Chapter 3
THE STUDY AREA

The research work carried out for this thesis pertains to the National Capital Territory (NCT) of Delhi. The NCT of Delhi is one of the top ten most populated urban centers on the face of the planet and the capital of the world’s largest democracy, India. ‘Delhi’ finds prominent references in the epic *Mahabharata* and has a consistent historical record since tenth century AD. In 1911, the British shifted the capital of Imperial India from Calcutta (now Kolkata) to New Delhi following which Delhi became the centre of modern day political activities. Post-independence, Delhi was made a Union Territory in 1956 and was declared the ‘National Capital Territory’ in 1991-92. The NCT of Delhi today is witnessing large-scale urbanization which is exerting an increasing pressure on the region’s natural resources, especially its water resources. Scarcity of fresh water is now accepted to be a matter of grave concern (DoE, 2010) and an impediment to urban development of the NCT of Delhi. It is for this reason that the NCT was selected as the study area for the present research work. The NCT of Delhi enjoys the dual status of being a state and a union territory. It is federally administered and is composed of nine administrative districts (Fig. 3.1c). North-west, South-west and the South districts are comparatively larger than the other districts, North, North-east, West, Central, East and New Delhi.

3.1 Location

The NCT of Delhi is a part of the Indo-Gangetic Alluvial plain in Northern India and lies between latitude 28°24’17’’ to 28°53’00’’ N and longitude 76°50’24’’ to 77°20’37’’ E (Fig. 3.1). It is spread in an area of 1,483 sq. km. with a maximum length of 51.9 km and its greatest width is 48.5 km. The NCT of Delhi has an elevation ranging from 198 to 220 m above mean sea level. The NCT of Delhi shares its border with the state of Haryana in the northern, western and southern side and with the state of Uttar Pradesh in the east. The NCT of Delhi is also nested within the National Capital Region (NCR) of Delhi (Fig. 3.1b). The Yamuna River and the terminal part of the Aravalli hill range (the Delhi Ridge) are the two most prominent physiographic features of the NCT of Delhi. River Yamuna enters NCT of Delhi
Figure 3.1: (a) Location of NCR of Delhi on map of India; (b) Location of NCT of Delhi nested within the NCR of Delhi; and (c) Map showing the nine administrative districts of NCT of Delhi along with River Yamuna.
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from north in the North-west district and divides the city into two unequal halves. The major part of the city is located on the right bank of River Yamuna. River Yamuna forms the boundary between North-east and East district on one side and North, Central, New Delhi and South districts on the other. The Delhi Ridge enters the NCT of Delhi from the South and South-west districts, forking into two and expanding into a wide tableland (Fig 3.4a). One part of this fork stems from Mehrauli to north of the city until the bank of the Yamuna, while the other passes by the historic Tughlakabad fort and culminates in South district.

3.1.1 Delhi triangle

The location of the NCT of Delhi is of strategic significance which has contributed to the success of the Delhi region as a state capital since over two millennia, at the least. This is largely because the Yamuna River and the Delhi Ridge together form three sides of what is known as the ‘Delhi triangle’ (Mann and Sehrawat, 2009). The geopolitical location of the ‘Delhi triangle’, enclosing a region of over 90 sq. km., gives it logistic and economic prominence (Fig. 3.2). It is because of this strategic location that Delhi is one of the oldest and most densely inhabited places in India. Historians have found evidence indicating that Delhi was a popular choice of habitation even during the Paleolithic era perhaps due to this strategic location (Sharma, 2007).

The location of Delhi is even more interesting as it located between the Himalayan and the Aravalli range. The Himalayas are the youngest mountain range in the world while the Aravalli hills ranges are one of the oldest hills in the sub-continent’s recorded geological history. Present day Delhi has grown beyond and above the topographic features that made Delhi the capital of choice for many Emperors. However, River Yamuna and Delhi Ridge continue to provide critical ecosystem services to the region and its people. At the same time, the NCT of Delhi continues to remain a destination of choice for millions who migrate for different purposes. The location of Delhi has indeed given it a splendid history that flows into the present. Consequently, Delhi is a symbol of India’s ancient values, cultural heritage and its merger with modernization.
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Figure 3.2: Area spanned by the ‘Delhi Triangle’ (includes almost all parts of present day South Delhi, New Delhi and some parts of Central Delhi, North Delhi and East Delhi districts).

3.2 Administrative Divisions

The NCT of Delhi is federally administered and is divided into nine administrative districts. Delhi has a democratically elected ‘state’ government which takes care of its political administration. At the same time, power for certain areas of political administration is vested with the Central government as well. The power for municipal governance of the NCT of Delhi was, until 2011, trifurcated and used to rest with the following three agencies: i) Municipal Corporation of Delhi (MCD); ii) New Delhi Municipal Council (NDMC); and iii) Delhi Cantonment Board (DCB). Of these, the MCD was known to be the largest and most prominent municipal body occupying 1,397 sq. km or 94% of the total geographical area of the NCT of Delhi. The municipal control of the NDMC and the DCB spreads over an area of 42.74 sq. km and 42.97 sq. km respectively (Fig. 3.3). The MCD included both rural and urban
areas of the NCT of Delhi and consequently was known to be one of the largest municipal bodies in the world. It had the unique distinction of providing civic services to rural and urban villages, resettlement colonies, regularized-unauthorized colonies, JJ squatter settlements, slum 'basties', private 'katras' etc. This exerted tremendous pressure on the MCD and due to this reason an initial proposal to split the MCD into at least eight municipalities was floated (MoEF and PD, 2001). In 2011, after considerable deliberations, the MCD was re-divided into three municipalities, viz. 1) North Delhi Municipal Corporation, 2) East Delhi Municipal Corporation and 3) South Delhi Municipal Corporation (GNCT of Delhi, 2011).

