CHALLENGES IN OPTIMIZING URBAN WATER FOOTPRINT

THE CASE OF THE DELHI CONURBATION

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CHALLENGES IN OPTIMIZING URBAN WATER FOOTPRINT

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Abstract: The world today is experiencing an unprecedented rate of urban population growth. The trend is more dominant but not limited to developing and under-developed countries (Mulligan and Crampton, 2005). This urban shift is perhaps the longest-lasting and most significant environmental impact of the industrial revolution. Urban phenomena such as "sprawl", "endless city", "edge effect" are pushing metropolitan cities beyond their limit and transforming them into mega cities and conurbations. The urban metabolism, defined as the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy and waste (Kennedy et al, 2007) is steadily increasing with this demographic shift. Consequently, urban areas have now become hot spots that are driving global environmental change (Grimm et al, 2008).

Water is an essential pre-requisite for supporting the scale of population being witnessed by present day urban centers. The words *'aabadi'* (*Hindustani* for population) and *'aabad'* (prosper) are both derived from the same Persian word *'aab'* meaning water (Kumar, 2002). The ancient civilizations that flourished were all along the banks of great rivers and may have fallen when the adjacent rivers dried up. Hydrologic changes due to global climate change and nearly three billion additional urban dwellers will lead to large-scale water shortage in cities around the world in the coming decades. Optimization of available water and its sustainable management is therefore the need of the hour especially in rapidly urbanizing megacities like Delhi.

This paper is an inter-disciplinary attempt at studying the challenges in optimizing the urban water footprint of the Delhi conurbation. We show how the geo-political location and affluence of the NCT of Delhi is threatening the water self-sufficiency of a major portion of North India. Further, as we lay greater emphasis on the NCT of Delhi, we review the overall water crisis being faced by the National Capital Region of the world's second most populated country. We point out key factors responsible for the depletion of available water quality and quantity from a management perspective. The status of water supply in Delhi is addressed from a perspective of urban metabolism. We stress upon the fact that though clean technology exists and can be implemented, better water management practices are imperative for sustaining the NCT of Delhi. The key issues in this respect are focused upon and analyzed as challenges that are threatening Delhi's urban sustainability. We conclude with a cautionary note that if these challenges are not met at the earliest, a major part of North India could enter an irreversible state of deepening water crisis.

Keywords: urban, water footprint, water management, sustainable development, Delhi

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1. INTRODUCTION

The world population became more urban than rural on May 23, 2007 (NCSU, 2007). Towns are converting into cities and cities into megacities and conurbations as a result of this demographic shift. This is threatening the sustainability of not just the urban centers but also the rural hinterland that supports it. At the same time, world urban population is projected to grow rapidly in the coming decades. This will increase water demand due to both high concentrations of people and the different lifestyles and aspirations of city dwellers (UN Habitat, 2008). In the paper entitled 'Megacities as global risk areas', Kraas (2003) identifies ten processes that make cities vulnerable to fatalities and damage all of which are urbanisation related. Rapidly urbanizing India and China are at a greater risk and are projected to have large number of cities with seasonal water shortage in the coming decades (McDonnell et al, 2010). India's current approach to managing cities could lead to a drop in average water supply from 105 liters to only 65 liters per day or even less in the near future (MGI, 2010).

Priscoli (2000) has attempted to use lessons from history to reframe the present day water policy debates including building an ecological realism around the much talked about water wars. Water is an integral component for ensuring sustainable development of rapidly evolving urban centers especially in under-developed and developing countries. There is a strong tendency of studying global cities in developing countries with the assumption that their development is following a similar trajectory to those of the West. Shatkin (2007) argues that we need to move beyond frameworks developed with reference to the West since contemporary urban change is a negotiated process. Cities today are being reshaped and urban landscapes transformed to address economic globalization, handle intercity competition and to meet the requirements of post modernity (Gospodini, 2006). At the same time, rapidly developing urban centers have a tendency to evolve into 'conurbations' often encompassing neighbouring cities, towns and urbanising areas. As individual conurbations tend to become increasingly prominent, they lead to complex economic, social and environmental implications.

The growth of an urban center does not remain limited to the stage of conurbation and an increasing trend observed today is the creation of sprawling mega regions as clusters of closely situated simultaneously urbanizing conurbations. Urban evolution can therefore be observed in the following stages of transformation: cities to megacities to conurbations to mega regions. Regional estimates of economic activity from selected megacities and mega regions are now being analyzed for effective economic planning in the near future (Florida et al, 2008). These mega regions exert greater load on natural resources and have positive and negative impacts on local and global environment. In terms of water resource management, megacities, conurbations and mega regions are a nightmare for policy makers, planners and urban ecologists. This is especially because access to safe water service has now been enshrined as a human right in the United Nations (UN) International Covenant on Economic, Social, and Cultural Rights (UN, 2002). This has made the already debatable issue of water pricing even more complex at a time when commodification of water has become a norm.

Delhi, the capital of the world's second most populated country, is also grappling with the urbanisation challenge, especially with respect to water. From a modest town with a population of 0.4 million in 1901, Delhi's population has been constantly on the rise after it became the capital of British India in 1911. Today, hundred years later, the population of the National Capital Territory (NCT) of Delhi stands at 16.9 million (Census of India, 2011). Delhi's social environment and availability of better job opportunities attract large number of people who have been coming to settle in the capital city since India's independence in 1947 (NCR Board, 2000). The NCT of Delhi has given way to the Delhi conurbation which now includes cities and towns beyond just the capital city. Due to this, the National Capital Region (NCR) Planning Board Act was enacted by the Parliament of India in 1985. The objective of this Act was to diffuse growth from the urban center to the periphery (Mookherjee and Geyer, 2009). Despite this measure, water demand of the region has continued to rise and measures to augment supply have not been able to bridge the gap. Scarcity of water, both surface and ground water and, in terms of quantity and quality is now accepted to be a matter of grave concern (DoE, 2010).

