Urban Floods: Case Study of Delhi

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Profile of the City

History

New Delhi, the capital of India, sprawled over the west bank of the river Yamuna is one of the fastest growing cities in India. It is surrounded on three sides by Haryana and to the east, across the river Yamuna by Uttar Pradesh. It traces its history to Mahabharata, the great epic tale of wars fought between estranged cousins, the Kauravas and the Pandavas for the city of Indraprastha. Historically, the city has long since been the foremost in political importance with successive dynasties choosing it as their seat of power, between the 13th and the 17th centuries. Remnants of the glorious past survive as important monuments in different parts of the city.

Mughals ruled Delhi in succession starting from Qutab-ub-din to Khiljis, Tughlaqs . The city of Delhi passed on to the hands of the British in 1803 AD. It was only in 1911, when the capital of British Empire was shifted from Calcutta to Delhi, that Delhi got its present prestige. After independence also, a kind of autonomy was conferred on the capital but it largely remained a chief commissioner's regime. In 1956 Delhi was converted into a Union Territory and gradually the chief commissioner was replaced by a Lt. Governor. In 1991, the National Capital Territory Act was passed by the parliament and a system of diarchy was introduced under which, the elected Government was given wide powers; except law and order which remained with the Central Government. The actual enforcement of the legislation came in 1993.

The myriad faces of the city are simply fascinating. In some places it remains a garden city, tree lined and with beautiful parks, but in some places it can also be crowded with heavy traffic. Turbaned Sikhs, colourfully dressed Rajasthani and Gujarati women working in offices, Muslim shopkeepers along Chandni Chowk in Old Delhi, Tibetians and Ladakhis in the street stalls along Janpath and Kashmiris in the handicraft emporia around Connaught Place, all add to the cosmopolitan feel of the city. Soaring skyscrapers, posh

* Contributed as Delhi city team under National Coordinated Project of NIDM (Gupta, Anil K. and P.G. Dhar Chakrabarti, *Disaster & Development*, 3 (1):1-14, 2009)

residential colonies and bustling commercial complexes can be seen along with the ancient historical monuments. Its boutiques and shopping arcades offer access to a wealth of traditional and contemporary crafts from all over the country. Old Delhi which looks entirely different from New Delhi area, is about 6 Km north of the city center [1].

Topography

It is located in the North-west portion of the country at latitude 28.68 N and longitude 77.21 E. The eastern portion of the Delhi Union Territory is adjacent to the State of Uttar Pradesh, simultaneously; the northern, southern and western portion is adjacent to the State of Haryana. In the east portion of the Delhi Union Territory, Yamuna River, a tributary of Ganges River flows to the south, and in the west, Aravalli Mountains forms the administrative boundary with the Uttar Pradesh Region.

The Delhi region exhibits a very gentle southerly master slope as indicated by the southerly flow of the Yamuna River, except at some places where the slopes have been locally reversed. The general slope in the region east of the Yamuna River is westerly. Similarly, the change in slope direction is also noticed west of the Yamuna adjoining Okhala Barrage [2].

Vegetation

Delhi geography divides the state into three parts- the Delhi ridge, the Yamuna flood plain and the plains.

The Yamuna river plains are very fertile as they are flooded by the river and is rich in alluvial soil. The Delhi ridge is the most important characteristic of the state and is a part of the Aravalli range that passes through Delhi. It is interesting to note here that each of these regions is marked by distinct type of vegetation. The ridge area of the city offers the right factors that favor the growth of acacias and other cacti [3]. However, during the monsoon, herbaceous plants grow in abundance in the ridge. As far as the plain region of Delhi is concerned, it is characterized by shisham trees. And finally, riverine type of vegetation grows along the plain of Yamuna. Vegetation of Delhi mainly comprise of medium size trees and herbs. However Delhi is known for its varied flowering plants [3]. Weeds and grass grow on the banks of the Yamuna river.

According to the Delhi weather records, extreme temperatures dominate the state capital. Delhi experiences extreme summer and winter seasons. Besides this, winter season also experiences immense fog which covers the city in its blanket.

Climate and Rainfall

About 160 kilometres south of the Himalayas, Delhi feels every chilly blast that lashes

the snowcapped mountains. From December to February temperatures range from 3°C to 21°C. The season is marked with light rainfall, frosty winds and an all-enveloping fog.

But the cold months of December-February soon give way to the balmy month of March. Birds sing out a full-throated welcome to Basant Bahar (the bloom of spring) as fresh grass and blossoms burst forth and trees sprout shiny new coats. Sometimes, when Delhiites are in luck, the spring gets an extra lease of life and tarries till mid-April.

Hot on its heels comes May which turns Delhi into a scalding charcoal tandoor (a large round clay oven). Thanks to its distance from the sea, Delhi bears the brunt of an extreme type of continental climate. The summer consequently is as hot as the winter is cold. The mercury, itself in danger of dehydration, soars to 47°C. One has to be carefully prepared before venturing out as heat strokes and dehydration are the order of the day. Violent dust storms and hot winds – locally dubbed "loo" – are part and parcel of the hot and dry Delhi summer.

The cruel onslaught of summer is cut short with the advent of the monsoon (moisture bearing winds) in early July. The monsoon, of course, is never known to have arrived when it is expected – it's either late, early or whimsically decides to just skip Delhi. It provides the city much-needed succor. The parched ground, plants, animals and people greedily soak up the moisture for the next two months as the temperature dips down to a bearable 30s°C. September though hot, is not dry but humid. In October the days become cooler and with November Delhi is very much in the arms of winter again [3].

Monthly average temperature, precipitation and Humidity of Delhi are shown in Table-1. Distribution of rainfall over entire Delhi with measurements at different rain gauges is shown in Figure-2. Average monthly rainfall is shown in Figure-3.

Table 1: Monthly Average Temperature, Precipitation and Humidity of Delhi

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)	14.3	17.3	22.9	29.1	33.5	34.5	31.2	29.9	29.3	25.9	20.2	15.7
Precipitation (mm)	25	22	17	7	8	65	211	173	150	31	1	5
Humidity (%)	62	47	39	25	25	30	67	73	65	49	44	55

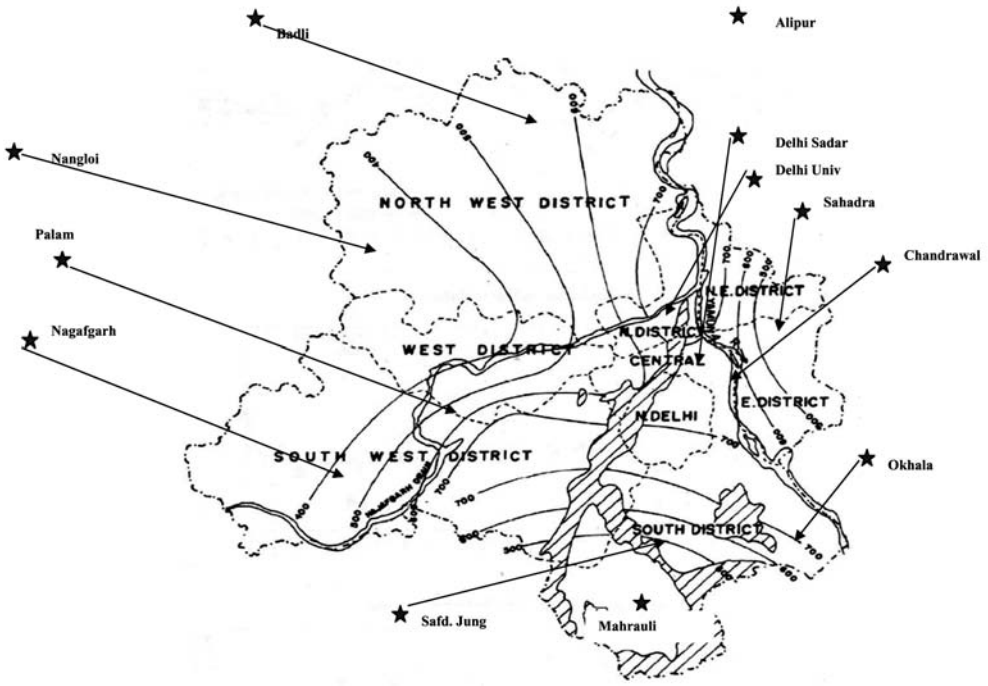

Figure 1. location of rain gauge stations and distribution of rainfall over Delhi