Figure 3.3: An outline map of NCT of Delhi showing area administered by the New Delhi Municipal Council (NDMC), Municipal Corporation of Delhi (MCD) and Cantonment Board (CB) (Source: MoEF and PD, 2001).

It must be mentioned here that right from the time when the British governed Delhi to the present date, Delhi has undergone several administrative changes. This is largely due to the special character of Delhi as the Empire/National capital. These changes have been more prominent in the last 64 years of India’s independence. To carry out any environmental study in the NCT of Delhi today, it is important to understand the
nature and implications of these changes. This is especially because the most prominent of these changes, the restructuring of the NCT of Delhi from one administrative district to nine, took place as late as 1996. Before this, the NCT was divided largely into five (and later, six) administrative blocks, viz. Alipur, Kanjhawala, Najafgarh, Shahdara, Mehrauli and later, City block (Singh, 1999). Consequently, studies carried out by researchers and policies drafted by policy makers for urban management of natural resources (e.g. water management) 15 years back were planned according to these blocks and related divisions. Any reference to data and information older than 15 years corresponds to these blocks and other administrative entities some of which may no longer exist in the present day. Therefore, it becomes very important to understand the chronological evolution of administration and governance of the NCT of Delhi at least during the course of the last century. A brief account of this is presented in the text that follows.

3.2.1 Evolution of ‘Delhi’

Urban centers are not static entities and evolve over time periods which are proportional to the geo-spatial, economic and political significance of the individual urban center in question. The strategic location of Delhi and the consequent economic and political significance has already been discussed. Due to this, the evolution of administrative divisions of Delhi and its growth and development has been dynamic in recorded history and has been even more rapid in the recent past. A hand drawn ‘sketch of the environs of Delhi’ in the year 1807 indicates that Delhi in that year thrived in and around the previously discussed ‘Delhi triangle’ (Fig. 3.4 a). The largest political outline of ‘Delhi’ today is the National Capital Region (NCR) of Delhi and has been illustrated in Fig 3.4 (b). In the last 200 years, there has been an expansion and growth in area of ‘Delhi’, from 90 sq. km to 1,483 sq. km. The various stages during this urban land expansion over two centuries had significant impacts on the conservation and management of natural resources (especially water) in the region. At the same time, the perception of what is ‘urban Delhi’ has been ambiguous largely due to this dynamicity. The ambiguity gets compounded in urban academic research with respect to ‘Delhi’ resulting in confounding conclusions, especially with respect to addressing urban sustainability. It is therefore important to spell out this
Figure 3.4: ‘Delhi’ over 200 years: (a) sketch of the environs of Delhi in the year 1807 obtained from GSI and (b) present day geographic expanse of the connotation (NCR of) ‘Delhi’. The green triangle of the size of (a) is placed on (b) to give an idea of the scale.
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ambiguity and investigate and eliminate it before carrying out further research work for this thesis. The aforementioned task has thus been taken as the first research objective.

Delhi became one of the five administrative divisions of the Punjab Province under the British administration towards the later part of the nineteenth century. It then consisted of six districts, viz. Hissar, Rohtak, Gurgaon, Karnal, Ambala and Shimla. On 12th December 1911, Delhi was proclaimed as the capital of India in place of Calcutta (now Kolkata) and the districts were remodeled. A year later in 1912, Delhi was placed under a separate local Government and was declared to be a new Province. The Delhi Province was enlarged by adding parts of Meerut district and its boundaries remained unchanged all through the Indian freedom struggle. The NDMC began as the Imperial Delhi Committee on 25th March, 1913 to facilitate the construction of the new capital. The name was changed to “New Delhi Municipal Committee” on 16th March, 1927. The Delhi Cantonment Board was established in 1914 with a total area of approx. 42.50 sq. km under it (DCB, 2010). After India attained her independence in 1947, Delhi was given the status of a ‘Part C’ state with a separate Vidhan Sabha. In 1956, on the recommendations of the State Reorganization Commission, Delhi became a Union Territory (UT) administered by the President of India. After the creation of the UT of Delhi, a strong need was felt for effective governance and management of the UT’s rapid urban growth. Consequently, on 7th April 1958, a Delhi Municipal Corporation Act came into being and all existing urban local bodies, excluding the DCB and the NDMC, were merged into a newly created Municipal Corporation of Delhi (MCD, 2010). As a result, the entire UT of Delhi, excluding DCB and NDMC areas, came under the jurisdiction of the MCD. This also included rural areas and villages that are characteristic of the city’s landscape even today. The MCD took over the functions previously entrusted to ten local bodies and three statutory Boards.

The UT of Delhi continued to function as a single administrative unit governed by the three municipal agencies (MCD, NDMC and DCB) until 1991. The New Delhi Municipal Committee was superseded in February 1980 and an Administrator headed
it till the introduction of new Act in May 1994. In May 1994, the NDMC Act 1994 (duly passed by the Parliament of India) replaced the Punjab Municipal Act 1911 and the Committee was renamed as present day New Delhi Municipal Council (NDMC, 2010). Delhi Cantonment Board today is a local municipal body under the aegis of Ministry of Defense and is governed by the Cantonment Act, 2006. Delhi Cantonment is a Class 1 Cantonment. The administration of Cantonment is a Central subject as per the Constitution of India. (DCB, 2010). During the Census period of 1961, Delhi constituted one district and one tehsil. The fair proportion of rural, agrarian territory and population ensured that the tehsil continued to be of administrative importance in the UT of Delhi. From 1971 to the 1991 Census, Delhi revenue district was divided into two tehsils, the Delhi tehsil and Mehrauli tehsil.