Delhi's water demand today is also a measure of the affluence of the city. Urbanisation is slowly yet surely accompanied by an increase in per capita demand levels. An improvement in living standards and providing of urban-styled basic needs such as all time water supply and greater access to sanitation facilities adds greater pressure on the water resource. A consequent increase in commercial and industrial water demand only aggravates the water situation. Water availability in Delhi is mainly sourced from River Yamuna which is diverted through the Wazirabad barrage in the North of the city. The water availability is seasonally challenged and inadequate supply in the lean season forces various sections of the society to cope with unreliable supply (Zerah, 2000). The Government of NCT of Delhi has now begun to use the affluence as well as political influence of the

National Capital to source water from far and wide from regions upstream of River Yamuna (MPD 2021, 2007). Research suggests that the first strategy in securing water should be to ensure replenishment of the Yamuna floodplain (Soni et al, 2009). However, the concerned agencies in the Govt. of NCT of Delhi have previously allowed construction on the floodplain and consequent concretization.

The Master Plan of Delhi (MPD) 2021 projects the water demand in 2021 as 1,380 MGD @ 60 gpcd for the projected 23 million population. An over 400 MGD shortfall that is indicative is planned to be fulfilled by the construction of Renuka, Kishau and Lakhwar Vyasi Dams in the extended catchment of River Yamuna. The MPD 2021 also includes other intra-city measures such as water reclamation, prevention of wastage and theft of water and regulation of ground water development. However, only one mega event of the Commonwealth Games 2010 witnessed the sidelining of normal planning procedures for land-use changes and urban development by concerned authorities (Uppal, 2009). History of urban waterfront development provides myriad examples of the ways in which material forms of nature have been transformed by a wide range of socio-political decisions (Bunce and Densfor, 2007). Thus, it becomes necessary to point out that political ecology plays an equally important role in the Himalayan task of making cities work.

2. REVISITING URBAN SUSTAINABILITY

"The end of human race will be that it will eventually die of civilization." – Ralph Waldo Emerson

Urbanisation can be defined as a gradual transformation from traditional-rural setups to modern-industrial economies (Datta, 2006). According to the International Encyclopedia of Human Geography, "urbanisation involves a complex set of economic, demographic, social, cultural, technological, and environmental processes that result in an increase in the proportion of the population of a territory that lives in towns and cities, an increased concentration of population in the larger settlements of the territory, and an increasing density of population within urban settlements" (Knox, 2009). Urbanisation has become an integral part of economic development and is ongoing with great impetus since the advent of the industrial revolution. Areas designated as 'urban' are characterized by high density of human population and presence of large number of civic amenities. The latter usually decrease along a transect drawn from the urban center towards the periphery. The economies of scale work with large population inviting synergy which facilitates the urban growth process. It also makes cities key centers of revenue generation thus inviting an ever increasing number of people to urban centers. Consequently, managing urban growth has increased in both scope and complexity and has become one of the most important challenges of the 21st century (Cohen, 2004). It is for this reason that integrated approaches to long-term studies of urban ecological systems are now being explored (Grimm, 2000).

Cities have been the cradle of human civilization, the birth place of ideas, innovation and the creative class. Urban centers have been the drivers of economic growth especially since the industrial revolution. The global urbanisation level increased steadily throughout the twentieth century. Since 1950, the first year for which the UN provides urban data for all countries, the percentage urban population rose from 30 percent of world population to an estimated 47 percent by 2000 (UN, 2000). The world urban population crossed the 50 percent mark in 2007 (NCSU, 2007) and is projected to reach 58 percent by 2025. World over, there is a consistent phenomenon of shifting to urban regions in search of livelihood opportunities and 'unlimited' resource availability. It is for the first time in the history of civilization that so many people are living in urban clusters and how we react to it will determine the future of mankind on this planet. The city is of course an illusion for many who immigrate with hope and aspiration for a more prosperous future. Conservative estimates suggest that population of urban poor inhabiting Indian cities alone could be as large as 80 million (UNDP, 2001).

Sustainable development of a city depends on three major performance indicators, economic, social and environmental. Cities are key centers of revenue generation as they have individuals with higher income groups as their constituents. In an attempt to accelerate economic performance, the social and environmental indicators may often get overlooked especially in cities located in developing countries. This could lead to unhealthy cities which lack optimized resource use and could even risk the life of its inhabitants. Thus, management and regulation of our urban centers will be critical in securing human and environmental health in the near future. At the turn of the last century, as we entered into the new millennia, the Millennium Development Goals (MDGs) accepted by world leaders reminded us that nearly one-sixth of the world's population lacks access to safe drinking water. A similar number of people are living in slums, mostly in the developing world, and lack access to water for drinking and sanitation purposes (UN, 2010). Cities are engines of economic growth, centers of the creative class and on top of the socio-political hierarchy. In having these, large-spread out cities and conurbations

in developing countries like India can become self sufficient in terms of water resources given the political will and necessary urban ecological inputs.

Urban researchers such as Rees and Wackernagel (1996) have already noted that the key to addressing global sustainability is to introduce measures for sustaining the increasing ecological footprint (EF) of our cities. EF is a measure of the human load, which is again a function of population as well as per capita consumption. Both these factors are increasing rapidly and every urban region today depends for its existence and growth on a globally diffuse productive hinterland up to 200 times its size (Rees, 1997). While the 1990s focused on urban sustainably with the EF concept, the water footprint (WF) concept was introduced in 2002 as an analogue of the EF. Whereas EF denotes the bio-productive area (hectares) needed to sustain a population, the WF represents the freshwater volume (cubic metres per year) required (Hoekstra, 2009). Ecologists are now exploring unexploited opportunities for research in urban ecology (McDonnell and Picket, 1990), and bringing forward hitherto unknown facts, findings and ecological interactions from urban areas. Almost simultaneously, the concept of urban hydrology was put forward to deliver scientific base for realization of new goals in urban water management. The goals of such management are not limited to the local environment but also encompass global environment and sustainable resource management (Niemczynowicz, 1999). Urban hydrology can be defined as a special case of hydrology applied for areas with very high level of human interference with natural processes.