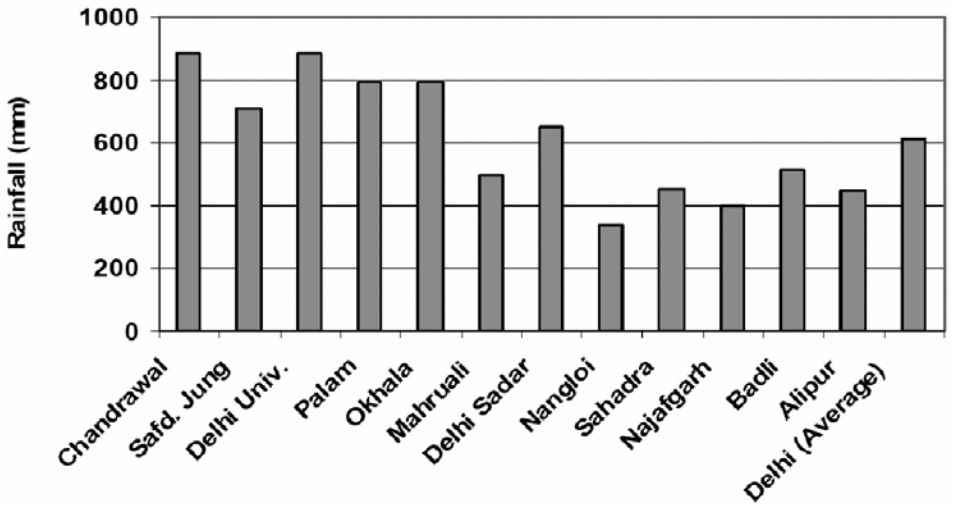

Figure 2 Average Rainfall at different Rain Gauges of Delhi (adapted from [4]).

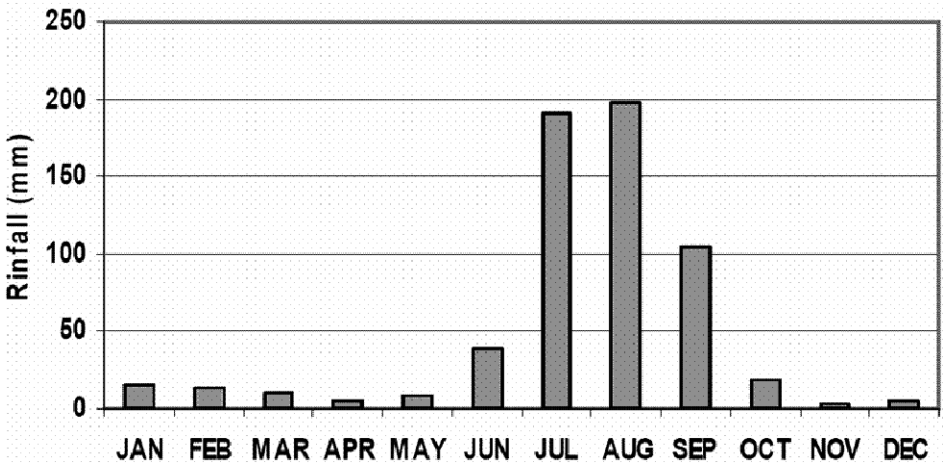

Figure 3 Average Monthly Rainfall of Delhi

Demographic and Settlement Pattern

The present administrative setup of Delhi city consists of Government of Delhi and various Municipal Corporation. The Delhi Union Territory including Delhi City is under jurisdiction of the Government of Delhi.

The Delhi City is divided into the following three municipality areas:

(1) Cantonment area in the western central part of the city where housing area was developed by United Kingdom for the higher military officers.

(2) New Delhi in the eastern central part of the city where the central government offices as well as many cotemporary buildings have been placed since 1911 when the capital of the republic of India has been formulated.

(3) Old Delhi is surrounding the above two municipality areas where the atmospheres of the Mugal Empire era is still heavily remaining and many buildings are disorderly located.

The total area of the Delhi Union Territory is 1,484 Km^2, while the area of Delhi city is 325 Km^2 consisting of 240 Km^2 of Old Delhi, 44Km^2 Cantonment Area and 41Km^2 of New Delhi.

The population of the Delhi Union Territory was 9.4 million in 1991, 89% of its population (8.4 million.) concentrating in Delhi City. The city is thirdly populated in India after Bombay City (12.6 million.) and Calcutta (10.9 million). The growth rate of population in Delhi City in the past 10 years is 3.4% that exceeds the nation wide average of 3.1%. Such relatively high population growth is due to the illegal population inflow to

the city area. According to the Slum & JJ Department, MCD, the number of illegal residents in Delhi City in 1984 was about 260 thousand households (about 1.2 million residents), while it has remarkably increased to about 480 thousand households (about 2.0 million residents) in 1994. Majority of illegal residents settles in Old Delhi, where the present population density is 30,000/Km^2 much higher than that of New Delhi and Cantonment area as shown in Table 2. As shown in figure 4 the population density of North district is 13 thousand/km2: North-East district is 29.5 thousand/km^2: Central district is 25.8 thousand/km2: North district is 5.0 thousand/km^2: South district is 9.1 thousand/km^2: South-West district is 4.2 thousand/km^2: West district is 16.5 thousand/km^2 and North-West district is 6.5 thousand/km^2.

Table 2: Population and Population Density in Delhi City

City	Population	Area (km^2)	Population Density (thousand/km^2)
Old Delhi	7,206,704	240	30.3
New Delhi	301,297	41	7.3
Delhi Cantonment	94,393	44	2.1

Socio-economic profile

Delhi, the capital of Republic of India, acts as the national economic center having its principal basis on service sector that employs about 22% of total working population. Succeeding to the service sector, the industrial sector is the second largest working population sharing 9%, and the agricultural sector is the third sharing 0.4%. Judging from the share of working population of Delhi, the economic structure of the city can be classified as urban type. The city recorded its per capita income of 872 rupees in 196-1961, which is much higher than the national average of about 330 rupees.

Delhi has accentuated its function as a banking wholesale-trade and distributive center. There exist the headquarters of the Reserve Bank of India and the regional offices of the State Banks as well as other banking institutions in Delhi. The city also has the large distributive share in the north-eastern region of India for bicycles, fresh fruits/vegetables, furs, skins, wool, motor parts/machinery and iron/steel. Most of the distributive trades are carried out from the Old – Delhi area, where most of the markets are located in close proximity to each other.

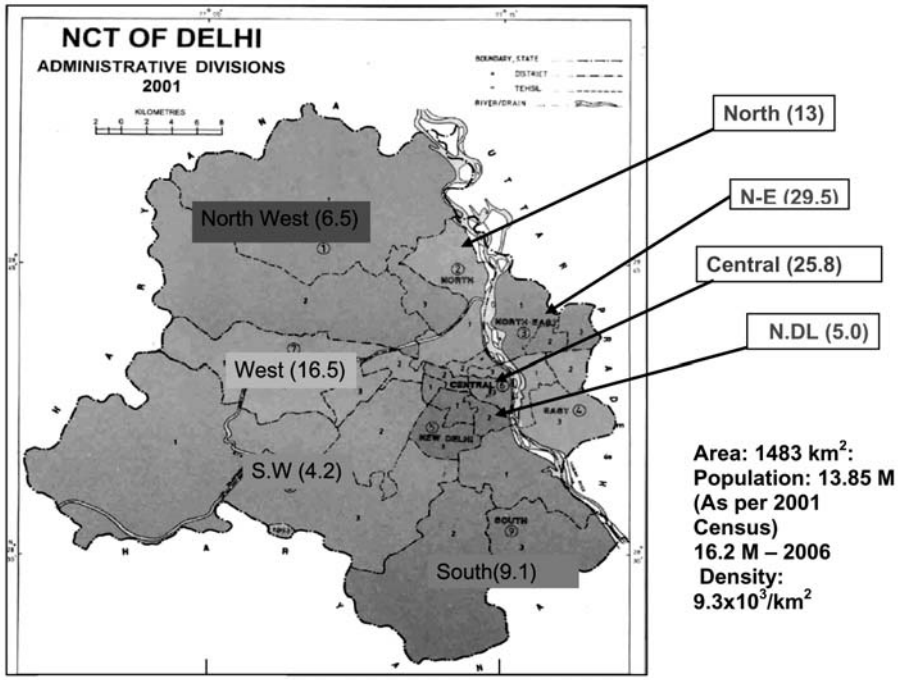

Figure 4: Population Density in various districts of Delhi

Moreover, Delhi has been traditionally famous for its artistic works such as ivory carving and painting, gold and silver embroidery, decorative ware, copper-ware and brass-ware. More recently, it has become important for the manufacture of various sophisticated products in small-scale industry such as electronics, automobile parts, precision instruments, lathes and drilling machine. Delhi has the largest number of establishments for manufacture of electronics goods in the country.