The National Capital Territory (Delhi) Act was introduced in 1991 and the Union Territory of Delhi became the National Capital Territory (NCT) of Delhi in January, 1992. The Act provisioned a unicameral legislative body (Vidhan Sabha) with 60 seats for the NCT and a Government of NCT of Delhi led by seven member Council of Ministers, headed by a Chief Minister. However it should be noted here that according to the Act, the Head of the Government continued to be the Lieutenant Governor who is directly in charge of the land issues, law & order matters and the MCD. Four years later, in 1996, a Gazette notification divided the National Capital Territory of Delhi administratively into 9 districts and 27 subdivisions. The MCD, the NDMC and the DCB are the three statutory towns which together made up the entire geographical territory of the NCT of Delhi until 2011. After the re-division of the MCD in 2011, the statutory towns that now make up the NCT of Delhi are 1) North Delhi Municipal Corporation, 2) East Delhi Municipal Corporation, 3) South Delhi Municipal Corporation, 4) New Delhi Municipal Council and 5) Delhi Cantonment Board.

Any urban environment study with policy implications in Delhi can be carried out only after resolving the following two challenges, at least one of which is characteristic to Delhi. 1) The NCT of Delhi is composed of different administrative sub-units with overlapping limits, and 2) ‘urban Delhi’ today includes an area beyond
the limits of the NCT and that natural resources do not restrict themselves to political boundaries. Figure 3.5 illustrated each of the three most prominent contemporary administrative sub-divisions of the NCT of Delhi. There is considerable literature available with respect to water resource scenario for individual units of these three sub-divisions under various nomenclatures of Delhi (Zerah, 1998; Datta et al., 2001; Trivedi et al., 2001; Kumar et al., 2011; Adhikary et al., 2011; Singh, 1999; Chatterjee et al., 2009). It is also interesting to note that while the status of sub-surface water pollution in the NCT is being assessed on a district-wise basis (DoE, 2010), its mitigation requires decisions at the level of the municipal agencies’ which are five in number and have administrative limitations other than the outlines of the nine districts. At the same time, it has been noted in Chapter 1 that the norms set for water demand are different for different ‘zones’ of the NCT, which do not overlap with any of the above discussed administrative sub-divisions (Fig. 1.8b). To further add to the complexity, city development and resource management is undertaken by multiple agencies in the NCT (DUD-GNCT, 2006). It is therefore not difficult to understand the scale and level of challenges in managing and optimizing Delhi’s water resources.

Figure 3.5: Administrative ambiguity: (a) blocks in Delhi, (b) districts of Delhi and (c) municipal divisions of Delhi.

In the light of the above, the only plausible solution in assessing and appraising the water resource of ‘Delhi’ is by studying the NCT in its totality. The solution gains more credibility from the recent Census survey which notes that 97.50% of the total population
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of NCT of Delhi is urban (Census, 2011). However, ‘urban Delhi’ exists beyond the NCT which has significant implications with respect to water resource-use and management. The thesis continues to keep its focus on the NCT largely due to logistical reasons and lack of any single agency managing the NCT of Delhi along with the contiguous urban areas. It needs to be mentioned here that the aforementioned contiguous urban areas are administered by two different states viz. the state of Haryana and the state of Uttar Pradesh. Urban growth and sustainability assessment of Delhi therefore becomes greatly difficult in the absence of such an agency.

3.2.2 Introducing the ‘Delhi conurbation’

Urban landscapes are dynamic ecological systems, rapidly transforming to meet the requirements of increasing populations and post modernity (Gospodini, 2006; Pickett et al., 2011). Cities evolve from towns and transform themselves into megacities in time scales proportional to the social, political and economic prowess of the city in question. With time, the more influential and magnetic among these cities evolve from megacities to conurbations. A conurbation has been defined as an extended urban area, typically consisting of several towns merging with the suburbs of one or more urban centers (Geddes, 1915). Satellite imagery obtained for the Delhi region notes the above-discussed trend in a consistently increasing manner. A comparison of satellite images between a gap period of 25 years (1974 to 1999) (Fig. 3.6 a&b) indicates rapid pace of urban growth in terms of built environment. Interpretation of the spectral analysis of this urban growth pattern indicates that Delhi’s urban growth has taken place without giving much respect to the political limitations of the NCT (Fig. 3.7 a&b). ‘Urban Delhi’ today is a contiguous area encompassing the NCT of Delhi along with the neighbouring Ghaziabad, Gautambudh Nagar, Faridabad and Gurgaon. It may be mentioned here that in order to diffuse the rapid pace of urban population growth in the NCT, a National Capital Region Planning Board (NCRPB) was formulated in the year 1985. The planning for the creation of the NCRPB had started as early as 1956 when it was felt that growth of Delhi could lead to problems of land, housing, transportation and management of essential infrastructure like water supply and sewerage (M. of Health, 1956).
Figure 3.6: Satellite imagery showing urban growth in Delhi over a period of 25 years. (a) 1974 Landsat MSS (80m resolution) image and (b) 999 Landsat Thematic Mapper (28.5 m resolution) image of the Delhi region (Source: UNEP, 2005).
Figure 3.7: Satellite image interpretation for growth in urban area over a period of 25 years in the Delhi region: (a) urban area in the year 1974, (b) urban area in the year 1999 (Source: UNEP, 2005).
As has already been discussed, the National Capital Region (NCR) includes 9 districts from the state of Haryana, 5 districts from the state of Uttar Pradesh and 1 district from the state of Rajasthan (Fig 3.1b). The primary objective of the NCRPB has been to prevent the very spillover urban growth which is being witnessed all across the eastern border of the NCT today. While it can be argued that the urban growth scenario in the Delhi region could have been much more sinister without the NCRPB, the fact that Delhi today has evolved from a megacity to becoming a conurbation remains undisputed. The ‘Delhi conurbation’ was conceived as part of a paper identifying challenges in optimizing Delhi’s water footprint (Bajwa et al., 2011).