The urban water scenario is governed by both natural and anthropogenic forces (Fig. 1) that need to be understood before we can initiate long term urban management and planning from a sustainability perspective. Global warming, due to the enhanced greenhouse effect is likely to have significant effects on the hydrological cycle (Arnell, 1999). Rainfall unpredictability owing to disrupted weather patterns today and in the near future will make it difficult for us to model the availability of water in rivers and other water bodies. Such a situation will make urban water management even more challenging. This is true even when cities have made attempts to secure more water than the global water cycle allocates to them. The natural flow of water is augmented by political flow through the means of big dams, river diversions and even purchasing and mobilization of stored water (Johnson et al, 2004) Urban population growth and modern amenities is increasing water demand as well as inter-sectoral competition for water. Managing urban water resources sustainably and through pricing mechanism has remained a big challenge till date. This is largely because using price policies requires significant government intervention so that equity and public goods issues are adequately covered (Rogers et al, 2002).

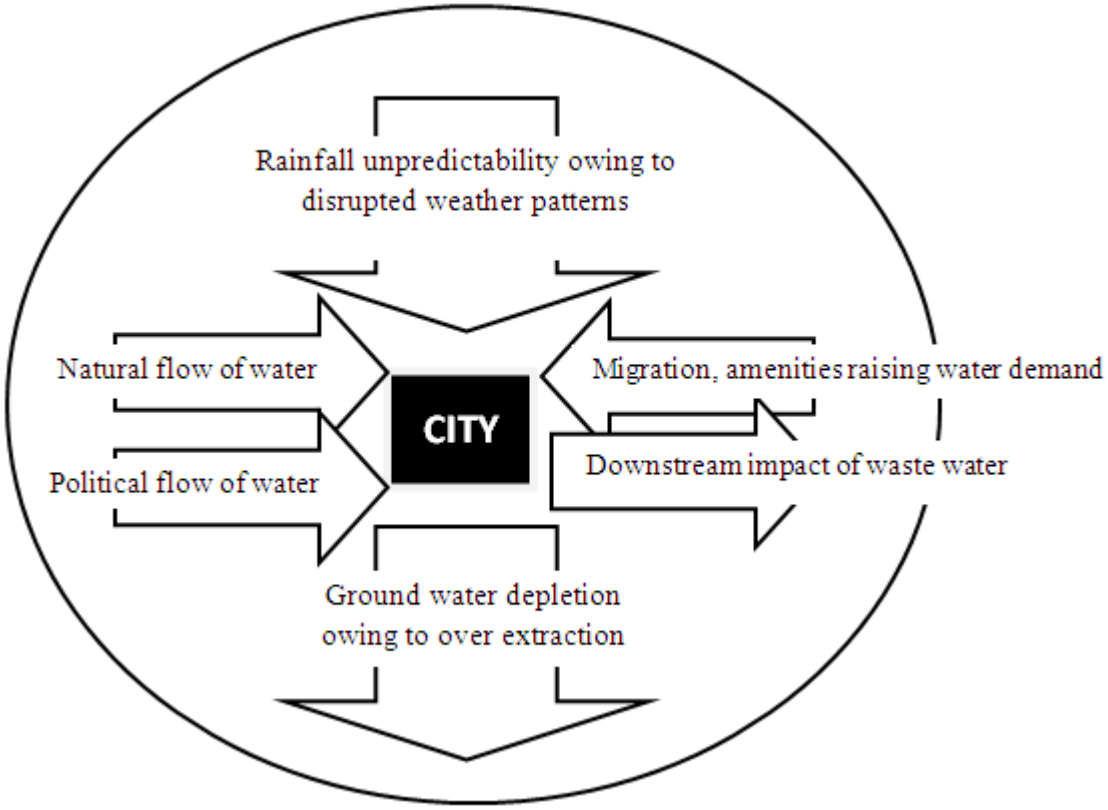


Figure 1. Natural and anthropogenic implications in the urban water cycle.

The unavailability of adequate water for potable and other uses is often responded by developing coping strategies by urban dwellers, rich and poor. Storing water when available is the most preferred of these strategies. The second most preferred is pumping out ground water using hand pumps and tube wells (Zerah, 2000). As a consequence, indiscriminate and unmonitored ground water withdrawal has led to a rapid fall in water table across the city (Maria, 2006). This is especially because almost the entire flow of River Yamuna is diverted shortly after it enters the city from the North-west district. The remaining 22 km stretch of the river in the city carries sewage which flows into it from Najafgarh and scores of other drains which form a part of the catchment for the 'Delhi stretch' of the river (CPCB, 2000). A key concern faced in urban planning today is of waste water management. Megacities which are located along rivers have significant downstream impact as is the case with Delhi and River Yamuna. The downstream impacts will only increase in the near future since cities are growing in size and number. A larger population and sprawling towns and cities along rivers reduces the inherent natural capacity of rivers to reclaim the flowing water quality. Thus, understanding the natural and anthropogenic implications of urban water cycle are critical in the effective management of the present and future urban water scenarios.

The World Commission on Environment and Development spelled out the definition of sustainable development as development which meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987). Pickett et al (2011) reviewed a decade of progress and scientific foundations of urban ecological systems in both patches within urban complexes and conurbation to conclude that ecological function still persists in these man-made settings. City planning should therefore focus on optimizing existing natural resources rather than negotiating and purchasing water from upstream or relying extensively on water down below the ground. The challenge is to develop an interdisciplinary approach which can bring together various skill sets in the mighty task of making cities work (Mcintyre et al, 2000).

3. DELHI: AN URBAN WATER MANAGEMENT MEGA-CHALLENGE

The NCT of Delhi is spread in an area of 1,483 sq. km, lying between latitude 28°24´17´´ to 28°53´00´´ N and longitude 76°50´24´´ to 77°20´37´´ E, of which 558.32 sq. km. is designated as rural and 924.68 sq. km. is designated as urban (Planning Department, 2008).