City Infrastructure

The usual city infrastructure involves a very wide spectrum of facilities, however, the present description is confined to only those infrastructure that are connected in some way to the flooding problems.

Roads

There are six different agencies maintaining the roads in the city - NHAI, PWD, MCD, NDMC, DDA and Delhi Containment Boards. The road network in Delhi was 31,183 kms

in March 2006, the number of vehicles has increased from 2.14 lakhs in 1971-72 to 48.30 lakhs (23 times)[5].

The imbalance between growth of vehicles and road network has led to heavy traffic congestion and reduced vehicle speed. A rough network of major roads is shown in Figure 5.

Sewerage

The existing capacity of sewerage system in Delhi is grossly inadequate, as only about 55% of the population is covered under organized conventional sewerage system and about 15% under on-site sanitation systems. Rest of the population does not have proper access to sanitation facilities. The increasing pollution in the river Yamuna is also a major indicator of lack of sewerage treatment facilities.

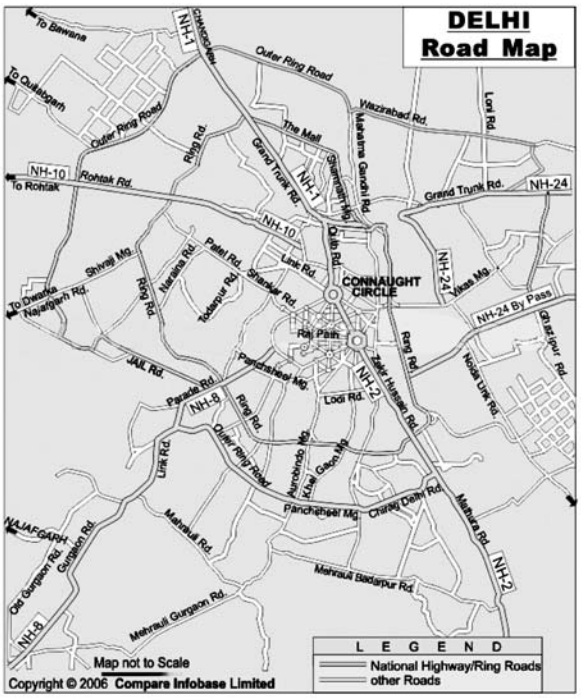

Figure 5: Major Road Network of Delhi [4]

By the year 2021 entire Delhi should be served by regular sewerage system in a phased manner. The areas where immediate regular sewerage system is not available, low cost sanitation system by individual families could be adopted as a short range provision.

These should be planned in such a way that in the long term regular sewerage facilities could be provided. To improve the sewerage and sanitation, the surface drainage and sewerage systems would have to be developed in an integrated manner.

The sewerage system is designed to handle domestic liquid waste @ 80 % of the water supply, which has to cater to 1472 mgd (6625 mld) of waste water by the year 2021. This excludes commercial and industrial waste water handling which needs to be treated separately. The waste water is also generated due to the use of ground water drawn from the bore holes installed by the public which is not included in the above figures.

Drainage System

Drainage has two aspects: flood protection and storm water discharge, which are interrelated. The storm water and flood protection in Delhi are not local but have regional bearing including areas of Haryana and Rajasthan. The main drainage system of Delhi is such that all water collected through main drains, link drains and small rivulets is discharged into Yamuna. On the basis of topographical characteristics and existing drainage network, NCT of Delhi has been divided into five drainage basins namely Najafgarh, Alipur, Shahdara, Khushak nallah and Mehrauli.

At present, rain water in Delhi City is drained through twenty five main drainage channels into Yamuna River. The outlet facilities for these drainage channels are classified into the following three groups; (1) natural drainage without reverse flow water gate, (2) natural drainage with reverse flow water gate and (3) pumping drainage system. The last drainage system is adopted in only three out of twenty five main drains. The pumping drainage channels, having relatively small pumping capacity of less than 1000 cusec (28.3 $m^3/_s$). Consequently, most of rain water in Delhi City could not be drained during a period of high water level of Yamuna River. The major drains out-falling in river Yamuna are shown in Figure 6. The major drainage Basins of Delhi are shown in Table-3

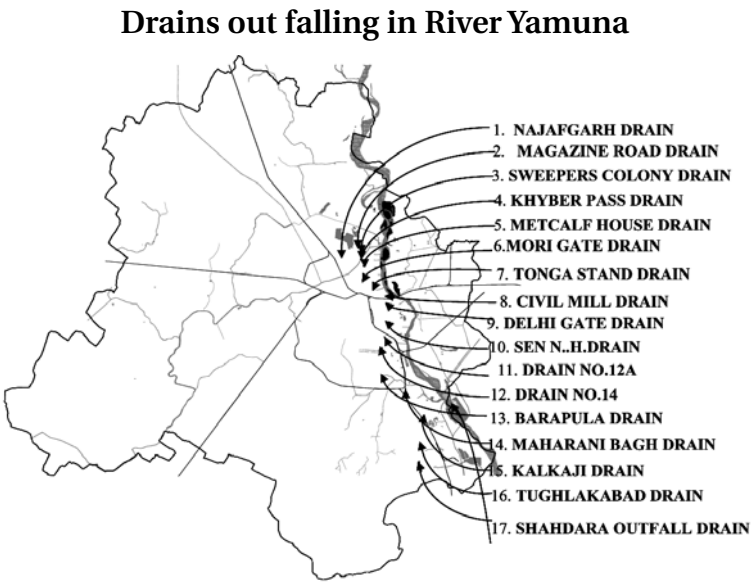

Fig. 6 Major Drains falling in river Yamuna.

Table 3: Drainage Basins

Basin	Location	Length of Drain in Km	Discharge in cumecs
Alipur	North	144	174
Khanjhawala	West	120	52
Najafgarh	Central-North & West &South	105	369
Khushak-Barapulla	Central-South & East		120
Trans-Yamuna	East	45	158
Mehrauli	South	5	86
Trans-Yamuna	East	45	158

Among the main drainage channels, Najafgarh drainage channel which is controlled by Irrigation and Flood Control Department of Delhi Government has the largest flow capacity, covering extensive drainage area. The flow capacity of Najafgarh drainage channel is 20,000 cusec (566 $m^3/_s$), and after the supplementary drainage that is now under construction, is connected to Najafgarh drainage channel, the future flow capacity will increase to 25,000 cusec (708 $m^3/_s$) in all. However, Najafgarh drainage channel naturally drains to Yamuna River without reverse flow water gates. Consequently, the reverse flow in the drainage channel occurs due to backwater effect of Yamuna causing serious damages in the city as experienced in 1995.

Land-Use changes

The Delhi Development Authority's 20-year master plan implemented from 1962-81 broadly divided up the city on the basis of public, semipublic and residential use of land. Public and semipublic land use was concentrated in the Central Secretariat area of New Delhi, the Old Secretariat area in the Civil Lines, Indraprastha Estate, the CGO complex and RK Puram (an office-cum-residence complex).

Small manufacturing units have sprung up in almost every part of Old Delhi, but the main industrial areas are along Najafgarh Road in the west and on Mathura Road in the south, where a large planned industrial estate, Okhla, has been established. Areas for

commercial land use are confined mainly to Chandni Chowk and Khari Baoli (both in the north), the Sadar Bazaar of Old Delhi, the Ajmal Khan Road of Karol Bagh in western Delhi, and the Connaught Place area of New Delhi. A number of district and local shopping centres have also developed in other localities.

