attributes similar to those of a *water-sensitive city* (Brown et al. 2009). During the pre-Colonial period, Delhi was self-sufficient for water and used groundwater and stormwater sustainably. The institutions followed the participatory approach, and with the community life centred around water, communities were also responsible for the maintenance of water sources: water was neither a means for rulers to exercise their authority nor a commodity to be taxed and used as a source of revenue. Besides, the pattern of settlements was shaped by the availability of water. Water structures of those periods, so carefully and beautifully designed and constructed, demonstrate the importance of water in lives of people of those times.Nevertheless, the caste system and class biases in India were prevalent duringthe pre-Colonial period, and it cannot be denied that access to water structures was based on these axes. There was no mechanism to treat wastewater, which was directly discharged into water bodies, yet no water pollution was evident because of low population pressure (Spear 1994; Cherian 2004), and the discharge was well within the carrying capacity of the water bodies. During the Mughal period, as can be ascertained from literature (Cherian 1994), the localities surrounding water structures were homogenous and therefore without any major problems related to discrimination. The Colonial period marked major advances in waterworks construction, a change in the scale of management, and technology transfer. Thesewere useful developmentsfor the growing population and the expanding city. However, the administration of the time was inclined more towards asserting power and less towards meeting the needs of people. Thus, the old structures were dismantled, which destroyed the normative values associated with water. The regulative framework was bent to favour only a few. Thus, the advantages of this period turned into a bane. Further, in independent India, the population kept growing at an unimaginable rate both from growth within and from migration (Bhagat 2011). The technological structures and methods that were transferred to the newly independent state by the British were adopted without change and were considered the symbols of modernization and therefore strengthened accordingly. The sanitation system served only the inhabitants of civil lines and cantonments, meant for the elite and the rulers. The trend of class-based inequality towards water access and negligence of sanitation systems has continued even in independent India (Hardiman 2002). During the first fifty years of India's independence, the emphasis was more on the supply of drinking water and less on sanitation. Reasons for this are many.First, water supply itself was woefully inadequate, even below 140 to 200 litres per capita per day(lpcd)—the minimum required for a sewage system to function (BIS 2003), and underground drainage was not a priority except in a few large cities. Secondly, limited financial resources did not allow the state to do justice to the sanitation sector. Yet, proper collection, treatment, and hygienic disposal of sewage are necessary to protect drinking water from contamination. Therefore, these two sectors – water supply and sanitation – require synchronization at operational levels, which is missing in Delhi's water management schemes at present. Hence, the cognitive merits of the system overshadowed the institutional and the normative disadvantages, an oversight that has consigned Delhi to a perpetual scarcity of water.

Thus, the hydro-social construct has remained limited to merely providing water. Although in recent years, the management of sewage and drainage has received some attention, the management lacks effective inclusion of sanitation and sustainability aspects.

Conclusion

A paradigm shift in the pattern of water management in Delhi has led the city to rethink its water systems. With socio-economic changes, rising population, and changes in landuse, Delhi has changed from a water-sensitive city (Wong and Brown 2009) to a water-scarce city. According to Brown et al. (2009), cities must change their priorities for water management as they mature; from a mere demand-supply system, the cities must switch to a multi-criterion system that deploys advanced technologies and policy interventions to deal with such challenges as climate change, vulnerability, and human settlements. However, Delhi and similar megacities of the world, being clusters of several developmental activities, fail to manage their resources efficiently and thus fail to meet the demands of a mature city.

The present paper sought to answer two questions: 'Do past changes in water provisioning offerany key inputs to the present-day water debate in Delhi?'and'Can a city be made water sustainable when water is reduced to a mere commodity that money can buy?' These questions can be understood better inlight of the following challenges.

1) Finite availability of water.

2) Shift in income pattern from primary to tertiary and a population moving farther from water sources, which constrains theavailability of good qualitywater even further.

3) An exponential increase in water demand from a necessity to a luxury (water for gardening anda 24/7 supply) that stretches supply and increases wastage at the same time.

4) High population density that not only deterioratesthe quality of surface water but also threatens hitherto safe groundwater reserves, resulting in outbreaks of water-related diseases, worsening the quality of life.

All these factors disturb the balance between progressive urban developmental agendas related to water and societal goals—the crux of the debate on the sustainability of the urban hydro-social construct. The present paper identifies some factors, based on a study of the past, which need to be taken into account in strengthening the hydro-social construct in the context of large cities.