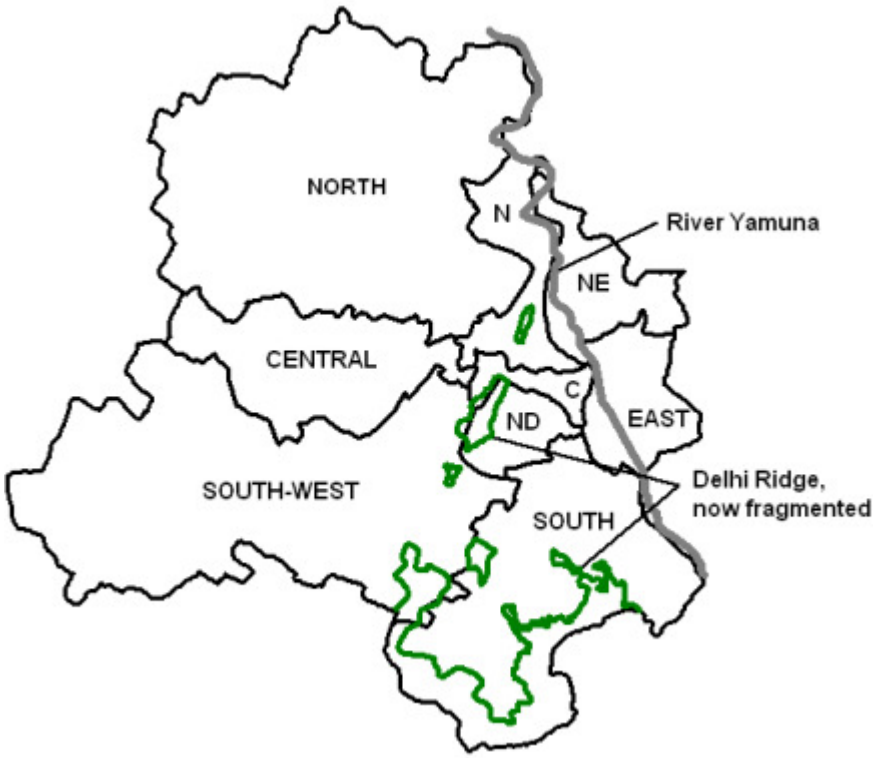


Figure 2. A district map of the NCT of Delhi showing River Yamuna and Delhi Ridge
(C: Central; ND: New Delhi; NE: North-east)

The maximum length of the NCT of Delhi is 51.9 km and the greatest width is 48.5 km. The climate of Delhi is semi-arid with high variation between summer (25 to 46°C) and winter (5 to 22°C) temperatures. The average rainfall is approximately 714 mm (28.1 inches). The convergence of Gangetic alluvial plains and Aravalli hills at Delhi gives it a mixed geological character with eastward sloping alluvial plains as well as quartzite ridges. Two natural features of the city probably made it a desirable 'capital' for various rulers of North India from time to time. These are the (Delhi) Ridge and River Yamuna and are also known as the lifelines of Delhi. The former provided natural protection while the latter a perennial source of water right at the gateway to the vast Indo-Gangetic plains. The various cities of Delhi through the ages have been cradled by these two landscape features.

According to the Census of India 2001, Delhi was the third most populated city in the country followed by Mumbai and Kolkata. However, due to the spatial advantage not available to Mumbai and Kolkata, Delhi is expanding on all sides with much pace. The population of Delhi was 13.8 million as per the 2001 Census of India report as against 9.4 million in 1991. This figure now stands at an alarming 16.6 million. At the same time, a rapid urbanisation trend has resulted in sharp increase in the density of population in Delhi. In 1901, the density of Delhi was 274 persons per square km which increased to 1,176 persons per sq. km. in 1951 and 9,294 persons per sq. km. in 2001. This figure now stands at an astonishing 11,297 persons per sq. km. with the North-east district of Delhi earning the credit of the most densely populated among all districts in the country (Census of India, 2011).

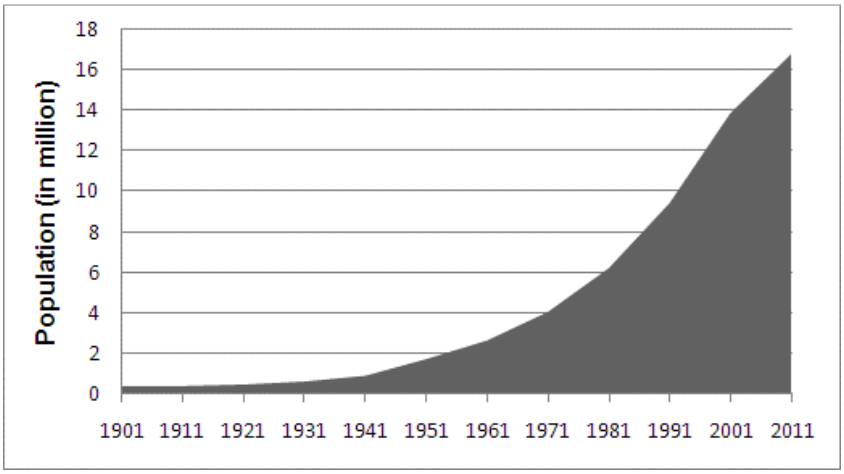


Figure 3. Decadal growth in population of Delhi, from 1901 to 2011.
(Source: Census of India, 2011)

Two prominent factors threatening global water resources and their management are established to be climate change and population pressure along with human development. Vorosmarty et al (2000) carried out an extensive study to identify the contributions of climate change, human development, and their combination to the future state of global water resources. Their work shows that impending global-scale changes in population and economic development over the next 25 years will dictate the future relation between water supply and demand to a much greater degree than will changes in mean climate. Much of the world's population growth over the next few decades will occur in urban areas which are projected to double in size to near 5 billion between by 2025 (UN, 2000). The projected increases in water scarcity will therefore be greater on rapidly expanding cities of which the NCT of Delhi is one. At the same time, detailed research on assessing water footprint of cities, including concepts of virtual water have only just begun (Velazquez, 2007; Bouwer, 2000).