The University of Delhi, India's most prestigious university, is located in the north, where a number of educational institutions for college education and for higher studies are located. It attracts students from all over the world and is hotbed of educational, research and cultural activity. Its southern campus is located near Dhaula Kuan. Another educational complex that includes Jawaharlal Nehru University, the Indian Institute of Technology, and other institutions has been developed in southern Delhi. The current land use pattern is shown in Figure

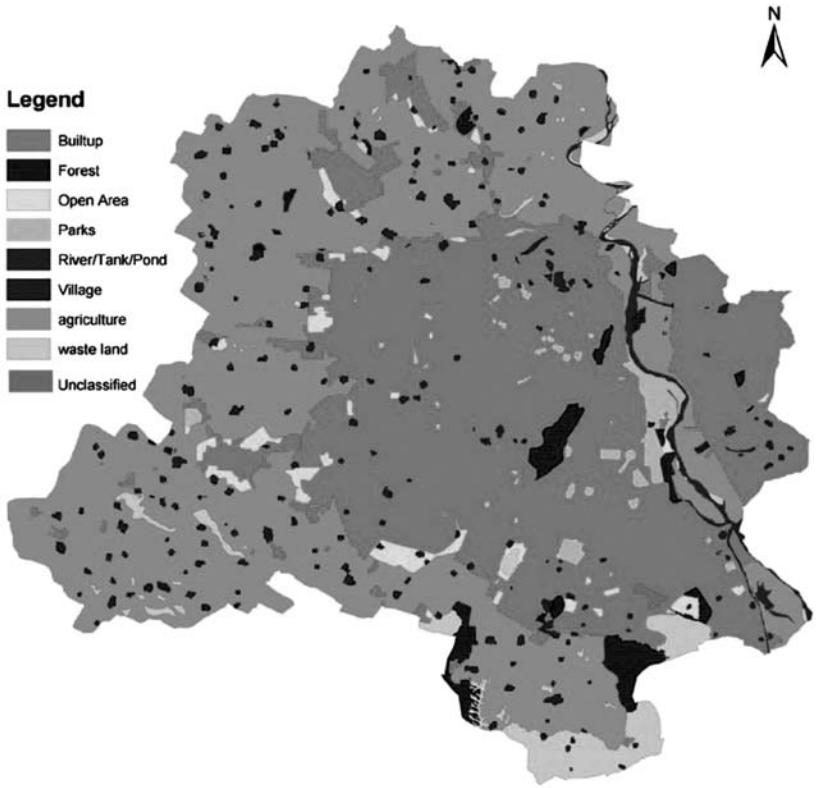

Figure 7: Current Land use of Delhi

The Land Use Plan-2021 has been prepared based on

i) The policies enunciated for different urban activities,
ii) Requirement of additional social and physical infrastructure,
iii) Transportation and work centers,
iv) Restructuring of land uses along the MRTS corridors based on the studies and considering the inter relationship between the urban activities, environment and the image of the city and
v) Already approved Zonal Development Plans and land use modifications.

In order to control the development, the areas have been designated as one of the 27 use zones identified in the Development Code. These use zones have been classified broadly in ten categories of land uses namely Residential, Commercial, Industry, Recreational, Regional Park / Ridge, Transportation, Utility, Government, Public and Semi Public Facilities and Agriculture and Water Body. The development in these use zones would be carried out in accordance with the regulations as given in the Development Code and respective chapters.

Table 4: Zone wise area as given in MPD-2001

Zone	Name of Zone	Area (Ha.)
A	Old City	1159
B	City Extn. (Karol Bagh)	2304
C	Civil Line	3959
D	New Delhi	6855
E	Trans Yamuna	8797
F	South Delhi-I	11958
G	West Delhi-I	11865
H	North West Delhi-I	5677
J	South Delhi-II	15178
K	K-I West Delhi-II K-II Dwarka	5782 6408
L	West Delhi-III	22840
M	North West Delhi-II	5073
N	North West Delhi-III	13975
*O	River Yamuna / River Front	8070
P	P-I Narela P-II North Delhi	9866 8534

Zonal Development Plans

The NCTD has been divided in 15 Zones (Divisions). The Zonal Plans of seven zones have been approved and notified whereas the Zonal Plans for the zones 'G', 'H', 'M' and 'P' (Narela) is at various stages of approval. The boundaries of the zones 'O', 'P' and 'N' as given in the MPD-2001 have been modified and accordingly the areas have been computed approximately as given in the table-4.

The Walled City and its Extensions, Karol Bagh and the area in between with contiguous specific use has been designated as Special Area for the purpose of development since it is not possible to develop the old built up area in accordance with the general use zone regulations given in the Development Code. Land use plan as per Master Plan is shown in Figure 8.

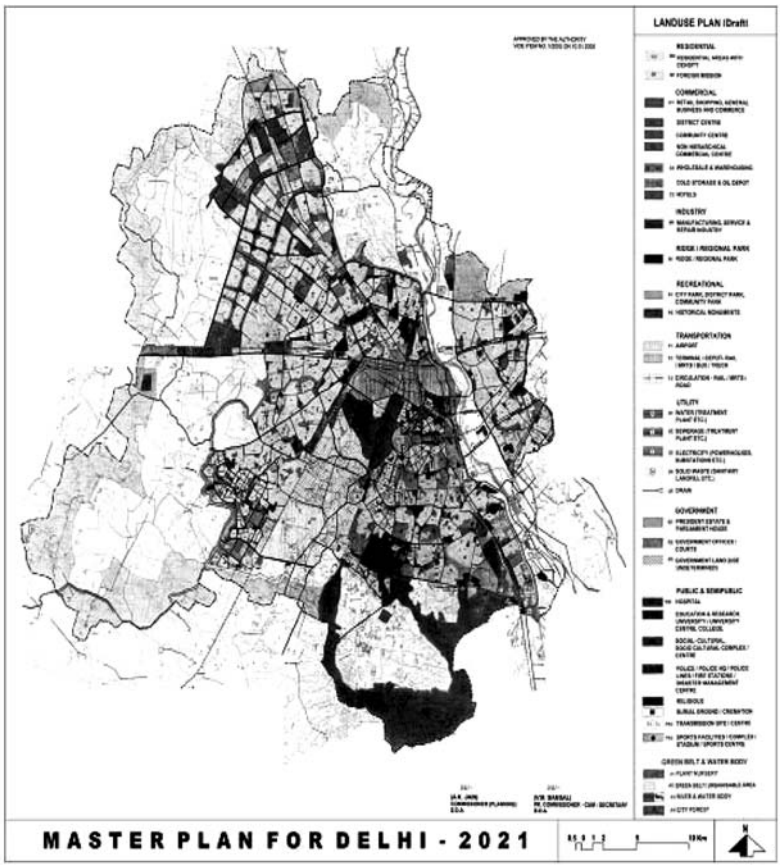

Figure 8. Land use plan as per Master Plan Delhi-2021

Floods in the City

Flood vulnerability

Delhi has a history of floods in river Yamuna. Regular flood monitoring in river Yamuna in Delhi started only in 1958 after the construction of the Yamuna Pushta (Left Marginal Bund) and the 'danger level' was then fixed at the Old Railway cum Road Bridge at 672 ft which on conversion to the metric system became 204.83 m. The 'warning level' has been fixed at 204 m.

The city has been experiencing floods of various magnitudes in the past due to floods in the Yamuna and the Najafgarh Drain system. The Yamuna crossed its danger level (fixed at 204.83m) twenty five times during the last 33 years (table 3.1). Since 1900, Delhi has experienced six major floods in the years 1924, 1947, 1976, 1978, 1988 and 1995 when peak level of Yamuna River was one meter or more above danger level of 204.49m at Old Rail Bridge. The highest recorded level of 2.66m above the danger level occurred on September 6, 1978. The second record peak of 206.92m was on September 27, 1988.

A profile of recently experienced floods indicating the extent of damage caused is as follows[9].

1977: Najafgarh drain experienced heavy floods due to discharge from the Sahibi River. The drain breached at six places between Dhansa and Karkraula, marooning a number of villages in Najafgarh block. Six human lives were lost due to house collapse. 14 persons died in a boat mishap. Crop damage was estimated at Rs 10 million.

September,1978: River Yamuna experienced a devastating flood. Widespread breaches occurred in rural embankments, submerging 43 sq km of agricultural land under 2 meters of water, causing total loss of the kharif crop. In addition to this, colonies of north Delhi, namely, Model town, Mukherjee Nagar, Nirankari Colony etc. suffered heavy flood inundation, causing extensive damage to property. The total damage to crops, houses and public utilities was estimated at Rs 176.1 million.

September, 1988: River Yamuna experienced flood of very high magnitude, flooding many villages and localities like Mukherjee Nagar, Geeta Colony, Shastry Park, Yamuna Bazzar and Red Fort area, affecting approximately 8,000 families.

September, 1995: The Yamuna experienced high magnitude flood following heavy rains in the upper catchment area and resultant release of water from Tajewala water works. Slow release of water from Okhla barrage due to lack of coordination between inter state agencies further accentuated the problem. Fortunately, the flood did not coincide with heavy rains in Delhi, and could be contained within the embankments. Nonetheless, it badly affected the villages and unplanned settlements situated within

the river-bed, rendering approximately 15,000 families homeless. These persons had to be evacuated and temporarily housed on roadsides for about two months, before they went back to living in the river-bed.