One school of thought suggests that to make Delhi a water-sensitive city, it is necessary to revisit the past practices of decentralized planning and community participation, along with modern technologies customized for Delhi. The current form of decentralized planning and public participation will therefore be different from that in the past. However, we put forward, two questions: 1) ‘Is the city of Delhi facing the side effects of flawed design and assumptions stemming fromthe commodification of water and centralized planning in the name of modernization?’ and 2) ‘Is it not really feasible – that is, are there real barriers – to adapt the old water systems to the present, or is blaming the past for the present situation only a convenient excuse for not doing so?’

Since it is evident that the city of Delhi has undergone a major transition in its hydro-social construct and that the current water management schemes are inadequate to meetthe city’s needs, the present study offers fresh insights into framing contemporary water schemes in line with the criteria for labelling a city as water-sensitive. Such schemes should consider the following four measures.

1)Control the use of water.

2) Ration water and redistributeit among competing sectoral demands taking into account spatial and temporal variations in demand.

3) Measure water as a commodity using fiscal and economic instruments.

4) Undertake predictive studies to strengthen the estimates of future changes in the ratio of water demand and water supply.

Also, water schemes for the changing water-society relationship needs support ofpolicy initiatives,such as,curbing illegal water markets, allocating subsidies and incentives fairly, promoting water conservation schemes and ensuring their proper implementation, promoting synergy among sectoral water planners, and encouraging community participation to ensurethat people use water judiciously. An even larger issue is to balance the physical, economical, and social characteristics of water and superimpose on them a constraining function that establishes access to safe water as a basic human right.

Delhi in the post-Colonial period has seen severe pollution of surface water as a result of reduced community engagement, water management being considered the responsibility of only a central authority. However, the modern pattern of urban settlement has reduced groundwater recharge that is vital to maintain a city's water stock. Moreover, schemes of water supply drawn up during theColonial timescannot cope with the rapid change in landuse, and this inability has resulted in rapid depletion of groundwater, pollution, and dependence of sources of water far away from the site of demand. Accordingly, the present study suggests that water schemes be revisited for improved water supply, water structures be revived to enhance groundwater recharge and replenish water stocks, decentralized sources be adopted for fair allocation of this precious resource, and communities be encouragedto use water efficiently.

If Delhi is to be a water-sensitive city instead of a water-scarce city, it should have its own sources of water. The city can bemade independent by reinvigorating the hydro-social construct (taking into accounts the shifts in socio-economic patterns), by a greater understanding of water mass balance (water flow pattern and stocks maintained within the city), and by adopting effective management tools (material recycling and a closed-loop economy, for example) to make Delhi a 'smart' city in terms of its use of water.

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Table 1Annual groundwater development and end uses (million cubic metres) in Delhi: 2011 (CGWB 2011)

District	Recharge	Net availability	Gross Draft			Stage of development (%)
			Irrigation	Domestic and Industrial Uses	All uses	
Central	3.84	3.45	0.51	2.40	2.92	84.45
East Delhi	12.84	1.18	8.44	12.80	21.24	178.87
New Delhi	7.97	7.17	5.53	0.95	6.49	90.40
North-East	12.55	11.35	3.28	9.69	12.99	114.36
North-West	86.31	80.23	32.81	57.33	90.15	112.36
North	15.55	13.99	1.38	8.30	9.68	69.18
South-West	97.52	91.27	64.59	63.17	127.78	139.99
West	28.11	26.52	4.73	35.77	40.51	152.73
Total	**264.69**	**235.16**	**121.27**	**190.41**	**311.76**	**—**

Table 2Water works during the Colonial period (data compiled from archival sources)

Year	Water works	Capacity (million litres per day)	Source	Technology	Population (million)
1890	Chandrawal	4.5	Wells sunk along the river		0.19
1912	-	15	River Yamuna	Settling tanks and slow sand filters	0.23
1921	Wazirabad raw water pumping station; water carried to Chandrawal	32	-	-	-
1948	Works gradually increasing	159	-	-	-