In October 2012, a United Nations report also noted this evolution with the statement, “in recent past, Delhi has joined the league of ‘meta-cities’, those massive conurbations of more than 20 million people” (United Nations, 2012). A closer analysis of population density in the NCR reveals that out of the total of 15 districts (excluding the NCT of Delhi) which make up the NCR, only 5 note population densities above 1000 persons per sq. km (Fig. 3.8). These are Meerut, Ghaziabad, Gautambudh Nagar (NOIDA), Faridabad and Gurgaon. Among these, Meerut does not have the spatial advantage of sharing a physical border with the NCT. At the same time, Meerut along with central-eastern Ghaziabad does not show an urban growth pattern which is as influenced by the NCT as is the case in the rest of the districts comprising the NCR. It is for this reason that Meerut and central-eastern Ghaziabad districts do not form part of the ‘Delhi conurbation’.

In the case of Ghaziabad district, the district may be re-divided on the basis of pace and influence of urban growth. Such a re-divisioning and creation of a ‘Western Ghaziabad’ as an administrative entity would certainly help in more effective administration of the ‘Delhi conurbation’, as and when it is established. Although at first, such a proposal to divide Ghaziabad district may sound overly ambitious, lessons learnt from recent past indicate that such a re-divisioning indeed took place for two other districts in the NCR. The district of Mewat was carved out of the district of Gurgaon in the year 2005 while the district of Palwal was carved out of the district of Faridabad as recently as in 2008.
The ‘Delhi conurbation’ can be defined as a contiguous polycentric urban area with the NCT as the urban driving force and flanked clockwise from the NE onwards till SW direction by the districts of Ghaziabad (western part), Gautambudh Nagar, Faridabad and Gurgaon. This forms a region which, in total area, is certainly much greater than the NCT and is far less than the NCR. It is also a region which is well connected in terms of transport and communications infrastructure and it is commonplace to encounter residents of these administrative units interacting with each other on a daily basis.

In the past, attempts have been made to describe a Delhi Metropolitan Area (DMA) or a Central National Capital Region (CNCR) (NCRPB, 2005). But these entities have been 1) superfluous, 2) without the purpose of administering ‘urban Delhi’ and therefore also included areas which are not already urban but may become so in due course of time, and 3) often without any administrative powers or any kind of jurisdiction.

A need is therefore felt to establish the ‘Delhi conurbation’ and assign an overarching agency which has administrative powers in order to ensure sustainable urban growth of Delhi. An effective urban resource assessment and management study should necessarily focus on the ‘Delhi conurbation’ for it to be comprehensive and result oriented. However, in the lack of any administrative agency managing such an entity, this can only be possible by carrying out individual studies in the NCT and above-mentioned districts forming part of the conurbation and subsequently overlaying and analyzing these studies. This makes the work four-fold and thus leads to the lacuna of carrying out urban studies in Delhi without taking all of ‘urban Delhi’ into account. Such a limitation also forms part of the present study which focuses entirely on the NCT of Delhi.
The population of the NCT of Delhi has grown exponentially over the last hundred years (Fig. 3.9). The population of the NCT was 13.8 million as per the 2001 Census of India report as against 9.4 million in 1991. The total population of the NCT of Delhi today stands at an astonishing figure of 16.6 million (Census of India, 2011). The population density of the NCT is no less astounding and is a result of large scale increase in population as well as high migration rate in the limited geographical area of the NCT. In 1901, the population 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. The population density of the NCT of Delhi today stands at 11,297 persons per sq. km.

Figure 3.9: Decadal growth in population of Delhi, from 1901 to 2011. (Source: Census of India, 2011)

Among all nine districts of the NCT of Delhi, the North-west district records the largest population (3.6 million) (Fig 3.10) while the North-east district records the highest density of population at 37,346 persons per sq. km (Fig. 3.11). The North-east district of the NCT of Delhi has earned the credit of being the most densely populated among all districts in the country.