The flood situation is projected in the Flood Atlas map prepared by Central Water Commission. As per the map of the flood prone areas, Delhi has been classified into thirteen zones based on the flooding risk in relation to incremental rise in the water level of the Yamuna (DDA, 1993). These zones cover a range from 199m to 212 m level of water in the Yamuna. This zoning map covers part of North Delhi on the West bank of the Yamuna and almost the entire Trans Yamuna Area on the East bank. Besides this, the Delhi Flood Control Order also divides the NCTD into four Flood Sectors, namely Shahadra, Wazirabad - Babrapur, Alipur and Nangloi - Najafgarh sectors.

Although the unprotected flood prone area is only 1.7% or 25km only towards the south east and about 5% or 74 sq km in the north eastern parts which is protected by earthen embankments, every year water level rises in Yamuna above danger level and large population has to be evacuated to the top of the bunds and Delhi highways.

The Environment Status Report of WWF for Nature-India (1995) has pointed out that since 1978 the flood threat to Delhi has increased. In 1980, a discharge of 2.75 lakh causes at Tajewala resulted in flood level of 212.15 meters at the bund near Palla village in Delhi.

August and September 2008[12]: On 16th and 17th August 2008, Delhi was warned of possible flood. The peak of 205.71 m was reached on 20th August 2008 by which time deep flood waters could be seen in areas immediately downstream of the Wazirabad Barrage in east bank with flood waters gradually spreading over the entire available flood plain between the ring road in the west and the Yamuna Pushta (Left Marginal Bund) in the east. Residents of Jhuggi Jhompris all over the flood plain relocated themselves away from menacing flood waters and the villagers of Usmanpur, Garhi Mendu and Bela Estate were specially impacted as flood waters entered their houses and submerged standing crops. Even the residents of Mukherjee nagar were impacted as a result of backflow in the drain which had been closed by the authorities to prevent the flood waters entering the city from the several drains falling from the city into the river.

Again from 20th September 2008 onwards flood warnings for Delhi were given following heavy rains in Himachal, Uttarkhand and Punjab. Close to 3.80 lac cusec water had been released from the Hathnikund Barrage. It was almost double of what had been released in the month of August 2008 but still short of the 5 lacs cusec figure from 1988 and 1995. The peak of the floods was experienced in Delhi on 22nd and 23rd September 2008 and by 24th September the flood waters once again entered the available flood plain in the city and knocking at all the embankments of the river. The authorities had to resort to the use of

physical barrier like sand bags to prevent flood waters spilling on to the ring road near ISBT, while the Tibetan market and the entire Qudsia Ghat area went under deep water.

Once again in a short span of a month the life of people in Usmanpur, Garhi Mendu, Bela Estate and Chilla Saroda Khadar was upturned with most of them finding refuge at high places on the Yamuna Pushta and on the road sides. Farmers, of course, lost all that they had grown in the flood plains. This time around the flood waters which had barely touched the embankment next to the ongoing constructions like the Games Village and the DMRC depot during the August floods saw deep waters standing next to them.

Local Flooding

A significant phenomenon which has been increasing during recent years is that of local flooding. Urban areas are characterized by a high proportion of area under impervious surfaces (Roads, pavements, houses etc). High rates of development along with the resultant loss of soft landscape have led to high surface water runoff rates. This results in floods in the low lying areas even after moderate precipitation. Another factor adding to this effect is that of River Yamuna because the river is normally flowing at a higher level within its embankments during such periods. Thus, the water gets logged in the city areas and it takes several days to mechanically pump it out and bring the situation under control. Similarly, during the past few years, flooding due to the city's 18 major drains has also become a common phenomenon. Already under the pressure of the city's effluent discharge, these drains experience reverse flow from the Yamuna, which is in spate, and as a result they tip their banks, flooding the neighboring colonies.

Recent Floods in Delhi– Detailed account

Flood Problem Due Due To Sahibi Nadi

The Sahibi River originates in Jaipur district of Rajasthan. After passing through Alwar district in Rajasthan and Gurgaon district in Haryana it enters Union Territory of Delhi near Dhansa. Very little quantity of water used to enter Delhi due to interception of Jahajgarh and other jheels and the under ground reservoirs of Rajasthan and Haryana. But due to land developments and improvement in drainage system in Haryana, it is seen that every year, the quantity of water entering Delhi is increasing very fast and the Najafgarh Jheel areas have started remaining under water for full year. To check this entry of water in Delhi, the bund and regulator at Dhansa were constructed in the Year 1964 and the same year there had been an unprecedented heavy flood in Sahibi which caused breach in Dhansa Bund and resulted in submergence of most of areas of Najafgarh Block in deep waters.

Similar instances of heavy flood in Sahibi have been in the years 1967 and 1977. Though the flood of 1967 did not make any damage in Delhi area but 1977 flood created even worse position than 1964, when even the far off colonies of Delhi like Janakpuri, etc. were threatened by the Sahibi floods.

Every time after the flood in Yamuna & Sahibi different experts Committees had been set up who always recommended for increasing the capacity of N.G. Drain and Dhansa Regulator and also the raising of the banks to accumulate higher discharges inside them. Sahibi river belongs to special category of rivers in arid and semi arid areas in Rajasthan.

The flooding and consequent damage is caused mainly in the rural areas of Delhi in and around Najafgarh Jheel. It also causes damage to the urban areas situated along the banks of the Najafgarh Drain. There is no record of flooding and damage in Delhi area prior to 1964, when the capacity of the Najafgarh Drain was only 900 cusecs. Even the Reddy committee which examined the problem of floods and drainage in Delhi in 1957-58 did not mention any damage caused by Sahibi floods in the past. The first major flood of Sahibi as known in the recent past occurred in 1964. The Dhansa bund which was constructed in 1961-62 suffered damage when the level U/s rose considerably. A controlled cut was made through Dhansa bund which later on widened and resulted in a breach and the flood waters could not be contained within the Najafgarh drain, thus caused damage both in the rural and urban areas of Delhi. In the years 1967, 1975 & 1976 the flood was of less magnitude and there was some damage in Haryana, without effecting Delhi as Sahibi water could pass down the Najafgarh drain through Dhansa regulator. The real major flood after 1964 was that of 1977.

During 1977 two major floods were experienced in the Sabhibi catchment, the first storm occured between 29th to 31st July and the second between 4th & 6th of August. The Yamuna was already in spate when the Sahibi level rose. The level of Yamuna on 27th of July at old Railway Bridge in Delhi was 204.85m (672.07ft.) against a danger level of 204.83 m (672 ft.). The maximum level of Yamuna recorded at old railway bridge in 1977 was 205.85m (675.29 ft.) on 7th August 1977.

The Water level U/s of Dhansa was 210 M (688.98 ft.) on 11.7.77 i.e. 2.5 M less than the FRL. It started rising gradually and reached a level of 210.80M (691.58 ft.) on 28.7.77. Thereafter due to floods in the Sahibi, the level started rising rapidly and reached 213.575 M (700.71 ft) on 6th of Aug. 1977 whereas top of the bund at Dhansa is at a level of 214 M (702 ft.). Anticipating such a high rise of water U/s of the bund Delhi Admn., had started from 2nd August, temporarily raising the bund by means of sand bags, and on this account bund remained safe. As the bund is not connected to high ground at its southern

end, considerable flow started through that gap, which got further developed on account of high level on its U/S. During this period both the regulator were kept open and max. discharge of about 6000 cusecs was passing through regulators against the designed capacity of 3000 cusecs. It is roughly estimated that the max. discharge passed through Dhansa bund (Regulator as well as by-pass channel) was of the magnitude of 36,000 cusecs. On account of this heavy flow from Dhansa and also due to inflow from direct catchment of Najafgarh lake, the Jhatikara bund on the left-bank of Najafgarh Drain in Delhi breached on 6.8.77. Consequently the entire Najafgarh Jheel and vast area of Delhi came under submersion. The Najafgarh drain had a designed capacity of 3000 cusecs. Due to such heavy inflow, the Kakraula regulator was also by-passed and lot of water started flowing over-Najafgarh Dhansa road. The Najafgarh drain was carrying a discharge of about 6000-6500 cusecs for number of days against the designed capacity of 3000 cusecs. The excess discharge resulted in overflowing the banks of the drain inspite of the attemps made by Delhi Admn., to temporarily raise the banks by sand bags.

The max. level recorded D/s of Dhansa regulator was 212.80 M (697.98 ft) on 9.8.77 and the max. level recorded at Kakraula was 212.125 M (695.77 ft) on 16.8.77 and the same level was recorded at Basaidara on 17.8.77. The rural area in Delhi remained under water for about 3½ months and was free from submersion only in the second week of November.