The population factor is already exerting significant pressure on Delhi's water resource and has greatly increased the water demand of the city. In order to better manage the NCT, a Gazette notification in 1996 divided Delhi administratively into nine districts and twenty seven sub-divisions. Five out of these total nine districts rank among the top ten most densely populated districts in the country (Census of India, 2011). Simultaneously, the now urbanising NCT of Delhi has a greater water demand which is no longer proportional to the increasing population alone. This additional pressure does not let the city supply water services that are adequate, both quantitatively (cf. Rai, 2011) as well qualitatively (cf. Dasgupta, 2004). The most readily available decentralized coping strategy in Delhi is ground water. The over-exploitation of ground water and its decline is therefore linked with non-availability of adequate water, increase in population density and socio-economic development (Datta, 2005).

Sourcing water from the ground near to landfill sites in the city has led to severe health consequences as leachates from the landfill contaminate the ground water (Jhamnani and Singh, 2009, inputs from media reports). While policy makers discuss water pricing as a tool for its management (Boland and Whittington, 2000; Rogers, 2002), self-styled private players have come into play for fulfilling the basic requirement of water for the society at large (cf. Zerah, 1998).

Water access is the highest common factor in the pathway to urban development and going by the current trend, will pressurize the various concerned agencies in Delhi to explore all avenues of obtaining it. As the pressure of an increasing population mounts, sustaining the growth of Delhi will become an even greater challenge. Making accurate population estimates could help in adequate planning but this has not proven effective in the past. The population of Delhi in 2001 was 13.8 million as against the MPD-2001 projection of 12.8 million (MPD 2021, 2007). With the now apparent impacts of climate change across India, it is clear that urban migration in the near future will take place for more than one reason. Environmental refugees will migrate not just to protect themselves from climate vulnerable regions, but also for greener pastures (Bates, 2002). Delhi becomes a natural choice for migration due to its social and political character with a multi-regional demography pattern. The UN Millennium Development Goals (UN, 2010) and their associated targets have become central to the global development agenda. Water is critical for survival and essential for having a decent standard of living. Water is therefore a key factor for combating hunger, disease, environmental degradation, illiteracy, gender inequality and poverty. Governments across the world have committed to reduce by half the proportion of people without access to safe drinking water and basic sanitation by 2015. Water is the first natural resource that deteriorates, both in terms of quality and quantity, in the event of large scale urbanisation. While other indicators and indices may provide a theoretical approach towards understanding urban sustainability, 'access to potable water' and 'water footprint' analysis gives a practical measure of the sustainability and health of a city.

There are several indicators and indices available to carry out sustainability assessment at any level (Singh et al, 2009). Attempts have also been made at developing a holistic framework for sustainability assessment tools (Ness et al, 2007). Many of these tools can be used for assessing urban sustainability. However, the choice we make depends to a large extent on how the term 'urban sustainability' is defined. We emphasize on the use of 'ecological footprint' defined earlier in the paper, as a suitable environmental sustainability index for the NCT of Delhi. Deducing from this, a more focused analysis for urban sustainability is the 'water footprint' analysis. Water footprinting is a tools being used around the world to characterize water use and guide work towards water resource sustainability, especially in water scarce regions. Further, we believe that 'access to potable water' is an excellent sustainability indicator. It can be used for determining economic, social as well as environmental sustainability in an urban context. Water can therefore solve the dual purpose of acting both as a sustainability indicator as well as an index (WF) for carrying out sustainability assessment. The results from such studies could indeed be a 'blue alert' for the already dismal water situation in Delhi. While a comprehensive study and deduction of the WF is wanting, existing literature is sufficient to deduce that Delhi's WF needs to be optimized for ensuring a steady and sustainable availability of potable water for the city.

Water footprinting is a young and evolving science and further elaboration on it is beyond the scope of this paper. However, it may be mentioned that the WF of a nation includes the total volume of water that is used to produce the goods and services consumed by the inhabitants of the nation. Therefore, by definition, WF also includes virtual water, the water used in the production process of goods and services. Water footprint and virtual water assessment can be used for comparing the degree of sustainability and for public information. At the same time, its knowledge can help decision makers take the right decisions for making cities even more sustainable. Countries, regions or cities whose water is scarce can achieve their water security by importing water-intensive products from those countries or regions where water is abundant. A virtual water study carried out in the now parched Libya suggests that the country should import virtual water in its most economic form: food, and begin to retrain the country's existing agriculture population for alternative employment in its modern economy (Wheida and Verhoeven, 2007).