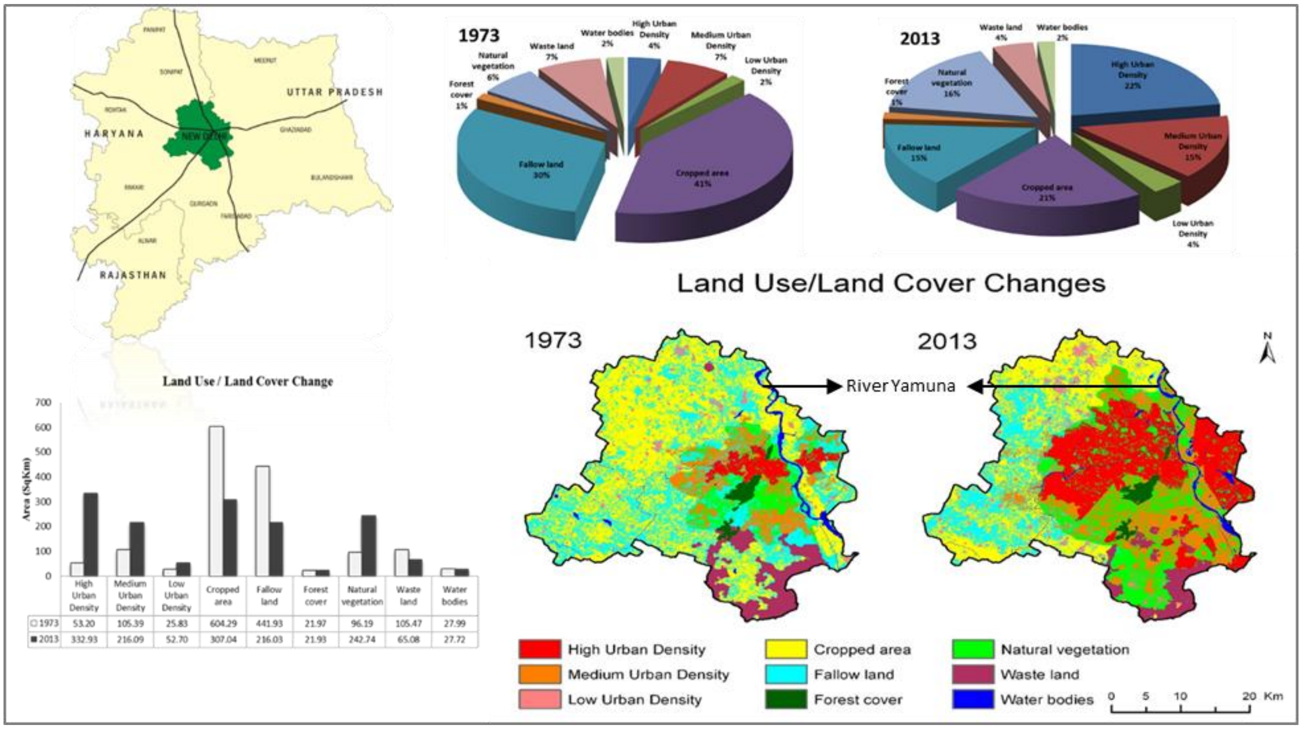

Fig.1 Land-use pattern in Delhi (1973–2013) (Source: Landsat image compilation)

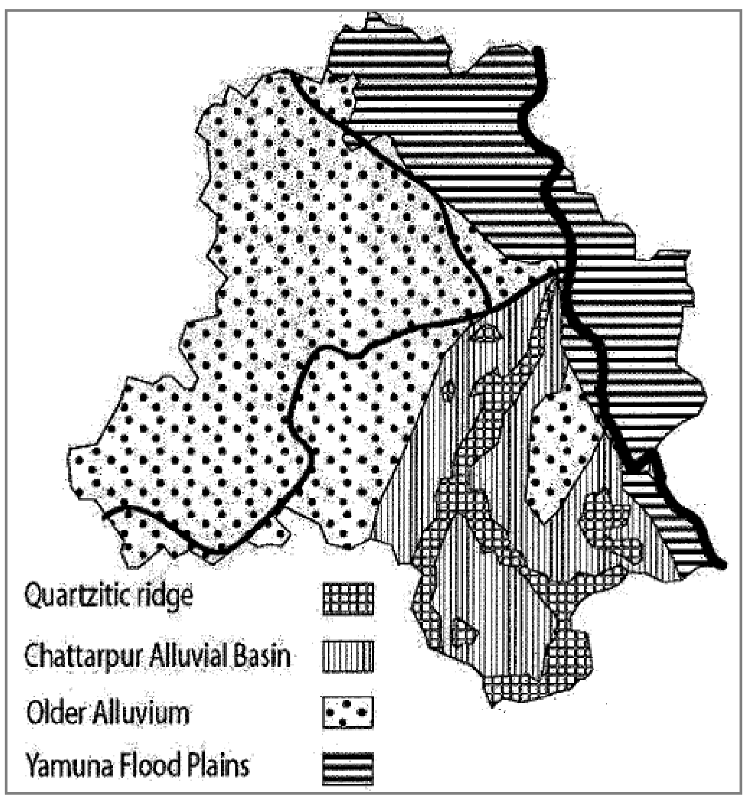

Fig. 2 Main geological formations of Delhi (Source: Maria 2008)