Flood Problem Due To River Yamuna

Yamuna is the main river of Union Territory of Delhi which flows in its Easterly direction from North to South. Keeping in view the topography, Yamuna catchments upto Delhi is divided in two parts - (1) The upper catchment from source in Himalayas to Kalanaur in Haryana - which comprises parts of Himachal Pradesh and hills of West Uttar Pradesh and (2) the lower catchment from Kalanaur to Old Delhi rail bridge which consists of West Uttar Pradesh and Haryana.

River Yamuna enters Delhi from the northeast near Palla at an altitude of 210.3 meters and after traverse of about 40km. it leaves Delhi at an altitude of 198.12 m near Jaitpur in the South. The width of the riverbed varied from 1.5 to 2.0km. in its flow from Wazirabad barrage, a network of seventeen drains joins the river on the West bank during its traverse in the northern parts of the city. Najafgarh and Alipur drains, due to heavy discharge from Sahibi river, inundate a number of villages in Nazafargarh block causing heavy damage to life and property. There was, however, little effect of it in Yamuna river flow. Only one drain joins on the East bank near the old rail bridge.

As per available records, during the last 40 years, the years 1967, 1971, 1975, 1976,

1978, 1988, 1995 and 1998 have been the high flood years for River Yamuna, when the water level in the river at old railway bridge was observed to be 206.0m or more.

Various Factors responsible for Floods

The Yamuna River is an alluvial river and hence has got a meandering tendency. In the past this river has caused serious flood problems in U.T. of Delhi by inundating large areas during flood season, and disturbing the normal life of people of Delhi. Prior to construction of Shahdara Marginal Bund and Left Marginal Bund in 1956, this river used to inundate the trans-Yamuna areas very often (nearly every year). In right side also before construction of Right Marginal Bund in 1977-78, most of the areas of Northern Delhi in Alipur block used to be inundated under deep waters. This has been the result of inadequacy of flood protection measures adopted in Delhi area in the past. Even in 1978 floods i.e. after the construction of Right Marginal Embankment upstream of Wazirabad upto Delhi-Haryana border the area of Alipur Block and even Model Town colony of Delhi city area was inundated in deep water due to a breach in this embankment. The main city areas of Delhi and New Delhi and Trans-Yamuna Area of Shahdara Block are although protected by embankments but there also remains a danger of breaches which may endanger the normal life of the residents in these areas. The floods of the years of 1924, 1947, 1955, 1956, 1967, 1971, 1975, 1976, 1978 are the main examples of the flooding in River Yamuna when the normal lives of the residents of Delhi were disrupted. Nearly every year there is flooding in River Yamuna, the intensity of which may be low, medium or high. The general water level of Yamuna at the Old Railway Bridge during dry season is found to be nearly 202.00 m (662 to 663 ft.) The low intensity floods are those which are below warning level i.e. 204.22m (670.00 ft.). During this type of flood, the water generally remains within its regime and no danger is created to life and property. However due care is to be taken by departmental officers to keep a watch on the future discharges, the information for which is to be collected from Tajewala headwork, the controlling point in the upstream. The floods attaining water levels above 204.22m and below 205.44 m (674.00) are called medium floods. In this type of flood, the water spreads out of the regime and touches the embankments constructed on both sides.

At this stage backflow starts in most of the drains out falling in Yamuna and hence their regulators have to be brought in operation. The patrolling for watch & ward of embankments is to be intensified and done during day and night. Proper watch is kept on seepage points already earmarked and proper check is kept for new seepage points also. When the level in river goes above 205.44m (674.00 ft.), the flood is termed as high flood.

Efforts made to mitigate and manage Floods

Master Plan Provisions

The sustainable development of Delhi, and a minimum quality and standard of living pertains to the availability of, and accessibility to basic infrastructure facilities viz. sewerage, drainage and solid waste management. The rapid and almost uncontrolled growth of population has put these facilities under severe pressure, and there are significant deficiencies. Even a cursory analysis of the present state of affairs would reveal that infrastructure problems could become a cause of crisis. Sewerage and solid waste management are State affairs. Thus critical need of advance action and arrangement is required for the adequate provision of physical infrastructure. For each component a broad augmentation plan to meet the projected requirement is essential. GNCTD has prepare a detailed and integrated plan in coordination with concerned authorities, NGOs and community groups.

The Master Plan envisages an integrated approach that packages mutually supportive infrastructure components i.e. water-sewerage- drainage for recycling, harvesting and optimal use of water; solid waste sewerage- power for power generation, etc. The projected requirement of sewerage and solid waste management is listed in Table 4.

Table 4: Projected Requirements for the Year 2021

	Availability	Requirement		
	2001	2001	Projected 2021	Additional 2001-2021
Sewerage (mgd)	512	877	920	408
Solid Waste (tones/day)	5543	7100	15750	10207

Sewerage

Sewerage is the core element of physical infrastructure that determines the environmental status of any city and requires minute planning, development and management. Development of appropriate sewerage system with efficient sewage treatment is vital to facilitate balanced and harmonized development. Augmentation of existing inadequate systems / treatment facilities as well as adoption of new

technologies of waste treatment demands special efforts. Further, it is pertinent to point-out that the existing capacity of sewerage system in Delhi is grossly inadequate, as only about 55% of the population is covered under organized sewerage system and about 15% under on-site sanitation systems. Rest of the population does not have proper access to sanitation facilities. The sewage treatment facility is also inadequate. The increasing pollution in the river Yamuna is a major indicator of lack of sewage treatment facilities.

Delhi has 17 STPs. In east Delhi, Delhi Jal Board has planned to augment the capacity of Sewage Treatment Plant by 45 MGD at Kondli and 25 MGD at Yamuna Vihar.

The existing Sewerage Conveyance System is a large network of branch peripheral and Trunk Sewers. There are 28 main Trunk Sewers with sizes ranging from 700mm dia. to 2400 mm dia. with a total length of about 130 kms. The balance length of sewage conveyance system comprises of peripheral sewers and internal sewers of small sizes and a total length of approximate 6000 kms. The Trunk Sewers have been laid over the years at different stages. Some of these are as old as 40-60 years old. The condition of Trunk Sewers specially the older ones have deteriorated as a result of silting and settlements.

It has been projected by DDA that for 2021 projected population of the city will be 230 Lacs and requirement of potable water shall be 805 MGD and non-potable water shall be 1035 MGD. Total sewage generated has been worked out to be 1012 MGD (DDA) which seems to be on the lower side keeping in view of the requirement of water worked out by DDA to the tune of 1840 MGD (805 MGD + 1035 MGD) whether it is potable or non-potable because both the water will generate the waste water.

Proposed Strategies For Different Aspects Of Sewerage System:

Drawing up a detailed blue print for augmenting sewerage system of Delhi, following key proposals are included.

1. Phasing of new work for total coverage of city with interim arrangements.
2. In the old city and other areas identified in some places, new sewerage lines can not be laid and the existing sewer lines have to be de-silted and rehabilitated.
3. Technological changes: The Delhi Jal Board has switched over to the Design Build & Operate (DBO) Contracts for setting up the STPs. In these cases, availability of land with the DJB is mentioned and the contractor has the option for offering the suitable technology, which can fulfill other specified parameters. Sewerage system in Delhi except NDMC and Cantonment area is being laid and maintained by Delhi Jal Board where as surface drains are being constructed and maintained

by General Wing, MCD, CSE (MCD), DDA, PWD, Irrigation and Flood Department, and Govt. of NCT of Delhi etc. Decentralized STPs with capacity of 3-5 MLD at the sub-city level, (10-15 Lacs population) can be set up keeping in view the techno economically feasibility and viability and availability of land by the DDA.

Drainage

To improve the drainage system of Delhi, effluent treatment plants should be provided at outfall of drains and aeration units at interceptions with advanced techniques for maintenance of drains. A time bound action program for augmentation and capacity revision of existing and new drains (due to increase in run off from urban extensions) is also vital. Check dams and depression/ lakes may be designed for increasing ground water table and as storm water holding points wherever needed. The design shall preserve the natural drainage pattern after the development of an area.

Drainage should be linked with the ecology and green networks, by adopting the concept of "bio-drainage". Regular desilting of drains and control of dumping of solid waste/ malba into the drains should be taken up. Other measures essential for proper drainage are the following:

1) Drainage to be integral part of Road Development Plans/ flyover/ Grade Separators.
2) GIS based drainage mapping and planning.
3) Sub-wells need to be developed under flyover for trapping rainwater. Pump houses in low-lying areas should be operational and given back-up power.
4) Remodeling of selected drains may also be required considering the upstream flow in the region.