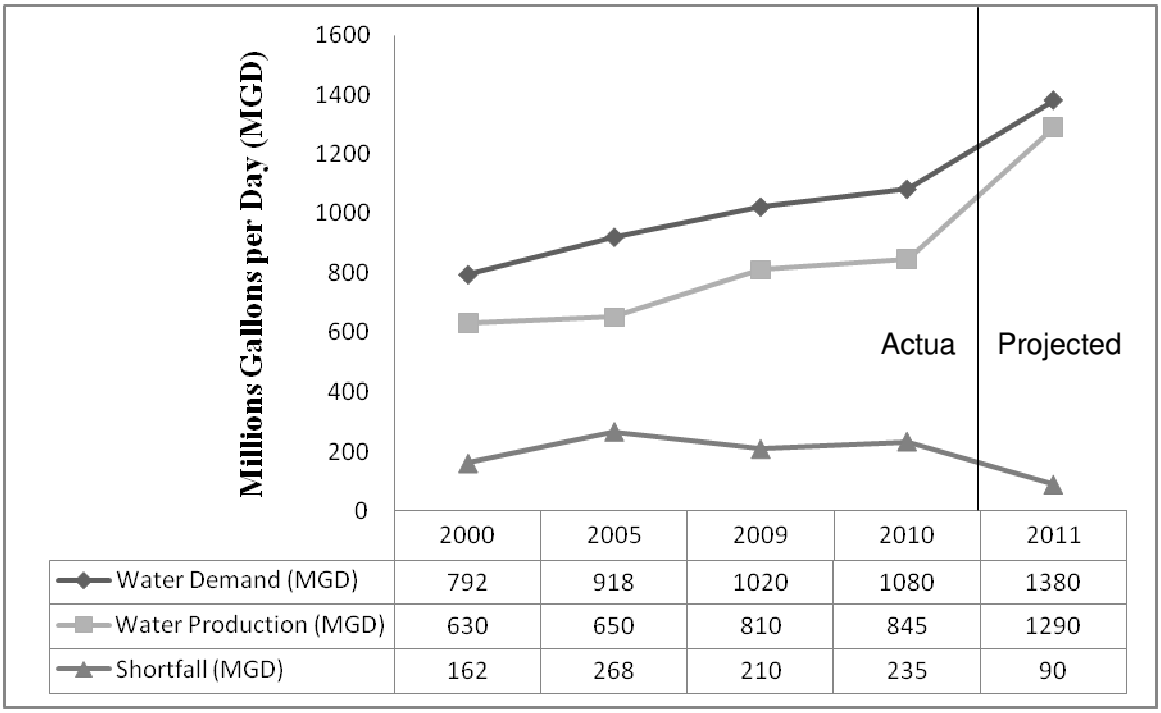
Optimization of water availability and its management is even more important in prospering cities like the NCT of Delhi where governments, municipal authorities or a good majority of people can buy their way out of the water crisis. And in being able to do so, cities like Delhi threaten not just their own ecologies but also that of the surroundings regions, towns and villages. Urgent intervention is required for sustaining the needs and demands of Delhi's urban growth today. Optimization of Delhi's water supply system could be the first effective step in this direction. This requires a thorough understanding of the challenges in optimizing Delhi's urban water footprint which are illustrated and discussed in this research contribution.

4. OPTIMIZING DELHI'S WATER FOOTPRINT: KEY CHALLENGES

The water footprint of an individual, business, city or region is defined as the total volume of freshwater required for sustaining it, in the form of water that is consumed directly and water that is used to produce the goods and services as per the demands of that particular individual, business, city or region. Optimization of Delhi's water footprint implies efficient use and allocation of this precious resource. Following are seven key challenges in the optimization of Delhi's urban water footprint. These challenges have been deduced after reviewing existing literature and carrying out formal and informal communication with various stakeholders. The challenges are a result of inter-disciplinary analysis of the water scenario in the NCT of Delhi. These are presented for policy makers, relevant government agencies and urban water researchers. The challenges are such that overcoming them would require greatest skills and intervention from a political ecology perspective within urban water management. Consequently, factors away from our immediate control such as introduction of greater unpredictability in water availability due to climate change have been kept out of this enumeration.

4.1. Deficit in drinking water supply against demand

The first and foremost challenge encountered in the optimization of Delhi's water footprint is the fact that Delhi faces a lack of availability of water. There is a deficit in drinking water supply which falls short of the total water demand of the NCT of Delhi. The Delhi Jal Board (DJB) is the principal agency of the Govt. of NCT of Delhi responsible for procurement, treatment, transportation and distribution of water to the Municipal Corporation of Delhi (MCD) areas. It also supplies bulk water to the New Delhi Municipal Council (NDMC), and Delhi Cantonment Board (DCB).



	2000	2005	2009	2010	2011
Water Demand (MGD)	792	918	1020	1080	1380
Water Production (MGD)	630	650	810	845	1290
Shortfall (MGD)	162	268	210	235	90

Figure 4. The gap between water demand and production in the NCT of Delhi. The shortfall in water supply is also shown. (Source: DJB, 2010)

The total water production in Delhi has not been able to meet the total water demand all throughout the last decade (Fig. 4). As of 2010, the water production (in MDG) figure of the DJB was 845 MGD which fell short of the water demand of Delhi by 235 MGD (DJB, 2010). The chief reason of this ever increasing water demand is steady increase in population of the NCT of Delhi (Fig. 3). The shortfall in water supply has several far reaching and long standing implications which further threaten the sustainable growth of the city. Steps that need to be taken for stabilizing the water demand are 1) checking large-scale increase in population and 2) increasing efficiency in

water distribution to save wastage of water and 3) discouraging the growth of small and large scale industrial units which have large WFs.

4.2. Nature of population and "informal" settlements

The nature of population in the NCT of Delhi varies from people living in villages to those residing in high rise residential complexes even as Delhi remains the most urbanized city across India. There is visible evidence on the variable water demand of the residents living in affluent colonies and those residing in less affluent parts of the city. The Human Development index of Delhi points out that the population living below the poverty line in Delhi has declined considerably in the past two decades (Planning Department, 2008). However, this decline fails to capture the rapid increase in migrants from other parts of the country as well as large proportion of slum-dwellers and squatters living in Delhi's 'unauthorized' colonies. The urban poor in Delhi reside in various forms of habitations ranging from unrecognized squatter settlements to resettlement colonies. The slums–JJ clusters, resettlement colonies, and notified slum in old Delhi – are directly administered by the MCD which is the responsible agency for fulfilling the water needs of this population. In addition to these, other squatter settlements are usually seen as "informal" leading to skewed distribution of water in these colonies. Due to their "informal" nature, the concerned agencies do not maintain adequate information on total population, water demand, etc. from these settlements. The doubtful nature of the existence of these "informal" settlements only aggravates the problem. Including this population in water distribution as well as providing adequate water to them needed for healthy living is a big humanitarian challenge.

According to the "Profiling informal city of Delhi" report by WaterAid (2005), informal settlements depend on community level sources for water supply. In JJ clusters and resettlement colonies, community stand posts are the main water supply sources; in unauthorized colonies, it is hand pumps and tankers, while in urban villages the main sources are piped water supply by DJB and hand pumps. The average duration of water supply in informal settlements is one to five hours a day. Since a sustainable city provides for the needs of individual inhabitants, measures should be taken to ensure all sections of the society have access to potable water. This is important from the point of view of effective water management as well. Research on water inequality in Delhi points out that on any given day, residents across the city depend on a variety of informal, and often illegal techniques and practices to access water (and sanitation) (Truelove, 2011). While some of these coping strategies could put citizens at risk (Jhamnani and Singh, 2009), others have the potential of jeopardizing the present and future water resources of the city (Datta, 2005). A key solution to this challenge is to ensure a well planned urban growth since features like slums and squatters are a result of *ad hoc* urbanisation.