In fact, if a list of top ten most densely populated districts of India is prepared, five of these will be districts of the NCT of Delhi. These are North-east, East (26,683 persons per sq. km), Central (23,149 persons per sq. km), West (19,625 persons per sq. km) and North Delhi (14,973 persons per sq. km). The New Delhi district records both the lowest population (1,33,713) and lowest density of population (3,820 persons per sq. km) among all nine districts. If the present demographic trend continues, the total population of the NCT of Delhi is predicted to be 22.5 million by 2021 which will be distributed unevenly along its length and breadth.
Among all the states and union territories in present day India, the NCT of Delhi is most urbanized with 97.50% proportion of its population living in urban areas. Delhi’s urban population was 52.76% in 1901 and in the hundred year’s period after that, it rose to 93.18% in 2001 (Fig. 3.12). This is indicative of the rapid urbanisation that has taken place in the capital city and is still ongoing with a high pace. Consequently, the urban area in Delhi increased from 22% in 1961 to 46% in 1991 and to over 62.5% of the total area in 2001 (Fig. 3.13). At present, 70.66% of the total area of the NCT of Delhi is designated as urban. The annual average exponential growth rate of population of Delhi was the highest (6.42%) during 1941-1951 due to large scale migration from Pakistan to India after partition in 1947. The annual growth in population of the NCT of Delhi was 4.22% during 1951-1961, 4.22% during 1961-1971, 4.25% during 1971-1981 and 4.15% during 1981-1991. The annual growth rate of population of the NCT during 1991-2001 showed a marginal decline to 3.85% but was still double that of the national average. The NCT of Delhi is one among the seven states/UTs in India with more population living in urban areas than in rural areas (other beings Chandigarh, Lakshadweep, Daman & Diu, Puducherry, Goa and Mizoram). The growth in population of the NCT has slowed down from 52.24% in 1991-2001 to 26.69% in 2001-11 (Fig. 3.14).
Figure 3.11: Density of population in the nine districts of NCT Delhi. N: North, NE: North-east, E: East, C: Central, ND: New Delhi, S: South, SW: South-west, W: West, NW: North-west district. (Data source: Census of India, 2011).

A reason for this could be the success of family planning measures since this decline in population growth corresponds to a decline in the population proportion of children (0-6 years of age) from 14.39% in 2001 Census to 11.72% in Census 2011. Another major reason for the fall in decadal growth rate of the NCT of Delhi could be the large-scale removal of slums, *jhugi jhonpri* (JJ) clusters and squatter settlements from various parts of the city in 2001. According to the descriptive analysis of the Census of India 2011, major clusters removed during the mid-2000s include the Yamuna *Pushta* spread along the Yamuna River bed in New Delhi, Central, North and East districts. While some of these slum dwellers were shifted to rehabilitation colonies in North-west and South districts, it is unclear whether others stayed in the NCT or migrated to other cities.

The intra-city migration from one district to another led to a sudden change in the comparative demographic pattern of individual districts within the NCT. The overall sex ratio of the NCT is 866 females per 1,000 males (Census of India, 2011). The demographic pattern of the NCT of Delhi is unique and characteristic of its ‘National Capital Territory’ status. A transect drawn from one end of the NCT to the center will
traverse different housing patterns such as rural villages, resettlement colonies, slums, squatters, *jhugi jhonpri* (JJ) clusters, urban villages, mixed land-use with commercial units on the ground floor and residential units built above them, multistoried residential colonies with single unit residential plots and those with large front and back lawns.

![Decadal growth in urban population from 1901 to 2011. (Source: Census of India, 2011).](image)

**Figure 3.12:** Decadal growth in urban population from 1901 to 2011. (Source: Census of India, 2011).

The NCT of Delhi has been divided into 15 Zones from A to H and J to P, of which 8 Zones are in the urban area, one in Riverbed and remaining 6 in the rural area. Population growth of the NCT of Delhi is creating a need for more and more residential areas. Already, the Delhi Development Authority (DDA) has launched three sub-cities in the NCT of Delhi as extensions of the existing urban area. These are Rohini sub-city, Dwarka sub-city and Narela sub-city. A large chunk of the housing requirement of the increasing population of the NCT of Delhi is also being fulfilled by the neighbouring cities of NOIDA, Ghaziabad, Faridabad and Gurgaon, which form a part of NCR. It should be noted here that the increase in population of the NCT of Delhi is not a result of population growth alone. The contribution of migration of people to the NCT plays as great a role in increasing the population of
the national capital as does natural growth in population. For example, the natural growth of population of the NCT of Delhi in the year 2007 was 52.58% while the percentage growth of population due to migration in the same year was 47.42%. Migration to Delhi is largely taking place for better livelihood opportunities and better standard of living in the NCT.

Figure 3.13: Percentage growth in urban area of NCT of Delhi since 1961. Urban area has increased from (a) 22% in 1960 to (b) 46% in 1991, (c) 62% in 2001 and to (d) 71% in 2011 (Source: DES-GNCT, 2011).

The largest populations of migrants arrive to the NCT of Delhi from the following states: Uttar Pradesh (43.56%), Bihar (13.87%) and Haryana (10.26%) followed by Rajasthan (5.17%), Punjab (4.72%), West Bengal (3.18%) and Madhya Pradesh (1.85%) (Fig. 3.15). Due to the lack of adequate and affordable housing facilities in the NCT, a large number of these migrants reside in unauthorized colonies or are
forced to live on public land (Singh and Shukla, 2005). Development indicators reveal that the migration trend will be maintained and better livelihood opportunities and a higher standard of living in Delhi will continue to invite migrants from across India (Bajwa et al., 2011).

Figure 3.14: Decennial population growth percentage in the NCT of Delhi. The sharp rise during 1941-1951 is due to bulk migration during partition after India’s independence in 1947 (Source: Economic Survey of Delhi, 2009 & Census of India, 2011).