Inquiry and fact finding report.

Delhi Jal Board proposed that the capacity of new urban drainage facilities should be designed to cope with the probable rainfall intensity of 5 to 10-year return period. The actual flow capacity of present facilities is, however, far smaller than the proposed design level and, inundation by storm rainfall occurs almost every year, at many parts of Delhi City. The main causes of deterioration in the present drainage system are enumerated as follow:

(1) The solid wastes and sediment have accumulated in the present drainage channels seriously affecting the smooth channel flow. Especially, soil accumulation in the Najafgarh drainage channels is posing serious problem.

(2) Since most of rain water in Delhi City is to be drained without pumping as mentioned above, it is virtually difficult to drain during the high water stage of Yamuna River.
(3) The development of drainage networks does not catch up with the rapid urbanization of Delhi City, and the present drainage channel networks are very insufficient in comparison to the extent of urbanization.

The government of Delhi as well as Delhi Jal Board has carried out cleaning work for the existing drainage channels, but such works have not been satisfactory due to lack of cleaning machinery. The solid wastes are being dumped into the channels in spite of the protective fence constructed around drainage channels. Although the development of various drainage facilities and the network of drainage channels are planned and partially implemented, the development could not cope with the rapid expansion of urbanization of Delhi City.

The local flooding of Delhi can be attributed to following factors:

i) Unlined open sewerage drains have resulted in a number of environmental problems. In the Najafgarh area, in the west and in some areas east of the Yamuna River, these drains have acted as influent seepage channels, and have polluted shallow aquifers through the infiltration of leachate. The drains were initially designed to transport excess storm water and sewerage flow. However, due to poor design and improper maintenance and unsuitable geomorphic conditions, these now form pools of stagnant water in north-west and northern parts of Delhi and are potential sources for groundwater pollution and sites for mosquito breeding. These drains join the Yamuna River at its lowest flow level, thus resulting in back-flow due to the rise in water level in the Yamuna River during monsoon showers. The Najafgarh drain passes through structurally weaker zones that act as channelways in unlined sections of the drain and directly pollute the aquifer system in its area of influence.
ii) The area to the east of Delhi Ridge is one of the heavily populated regions of Delhi and also includes 'Connaught Place', the hub of commercial activity. Unfortunately, it is also the site for heavy water impounding during storm showers causing disruption of traffic and normal life. This may be attributed to providing concrete surface over the entire available surface on the pretext of beautifying the area. The non-availability of sufficient recharge surface has compounded the problem of water impounding. These features were overlooked while developing the area.

iii) In some of the regions of Delhi, the old practice of human fecal disposal into soak-pits/septic tanks is being followed. The influent nature of open drains in these areas has changed the geo-hydrological scenario by lowering the water table and by development of artificial recharge mounds at several locations. This has led to surface inundation/ impoundment on one hand, and pollution of shallow aquifers on the other. The failure of septic tank-soakpit systems, particularly during monsoon, can largely be attributed to water table rise. These problems have arisen by ignoring basic geomorphic parameters like slope-morphometry, groundwater conditions, soil characteristics, subsurface lithology, etc.

iv) Three barrages have been constructed on the Yamuna River in the Delhi region, probably without much morphological considerations. These are either in non-water tight locations or adjoining weak zones. As a result, the Yamuna River has locally developed an influent behaviour in contrast to its general effluent nature, as is seen in Kalindi Kunj area of south of Delhi.

Structural measures for mitigation of Floods.

The National Capital Territory of Delhi has been experiencing floods, mainly from Sahibi Nadi (passing through Najafgarh Drain in Delhi) and Yamuna River. Local drainage system has also been found to be inadequate to meet the requirement whenever there is heavy rainfall in the catchment of these drains or during in flow of flood water from adjoining states in Yamuna river. Several flood mitigating measures like raising and strengthening of Yamuna marginal embankments, remodelling and lining of Najafgarh Drain for a discharge of 10,000 cusecs from Kakraula regulator to its outfall into river Yamuna, strengthening of Dhansa Bund, Construction of Supplementary drain to Najafgarh Drain to cater to excessive in-flow of flood discharge in the Najafgarah Drain have been taken up over the years so that there is no repetition of flood like the one experienced in Najafgarh drainage system in 1997 and in Yamuna river during the year 1997-98.

The marginal embankments along Yamuna River in Delhi can withstand only a discharge upto 2.5 lakh cusecs in the river against the requirement of 3.5 lakh cusescs for a flood frequency of one in hundred year as is suggested by Central Water Commission, Govt. of India. The work relating to construction of Supplementary drain to Najafgarh Drain was supposed to be completed in the 10th Five Year Plan. So far, 82% of the works on this project has been completed. In order to identify the weakness in the flood management system and to suggest remedial measures, the then Chief Minister, Govt. of Delhi constituted an 11 member committee in 1995 headed by Minister of Development

and Education Govt. of Delhi. The committee recommended the following short term and long term measures relating to the works of Irrigation & Flood Control Department.

Short Term Measures

I. Flood Proteaction/Embankment Works

1. Strengthening of right marginal embankment of Yamuna River from Palla to Jagatplur including jagatpur Bund.
2. Raising and strengthening of Yamuna Bazar Wall.
3. Construction of new walls from Metcalf house to Qudsia Ghat drain, Strengthening of river training works along left forward bund near Sonia Vihar
4. Improvement of Shahdara Marginal bund from Loni Road to G.T. Road
5. Improvement and strengthening of river training bund along left forward bund from old Railway bridge to Noida Bund
6. construction of Mundela bund along Delhi-Haryana Border near Mundela Khurd Village.

II. Elaborate desilting of Najafgarh Drain which is lifeline of present drainage system of Delhi by way of deployment of draglines, dredger and pumping of silt in Yamuna. The desilting work is shown in Figure 9.

Figure 9 Desilting work going on at Najafgarh Drain.

III. Making supplementary drain functional by way of excavation lining and improvement of drainage network in Najafgarh and Kanjhawala Block byremodeling various existing drains.

Long Term Measures

1. Flood Protection/Embankment works.
   i. Construction of new embankments from Palla to G.T.Road.
   ii. Raising of right side bund downstream of Okhla Barrage.
   iii. Strengthening of Eastern and Westren marginal bund of Yamuna River downstream of old Railway Bridge after removal of jhuggies.
   iv. Completion of Jahangirpuri Drain and completion of balance work of supplementary drain.
2. Improvement of major drains namely Bawana Escape drain, Palam drain, Pankha Road Drain, Mundella Drain, Karari Suleman Nagar Drain, etc.
3. Apart from remodeling, permanent pumping arrangement with captive power should be made at outfall of some of the drains of Alipur Block like Burari Drain, Burari Creek and in Shahdara Block for drainage of area located between Shahdara Marginal embankment and left Forward Bund in Sonia Vihar & Rajiv nagar, etc.
4. New Trunk Drains in Sarita Vihar and Dwarka residential area are required to be constructed.
5. Alternative ponds are to be developed in place of village ponds which are coming inside village boundary so that new ponds may moderate the flood discharge and help in recharge of ground water. In addition to this a number of water harvesting schemes have also been taken up by deepening of existing drains such as Bawana Escape drain, Najafgarh drain and Mungeshpur drain.

Non Structural Measures

To cope up with monsoon the Irrigation & Flood Control. Department (I&F) undertakes pre-monsoon anti water-logging & flood control measures every year, like desilting of all the Trunk Drains, restoration of anti erosion works like spurs, installation of control rooms and check post at various stations etc.

A **Flood Control Order**, giving contingencies plans to meet any serious floods in river Yamuna, is issued every year prior to onset of monsoon.

The Divisional Commissioner who is incharge of Flood Control and Relief Measures functions as Convenor Secretary of the Committee. He is assisted by Deputy Commissioner (East) in discharging his functions.

The Apex Committee under the chairmanship of Hon'ble Lieutenant Governor of Delhi meet on the last week of June every year to take the stock of preparations. The committee also meets during the monsoon depending on the exigencies assessed by the

Central Flood Control Room (vested with the responsibility). A brief account of the Central Flood Control Room and its functionality is described below.