4.3. Indiscriminate and private dependency on ground water resource

The ground water situation in entire North India (including Delhi) is very alarming (Rodell et al, 2009). A continued and unregulated dependence on this water resource in the NCT has degraded it qualitatively (Deb, 2009). As discussed in 4.1 and 4.2 above, the gap in water supply and demand has led to the development of coping strategies by individual households in several parts of Delhi. Storing water when available is the most preferred of these strategies. The second most preferred strategy is the pumping of ground water using hand pumps and tube wells (Zerah, 2000). The pressure on Delhi's ground water resource can therefore be well understood. At the same time, ground water quality in Delhi is being depleted with a greater number of districts reporting higher concentration of pollutants than before (CGWB and CPCB, 2000; Deb, 2009; CGWB, 2010a). This is alarming since dependency on ground water for anthropogenic uses will only increase in the near future. Its indiscriminate and unregulated use today is a threat to the sustainability of this water resource. As per a notification by the Department of Environment, Govt. of NCT of Delhi (2010), no person, group, authority, association or institution is allowed to withdraw ground water without prior permission from the concerned agency. However, this needs to be followed with a strict enforcement which is critical for the implementation of such a regulation.

4.4. Need for adequate water storage facilities and RWH

River Yamuna is the major source of fresh water for treatment and supply to the NCT of Delhi. Although Yamuna is a perennial river, the flow in the river varies significantly during the monsoon months. The river constitutes maximum flow i.e. around 80% of the total annual flow during monsoon months of July-August (CPCB, 2006). This is because of heavy rains in the catchment of the river upstream of the NCT of Delhi in these months. This "floods" the Yamuna River for a time period of about one month in the entire year. There is thus a need to store

this water in a manner that it can be used for treatment and supply during the dry season. One way of doing this could be the designating of the entire Yamuna floodplain as a recharge zone after removing of existing constructions and encroachment on it. Once recharged, the Yamuna floodplain can be later tapped for fresh water during the rest of the year (Soni et al, 2009). At present, the North-west part of the Yamuna river floodplain in the NCT of Delhi is tapped for extracting potable water (Rao, 2007).

An auxiliary method already being followed is the installation of underground reservoirs (UGR) for storing water after treatment. DJB (2010) estimates the total storage required in these UGRs to be of the order of 520 MG and the 90 functioning UGRs at present store about 365 MG of water. Strategically locating these UGRs could prove very useful in equitable supply of potable water to the NCT of Delhi. However, looking at the future water shortage, UGRs may be constructed for raw water as well. The challenge remains in finding suitable sites for prospective UGRs since land itself is a priced resource in Delhi. At the same time, as is the case with River Yamuna, Delhi receives good rainfall mainly during the monsoon months of July-August. Catching rain where it falls and storing it for later use has been promoted by various government agencies since the past two decades. A suitable method of doing this is to let rainwater recharge the ground water which can then be tapped for later use. However, urbanisation is accompanied by drastic reduction in surface area for natural infiltration of rain water into the ground thus diminishing the recharging of ground water (DJB, 2010). It is therefore necessary to incorporate artificial ground water recharge measures for recharging and augmenting the ground water resource of the city. The Ministry of Urban Affairs and Poverty Alleviation and the Central Ground Water Board have made RWH mandatory in the NCT of Delhi. However, based on direct observation on ground water withdrawal in Delhi, stricter monitoring of this regulation is needed for its effective implementation. Dissemination of information to the public on the need of RWH will also go a long way in sustaining the urban growth of the NCT of Delhi.

4.5. Lack of centralized water management authority

Under the constitutional set up in India, water is designated as a 'state' subject. In urban centers, water governance rests with urban local bodies in their areas of jurisdiction (CWC, 2011). The primary tasks of acquiring water, its treatment, supply and even that of waste water treatment in the NCT of Delhi has been assigned to the Delhi Jal Board (DJB). The vision document of the DJB states it to be constituted under the Delhi Water Board Act, 1998, and responsible for production and distribution of drinking water in Delhi. The Board is also responsible for collection, treatment and disposal of Waste water/sewage in the capital (DJB, 2010). It may be mentioned here that the NCT area consists of three municipal areas, viz. New Delhi Municipal Council (NDMC) spread over an area of 42.7 sq. km, Municipal Corporation of Delhi (MCD) spread over an area of 1,397 sq. km, and the Delhi Cantonment Board (DCB) occupying of 42.9 sq. km. of the total area. Further, there are agencies which maintain civic amenities in these different municipal areas leading to the creation of multiple water management units. For example, the construction and maintenance of drains in Delhi is jointly managed by DJB, MCD and Public Works Department (DUD, 2006).

The multiplicity of municipalities and existence of different agencies maintaining civic amenities and infrastructure in the NCT of Delhi may be a hindrance to centralized planning and management of the city's water resources. Water management requires a holistic approach which is not possible in a scenario where one part of the system is not communicating with the other. At the same time, detailed literature survey and Government documents point out that different component of urban water management in Delhi viz. need assessment, pollution monitoring, Yamuna flood water regulation, ground water depletion, ground water quality deterioration, implementation of RWH, etc. are the responsibilities of more than one agency. Consequently, a nodal agency or body is needed which is adequately empowered to 1) mediate within all existing agencies and 2) to supervise them. Further, the sole objective of such an integrated agency should be water management and its related aspects. Consequently, delegating this job to an existing federal agency in the NCT of Delhi may not serve the purpose. It is interesting to note that media reports are now suggesting the setting up of a regulatory body for water management (The Hindu, 2011) by the Govt. of NCT of Delhi. We hope this body will be constituted sooner, will have necessary executive powers and will be able to address water management from a sustainability perspective.