Another two interesting components of total population of the NCT of Delhi are, i) floating population and ii) illegal migrant population. A large number of people enter the NCT of Delhi from the neighbouring cities in the NCR every day, largely for work or education purpose. This constitutes the ‘floating’ population of the NCT and due to this floating nature, it is not possible to enumerate the percentage share of the floating population in the total population of the NCT. According to data available with the NCRPB, the sub-total of migrants in the NCT of Delhi arriving from areas less than 100 km from the NCT is 18.5 million (NCRPB, 2008). The second component of the NCT’s population is ‘illegal migrants’. This category not only includes those individuals who have entered into the country without valid travel documents but also those who are overstaying after the expiry of their visa period. There is no one official
figure on the total population of the ‘illegal migrants’ and popular literature suggests that the largest proportion of this population comprises Bangladesh migrants.

![Figure 3.15: Percentage share of population of migrants in the NCT from other states of India (Source: Economic Survey of Delhi, 2009).](image)

Demography and population have an inherent link with urbanisation and sustainability. High density of population and more resource intensive lifestyles and aspirations of city dwellers are factors leading to an increase in the consumption pattern of global urban centers. An increase in population growth of cities beyond their carrying capacity directly threatens their urban sustainability and also impacts the regional and global sustainability.

### 3.4 Climate and Precipitation

The climate of Delhi, which is mainly influenced by its remote inland position and prevalence of air of continental character, is characterized by extreme summer heat alternating with great winter cold. The climate of the NCT of Delhi is semi-arid and does not exhibit significant spatial variation. There is, however, high variation between summer (25 to 46°C) and winter (5 to 22°C) temperatures. A 100 year monthly averaging of maximum and minimum temperature of the Safdarjung weather
monitoring site indicates that the mean average temperature varies between 7.8° C and 39.8° C (Fig. 3.16).

![Figure 3.16: Climate data showing maximum and minimum temperature averaged over a time period of 100 years in the NCT of Delhi (1901 to 2000) (Source: IMD, 2011).](image)

The climate of Delhi is also a product of its location and is influenced by the climate of the desert area of Rajasthan to the West and South-west and the Himalayan Mountains towards the North and North-east. Summers are long, and begin from early April and last till October. In between this time period, the NCT experiences the monsoon season when oceanic air penetrates the country up to the region of Delhi and beyond. Winters are short, beginning from November and continuing till February-March. The onset of winters in the region engulfs the NCT with dense fog. The monsoon months of July, August and September lead to an increase in cloudiness, humidity and precipitation.

The NCT of Delhi is one of the highly polluted major cities of Asia which impairs its air quality and has implications on related factors. The NCT is also subjected to dust storms brought by winds blown from the desert in the west, especially during the summer season. Consequently, total suspended particulate matter concentration in the
NCT of Delhi during pre-monsoon season goes enormously high thus affecting local radiative forcing as well (Attri and Tyagi, 2010).

**Figure 3.17:** Climate data showing monthly rainfall averaged over a time period of 100 years (1901 to 2000) in the NCT of Delhi (Source: IMD, 2011).

Further, Attri and Tyagi (2010) have also reported that the NCT of Delhi has shown a decline in global irradiance to a factor of 3.4%. The long-term average of global irradiance at Delhi is 216.2 W/m² (σ: 10.2 W/m²). Such a trend of declining irradiance is also apparent from the other three urban centers of Kolkata, Chennai and Mumbai. Surface solar radiation reduction has implications for surface evaporation which may share a proportional relationship (Kiehl and Trenberth, 1997). According to Attri and Tyagi (2010), evaporation declined by 19% during the period 1971-2000 for the country as a whole.

The annual evaporation trends showed a variation between -42.5 mm per year at Delhi to -5.5 mm per year at Trivandrum (Attri and Tyagi, 2010). The average annual rainfall recorded in the NCT of Delhi is approximately 714 mm (24.11 inches) (Economic Survey of Delhi, 2009). Three-fourths of the total rainfall occurs in the three monsoon months of July, August and September (Fig. 3.17). At the same time, the Delhi area is included in the list of areas recording large incidences of drought.
The climate profile of India as contributed to the Indian Network of Climate Change Assessment’s National Communication (2010) of the MoEF categorizes the NCT of Delhi under high probability (> 15%) of experiencing drought hazard.

The weather pattern of the NCT of Delhi in the present day is showing a deviation leading to long term changes in Delhi’s climate. The climate of the NCT is facing two pronged pressure which is threatening Delhi’s urban sustainability. While on one side the NCT faces impacts of global warming and rising average temperature of the Earth's atmosphere, changes in micro-climate due to the urban heat island effect are equally concerning. The carbon map of Delhi shows an ambient concentration of CO$_2$ ranging from 491 ppm (village areas of South-west District) to 625 ppm in the unauthorized colonies urban environment (Ghosh and Deb, 2009). Further, the carbon map indicates that the transport (46%) and the domestic sector (34%) are the biggest contributors to greenhouse gas emissions in the NCT of Delhi. Simultaneously, rapid and large-scale urbanisation taking place in the Delhi region is creating urban heat islands (UHI) which can be defined as closely situated unit areas with high variation in Land surface temperature (LST). However, the causes and consequences of UHI formation are not entirely understood in the present day and it is believed that the causes of UHI are not same across different climate conditions and urban centers (Mirzaei and Haghighat, 2010).