A Central Flood Control Room is established to assist the Apex committee and functions round the clock in Room No. 13, A Block Office of the Deputy Commissioner (East) L.M. Bund, Shastri Nagar, Delhi w.e.f. 15th June to 15th Oct. every year or till monsoon withdraws, whichever is later. The S.D.M. Vivek Vihar is the Officer-in-charge of the Central Flood Control Room. Contact Telephone No. of this Control Room are 22444254 & 222444255.

The organizations/offices which depute a Liaison Officer (of a fairly senior level) to be available in this control Room in each shift are shown in Table 5 [8]:-

Table 5: Departments/organizations which Liaison with the Central Flood Control Room

• **MCD and NDMC**
• **Police**
• **Transport**
• **Health**
• **Home Guards & Civil Defence**
• **Food & Civil Supplies**
• **Flood Control Deptt.**
• **Delhi Development Authority**
• **Education Department**
• **P.W.D., Govt. of Delhi**
• **Delhi Vidyut Board**
• **Delhi Jal Board**

The deputed officers are present in the Flood Control Room after receipt of the first warning signal. Liaison Officers from Army/Air Force are also posted to the Central Flood Control Room when the Army /Air Force help is requisitioned by the Government of Delhi.

Following are the major functions of Central Flood Control Room:-

1. Receive flood warnings and other related information.
2. Submit Flood situation reports to the Chief Minister, Chief Secretary, Divisional Commissioner and Secretary (I&F) every evening, or as and when the circumstances may require.
3. Convey Flood situation reports and orders relating to flood control measures to the Sector Officers/Sector Control Rooms and the concerned Organisations/Departments of the Administration (through their Liaison Officers).
4. Issue necessary Flood warnings and directions for evacuation.
5. Arrange necessary food articles and relief supplies.
6. Maintain Liaison with Upper Yamuna Division of C.W.C., R.K. Puram, New Delhi and Army/Air Force, when ever required.
7. Maintain a fleet of vehicles needed for mobility of staff and the relief measures.

The control Room maintains a log-book of the messages received and dispatched by it. The directions received from the senior officers and transmitted are also recorded in the log-book under the initials of the Officer Incharge.

Flood Control Room of Irrigation & Flood Control Department is also set up at Inter State Bus Terminal, Kashmirigate in the office of the Chief Engineer (I&F), Govt. of Delhi. The Control Room remains in constant touch with wireless station at R.K. Puram-Central water Commission; Room No. 13 Office of the D.C. (East), L.M. Bund, Shastri Nagar. Delhi, and Coordinates the activities of the Flood Control Deptt.

In addition to the above, a number of regional posts and wireless stations of Flood Control Department are also set up at the important locations along River Yamuna, Najafgarh Drain, Supplementary Drain, Jahangir Puri Outfall Drain and Trunk Drain No. 1 to monitor the situation regarding floods or drainage congestion and handle any eventuality, effectively.

What went wrong?

Being the capital of India, the land–water system in this region has been under tremendous stress to accommodate a growing population and rapid urban industrialization of the region.

To accommodate heavy urbanization and population rise, the area has undergone tremendous environmental degradation resulting from a mismatch between adopted land use and drainage plan. The Delhi region is an example of regrettably ignored geomorphic inputs though essential in planning and urban development.

Delhi state has flat land, however there is a big depression in the southwest known as the Najafgarh jheel area, which receives the drainage from the adjoining states of Haryana and Rajasthan. The only outlet for these waters is the Yamuna.

The Sahib river that flows through Rajasthan and Haryana used to be absorbed in the sandy areas of Haryana and has no definite course downstream of Masani in Haryana. The waters of the Sahibi flow into Delhi through the Dhansa bund. The waters find a final outlet in to the Yamuna (throught eh Najafgarh nala) below wazirabad. There are barrages across the Yamuna in Delhi at Wazirabad, Indraprastha and Okhla. There are also some 18 drains that join the Yamuna in Delhi. Delhi's flooding is due to

- Spills from the Yamuna
- Drainage congestion due to intense rainfall
- Flooding from various drains of Haryana and the Sahibi nadi.

The Delhi region exhibits a very gentle southerly master slope as indicated by the southerly flow of the Yamuna River, except at some places where the slopes have been locally reversed. The general slope in the region east of the Yamuna River is westerly. Similarly, the change in slope direction is also noticed west of the Yamuna adjoining Okhla Barrage.The southerly and westerly flowing drainages change to the north easterly direction in the western part of area and join the north easterly flowing Najafgarh drain.

But what of course is surprising is the spread and damage experienced in the flood plain from a rather 'medium level' flood of 205.71 m as against all previous 'high' floods of 206 m and above. Clearly the observations made in the NEERI 2005 report that "the river has lost its carrying capacity and hence its remaining flood plains should not be compromised in any manner" are proving to be prophetic [12].

Strategies For The Future

Some of the popular non structural measures that can be adopted are discussed in brief here under:

Flood forecasting: Flood forecasting enables forewarning as to when the river is going to use its floodplains, to what extent and for how long. With reliable advance information/warning about impending floods, loss of human lives and moveable properties and human miseries can be reduced to a considerable extent. Flood forecasting and flood warning in India was commenced in a small way in the year 1958 with the establishment of a unit in the Central Water Commission (CWC), New Delhi, which is now responsible for issuing forecasts at 157 stations, of which 132 are for water level forecasting and 25 for inflow forecasting, used for optimum operation of certain major reservoirs. These stations are located in 11 flood prone states and two union-

territories. The accuracy of the forecast made by the Central Water Commission is increasing with time(CWC 1996) To improve the quality of forecasts further, the modernization of existing networks has been undertaken with international agencies, developed nations and national institutions such as UNDP, USAID, World Bank, IIT etc.

Dam break flood wave simulation: Worldwide many types of dam break models exist ranging from simple computations based on historical dam failure data that can be analyzed to complex models that require computer analysis. These models simulate the breach on the dam, and route the flood through the downstream terrain of the valley. Such information is very useful for planning purposes.

Flood inundation mapping: For flood mitigation measures and land use planning, flood inundation mapping is an important activity. Mathematical models are available that can predict the inundation knowing the forecasted flood. The Satellite remote sensing technology is also extremely useful in monitoring the dynamics of water spreads during the floods. Analysis of remotely sensed data gives a reasonable accurate assessment of water spread directly from the satellite images as a just processed information.

Flood plain zoning: A flood plain zoning means categorizing various zones based on administrative legislations for planning and development of the flood plains for various purposes such as agricultural activities, play fields, industrial areas and residential areas etc. Preparation of flood plain zoning maps takes into consideration the inputs from flood inundation, flood hazard and flood risk zone maps (NIH, 1988-89). The important aspect of zoning is that it can be used to regulate what uses the land can be put to and what kind of construction can be carried out on such areas. Zoning is also used to restrict riverine or coastal areas to particular uses, specify where the uses may be located and establish minimum elevation or flood proofing requirements for the uses.

However, many flood prone states in India have not adopted the recommendations regarding flood plain zoning and a continued persuasion for this purpose is essential.

Flood Insurance: In developed countries flood insurance scheme is found to be most effective method to regulate the land uses in the flood plains. Basically under this scheme, depending upon the nature and location of establishment in the flood plain, insurance premiums are charged. The insurance plan warrants a very high premium from the persons going for the costly establishments in the flood plain very close to the river banks. In India, at present, this scheme is not yet implemented.

Decision support system for real time flood warning and management: Decision support system for issuing the flood warning and managing the flood in real-time is an advance software which is capable of providing the information to the decision makers

for taking the necessary measures for managing the floods in real-time. Such system requires the spatial and temporal databases which include the basin characteristics, hydro- metreological variables, social and economical data etc. The databases are linked to the mathematical models developed for each component of DSS. The temporal information about the hydro-metreological variables are made available in the real time and the system provides the hydrographs of the river stages and corresponding discharges at required lead times. Such information is very much useful for the decision makers to take necessary actions for preparing the evacuation plan in real time during the flood.

For the development of such DSS in India, efforts are being made by some academic and research institutions on pilot scales. However, under the World Bank funded Hydrology Project II, which is under operation since2006, the development of DSS for real-time flood forecasting is one of the important proposed activities. The Hydrology Project II is being implemented by Ministry of Water Resources. In this project 13 States and 8 Central agencies are participating.

International cooperation: India is drained by a number of international rivers that originate beyond its borders and flow into India. India shares river systems with six neighbouring countries: namely Nepal, Bhutan, China, Myanmar, Bangladesh and Pakistan. Bilateral cooperation for various flood management measures is essential for India and the concerned country. Government of India has already taken initiatives in this regard. However, more active participation in the subject is required since river system do not understand the political boundaries and an integrated approach is the only way forward for effective management,

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