4.6. Issues in defining problem area: Delhi conurbation versus NCT, NCR

Historically speaking, the Delhi Ridge on one side and River Yamuna on the other gave 'Delhi' the prominence it gained as a suitable site for settlement since ancient times. Together, the ridge and the river constitute three sides of the 'Delhi Triangle' which spans over an area of 90 sq. km (Mann and Sehrawat, 2008).This Triangle

gave ‘Delhi’ a very prominent strategic, logistic and economic position in Northern India. In the present day, ‘Delhi Triangle’ includes the total geographical area of New Delhi and South districts along with parts of North, Central, East, North-east and South-west districts (Fig. 2). The area under the ‘Delhi Triangle’ remains the central focus of the NCT of Delhi even today and is the most urbanized. The NCT of Delhi in turn includes rural villages which are agrarian with vast expanse of land under cultivation. At the same time, satellite towns that have come up around the NCT of Delhi are outside the boundary of the NCT even when the latter has considerable area with potential for urbanisation. This urban growth pattern in and around the NCT is a big challenge for planning and implementation of laws and policies.

The NCR of Delhi is the outward geographical extension of the NCT of Delhi and was formed in order to diffuse growth from the urban center to the periphery (Mookherjee and Geyer, 2009). The total geographical area of the NCR is 30,242 sq. km, while that of the NCT is 1,483 sq. km. The NCR comprises eight districts of Haryana, five districts of Uttar Pradesh and one district of Rajasthan, in addition to the NCT of Delhi. The direct political authority of the Govt. of NCT of Delhi is applicable only within the NCT of Delhi. The different districts comprising the NCR are governed by the respective state governments. However, further investigation of both the NCT and the NCR bring forward interesting insights and underlying challenges in water management. A concept central to addressing this challenge is that natural resources do not remain confined to political boundaries. Thus, while political ecology may have constructive inputs in remaking urban socio-environments for more productive development (Veron, 2006), urban ecology principles are the need of the hour in order to ensure sustainable development.

What is also needed in the case of Delhi, at least from a research perspective, is the understanding of the study area in terms of water resource development. Urban growth in and around the NCT initially led to the creation and rapid growth of satellite towns like Gurgaon, Ghaziabad, NOIDA and Faridabad. In due course of time, these townships have become urban centers in themselves yet connected to the NCT in terms of flow of human and natural resource. This polycentric aggregation of urban centers has led to the formation of the Delhi conurbation. The term conurbation was first defined by Patrick Geddes in 1915 in his book Cities in Evolution, and is very relevant in studying the urban growth process and resource dependency for sustainable planning of the NCT and the NCR of Delhi today. A comprehensive understanding of the Delhi conurbation will be the first step in addressing the challenge of selecting the suitable study area for urban water management.

4.7. Long-term planning not able to push for sustainable practices today

The vision of Delhi, according to the Govt. of NCT of Delhi, is to become a highly livable city that offers a superior quality of life through a robust, employment generating economy; that is safe and inclusive, environmentally and socially sustainable; and is based on reliable infrastructure and offers a transparent, responsive system of governance dedicated to the city’s felt needs (DUD, 2006). The various Master Plans of Delhi are framed from time to time to direct the city and its various agencies towards this vision. The Master Plan of Delhi 2021 envisions making Delhi a global metropolis and a “world-class city”, where all the people would be engaged in productive work with a better quality of life, living in a sustainable environment (MPD 2021, 2007). However, in an attempt to compete with ‘world-class cities’, the 2021 vision seems to have overlooked regional impacts at least in terms of water resource management.

While the MPD 2021 does include ‘self-sufficient’ recommendations for rain water harvesting, ground water augmentation, protection of wetlands and rejuvenation of River Yamuna, it simultaneously talks of securing more water from upper stretches of River Yamuna through the construction of dams. Significant among these is the proposed construction of Renuka dam on River Giri in Himachal Pradesh. Likewise, while the MPD 2021 states that population is and will be a key challenge in sustaining the NCT of Delhi, the measures for effective growth mentioned in the Master Plan 2021 are all for planning along with this increasing population. There are no significant measures in the MPD 2021 for regulating population growth or its suitable dispersal in the NCT and NCR. This is a major challenge in the optimization of water footprint of the NCT of Delhi. A sustainability appraisal of the MPD 2021 is wanting, and will bring out all such factors that could be detrimental to the sustainable growth of the NCT.

5. CONCLUSION

Urban sustainability is a complex and desired state since cities impact and are impacted by natural systems beyond their physical and political boundaries. The NCT of Delhi is facing a sustainability crisis, especially with

respect to water management. While the threats of global climate change are said to be threatening every aspect of development today, research has shown that a more immediate crisis faced in water management is that of rapid increase in population density. Mega cities like the NCT of Delhi are facing this challenge and are struggling to optimize their water footprint. Consequently, understanding urban ecology is crucial to sustaining the growth of Delhi and in addressing the challenges in optimizing natural resource management. This is especially because interdependence between urban systems and regional and global environment does not seem to be reflected in urban decision-making in the present day.

An independent analysis of each of the seven challenges in optimizing Delhi's water footprint presented in this research contribution could go a long way in ensuring sustainable urban development of the region. Only a sustainable growth of India's national capital can lead to the fulfillment of the vision of the city as laid down by the Govt. of NCT of Delhi. The first step in this direction should necessarily be a sustainability appraisal of the Master Plan of Delhi 2021. This should be done especially with respect to the lessons learnt from previous Master Plans of 1962 and 2001. The objective of sustainable assessment is to provide decision-makers with an evaluation of global to local integrated nature–society systems in short- and long-term perspectives in order to assist them to determine which actions should or should not be taken in an attempt to make society sustainable (Kates et al, 2001). Sustainable assessment of the Master Plan of Delhi 2021 could therefore play a major role in the sustainability of entire North India. At the same time, a 'business as usual' approach in Delhi's water management may only lead to the deepening of the water management crisis in the NCT of Delhi.

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