The UHI intensity studies in the NCT of Delhi indicates that it varies during different time periods in the day and is found to be more at night at 9 PM (2.8°C to 8.3°C) and during afternoon hours at 3 PM (3.8°C to 7.6°C) (Mohan et al., 2009). The aforementioned global and local climate challenges require a trans-disciplinary approach towards mitigation and adaptation. In June 2008, a National Action Plan on Climate Change (NAPCC) was launched by the Prime Minister of India, Dr. Manmohan Singh for addressing these concerns (PMCCC, 2008). Subsequently, the Govt. of NCT of Delhi launched its State Action Plan on Climate Change (2009-2012) with the objective of incorporating the concerns of climate change in the development agenda. The climate change agenda for Delhi includes action points on
air pollution, water pollution, noise pollution, municipal waste management and greening (Mehta, 2009). The plan also advocates the protection and upkeep of over 600 water bodies scattered within the NCT of Delhi and is a comprehensive environment management document.

3.5 Geology and Physiography

The convergence of the Gangetic alluvial plains and the Aravalli hills at Delhi region gives it a mixed geological character with eastward sloping alluvial plains as well as quartzite ridges. However, geology (alluvium, rock and landform) does not vary significantly in the region. Physiographically, two important landmark features in the NCT are River Yamuna and the northward extension of the Aravalli hills, the Delhi ridge (Fig. 3.18). River Yamuna enters the NCT of Delhi near village Bhakhtawarpur in the North-east district and leaves Delhi near village Jaitapur in South Delhi after traversing a distance of about 43 km. The river flows from North to South along the city and divides it into smaller eastern (Trans-Yamuna) part and bigger western (cis-Yamuna) part (Jain and Sinha, 2001). The river occupies a floodplain area of about 97 sq. km. within the NCT of Delhi. The Yamuna River water is extensively used for domestic water supply in upstream stretch, while the downstream stretch water is used for industrial cooling, irrigation, washing and bathing at certain locations.

The Delhi Ridge is made up of quartzite with intercalated phyllites of the Alwar Group belonging to the Proterozoic Delhi Supergroup as defined by Heron (1953). The Alwar quartzites are intruded by pegmatite bodies of variable size, particularly in the southern districts. The Yamuna floodplain comprises typical river deposits, forming the younger alluvium. West of the ridge is occupied by older alluvium, comprising a polycyclic sequence of brown silt-clay with kankar and fine to medium grained micaceous sand. A part of this older alluvium also occurs in the hook-shaped part of the ridge to the south-east.
The ring-shaped part of the ridge to the south encloses the Chattarpur basin which is made up of fine to medium grained yellow sand with minor silt and kankar. The nearly closed Chattarpur alluvial basin covers an area of about 48 sq. km. It is
occupied by alluvium derived from the adjacent quartzite ridge (Sett, 1964). Soil types in the NCT of Delhi are mostly light with subordinate amount of medium texture soils. The light texture soils are represented by sandy, loamy, sand and sandy loam; whereas medium texture soils are represented by silty loam. The soil type in the entire NCT is generally suitable for agricultural purposes. The basic physiography of Delhi in local terminology consists of the *kohi* or *pahari*, the *khadar*, the *bhangar* and the *dabar*. The Yamuna floodplain comprises the new *khadar* or the current floodplain; old *khadar* or the earlier floodplain; and *bhangar* or the upper alluvial plain. The *kohi* or *pahari* are the hills which make the Delhi Ridge. The *dabar/sagar* is the low-lying flood prone area in South-west Delhi. The *kohi* or *pahari* making up the Delhi Ridge was devoid of the lush green forest which can be recorded today until as late as late nineteenth century. As has already been noted, the climate of the NCT is of semi-arid nature characterized by marked diurnal differences in temperature, high saturation deficit and moderately low rainfall. Such a climate is unfavourable for the growth of luxuriant vegetation. Consequently, afforestation activities first took place in the Ridge between 1883 and 1913 before which it was of shrubby type and lacked canopy cover (Maan and Sehrawat, 2008). It needs to be noted here that although the *khadar-bhangar* transition line is not permanent, the *khadar* landmass is known in traditional knowledge as a zone meant only for agriculture (Lahiri and Singh, 2006) and not for permanent settlements. However, the landmass characterized as *khadar* in the NCT today (and outlined by the North-east Delhi district) is recorded to be the most densely populated district in the entire country.

### 3.6 Hydrogeology and hydrology

The bed rock topography in the NCT of Delhi is partly overlaid by the surface geomorphology. The Delhi ridge has a maximum elevation of 264 m above mean sea level in the Central ridge and rises up to 91 m above the surrounding plains, acting as a ground water divide between the western and eastern parts of the NCT. The depth to bed rock in the NCT varies from less than 10 m in the Delhi Ridge to greater than 300 m along a transect drawn from NW-W-SW parts of the NCT (Fig. 3.19). It is interesting to note that depth to bed rock does not exceed greater than 100 m in the majority of the landmass enclosed within the ‘Delhi triangle’.
Figure 3.19: Depth to bed rock in the NCT of Delhi (Source: CGWB, 2009).

The nearly enclosed Chattarpur alluvial basin covering an area of about 48 sq. km is occupied by alluvium derived from the adjacent quartzite ridge (Sett, 1964). The depth to bed rock in the enclosed region falls to as much as 150 m. River Yamuna is
the principal surface water resource in the NCT of Delhi. The Najafgarh drain is another major surface water channel which traverses a large part of the NCT in the Southwest, West and Central parts of the city. The Delhi branch of the Western Yamuna Canal (WYC) is another prominent surface water channel in the NCT which spans the North-west district and meets the Najafgarh drain in the western part of the North district. The WYC is managed by the Haryana State Irrigation Department with an objective of transporting water to the Agra Canal via Najafgarh drain and River Yamuna (CWC, 2007).

Figure 3.20: Ground water movement in the NCT of Delhi (Source: CGWB, 2010).
The movement of sub-surface water in the NCT of Delhi is regulated by these three principal water channels as well as by other channels and more importantly, by the Delhi Ridge. In the northern part of the NCT, ground water movement is noted away from both River Yamuna and the WYC (Fig 3.20). Ground water movement also takes place from the Norht-west district (south of the WYC) across the West district and into the South-west district, on the eastern part of the Najafgarh drain area basin. The area west of South-west district perhaps notes a deeper aquifer which pulls the ground water from all sides. A similar situation is observed in the region in between the Najafgarh drain and the Delhi Ridge and in the Chattarpur basin. In the ‘Delhi triangle’, ground water moves from the elevated Ridge towards River Yamuna floodplain. On the right bank of River Yamuna however, ground water movement takes place from the river to the land surface in both the North-east and East districts. Ground water movement may also be influenced by the presence of surface water bodies like wetlands which are aplenty in the NCT, though now under the threat of extinction due to tremendous urban pressure. The Delhi Climate Action Plan enlisted over 621 such wetlands to have existed in the NCT, many of which have dried and/or are beyond recovery (Mehta, 2009).

Delhi’s landscape today is being transformed to accommodate the needs of rapid urbanisation and increasing urban metabolism of the city. Rising population and improvement in living standards and providing of urban-styled basic needs such as all-time water supply, better transport facilities and greater access to sanitation facilities, etc. is adding greater pressure on the urban landscape. Urbanisation is also accompanied by growth in the industrial sector which further contributes to surface and sub-surface water pollution (Singh, 1999). It should be noted here that Delhi hosts the largest clusters of small scale industries in India which are point source of heavy metal contamination of surface and sub-surface water resources (Rawat et al., 2003). Consequently, one can imagine the pollution load in the different drains of the NCT and also in River Yamuna. Interestingly, the development of sewerage system in Delhi had started soon after it was conferred the capital status in 1911. The Okhla Sewage Treatment Plant (STP) was the first STP set up in Delhi in the year 1938. It then had a capacity of 82 MLD which was augmented to 165 MLD by 1956. The STP
at Coronation Pillar (1957) and Keshopur (1960) were later constructed and had a treatment capacity of 55 MLD each (CPCB, 2004). The treatment capacity increased from 273 MLD in 1961 to 1273 MLD in 1993. The treatment capacity of waste water in the NCT of Delhi today is 2330 MLD (DES-GNCT of Delhi, 2011). However, the real problem today is not of inadequate treatment capacity but of unplanned and inappropriate spatial location of the STPs.

The Irrigation and Flood Control Department of the Government of NCT of Delhi maintains a detailed record of the number and type of drains, their flow rate and related hydrogeological information of drainage in the NCT. Unfortunately, even the most recent records of this department (I&FCD-GNCT of Delhi, 2012) populate the list of drains according to the different blocks of Delhi. A spatial representation of some of the major and minor drains, along with River Yamuna, is presented in Figure 3.21. Here, it needs to be mentioned that the ‘Delhi stretch’ of the River Yamuna, as has been categorized by the Central Pollution Control Board, does not cover the entire course of River Yamuna in the NCT. The ‘Delhi stretch’ of the River Yamuna comprises only of the 22 km stretch between the Wazirabad and the Okhla barrage. Such anomalies lead to an ambiguous understanding of the water scenario in the NCT and needs to be swiftly resolved if the water situation in the NCT has to be improved and sustainably managed.

The Wazirabad barrage, which stops the entire flow of River Yamuna in the lean season, was constructed in the year 1959 for the very purpose of water storage. The IP barrage was constructed in the 1960s, largely to link ‘Delhi’ to ‘Trans-Yamuna Delhi’. The Okhla barrage was constructed as recently as 1986, to divert for Agra through the Agra Canal. During the monsoon season, the catchment area of River Yamuna upstream of the NCT of Delhi experiences heavy rainfall. This has three implications: 1) it often leads to a dangerous flood like situation in the NCT and 2) much more water is discharged from Wazirabad barrage than in the other months allowing the river to rejuvenate itself and 3) the Yamuna river floodplain (especially between Wazirabad and Okhla barrage or the ‘Delhi stretch’) is reclaimed and the ground water is recharged.
3.7 Relevance to the study

The ground water in the NCT of Delhi is not an isolated natural resource. A large proportion of Delhi’s population directly depends on ground water as a drinking water source. However, the ground water resource in the NCT faces an acute ‘tragedy of the commons’. Surface water resources like River Yamuna are also facing considerable pressure due to the increasing urban metabolism of the NCT. Consequently, an
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appraisal of the water resources in the NCT of Delhi needs to include the demographic pressures. Since the strategic location of the NCT has a direct relationship on its growth and development, it becomes important to understand the nature and extent of this relationship. It is equally important to understand the role of different administrative divisions managing water resources in urban Delhi. This has been the motivation of the first part of this chapter and has been adequately addressed with respect to contemporary urban administration in the NCT of Delhi.

Urban processes usually have a collective impact over contiguous urban areas which necessitate the identification of the limitations of this urban area. This has also been suitably addressed in the chapter. In addition to the demographic pressure, climate and precipitation as well as geology, physiography, hydrology and hydrogeology have obvious implications for the research work carried out for this thesis. These factors have been investigated in detail and suitably analyzed with respect to appraising the water resources in the NCT of Delhi.