CLIMATRANS

Report on

Impact of Floods in Delhi

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Contents

1. INTRODUCTION

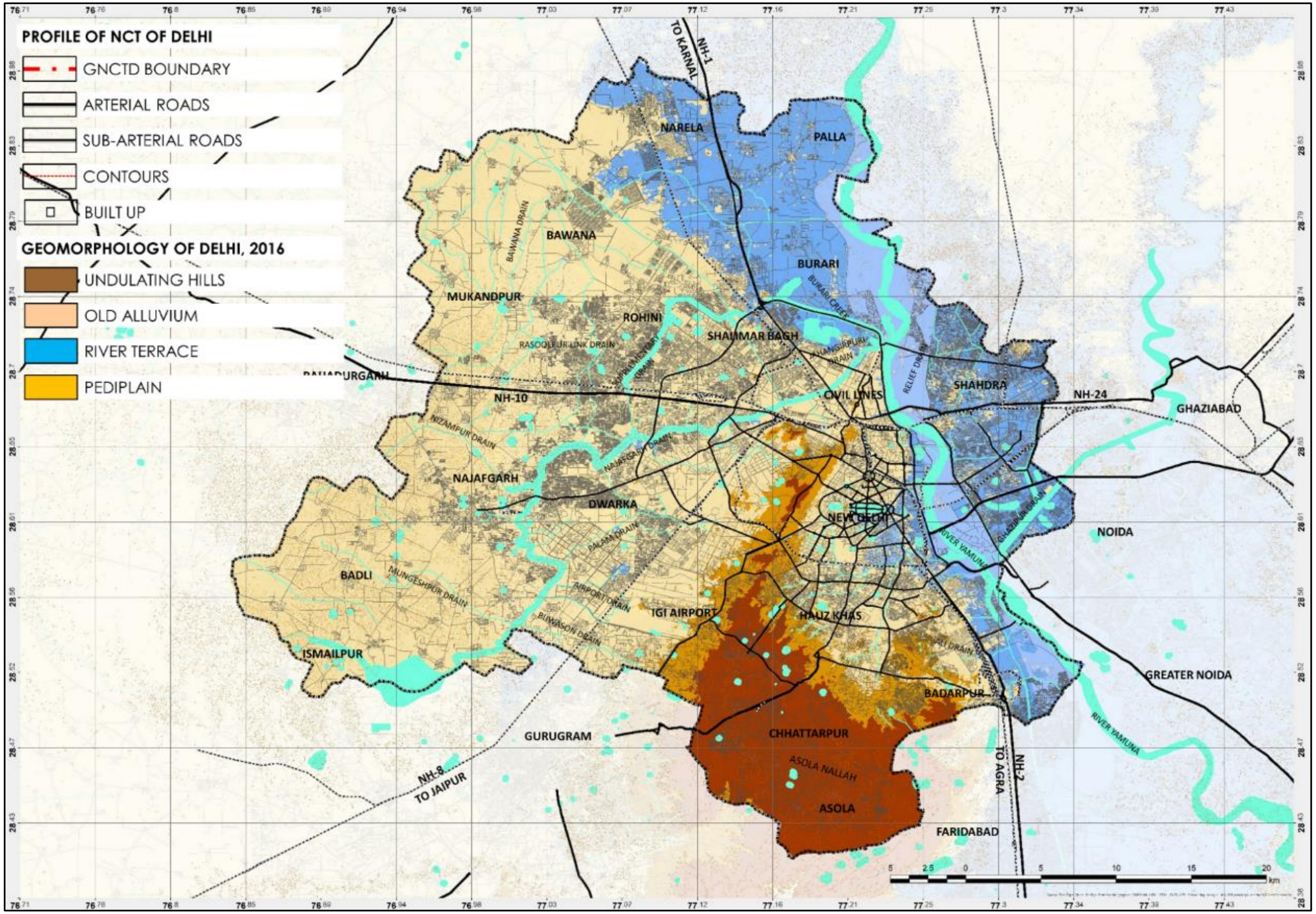
Delhi is located in northern India and shares borders with the States of Uttar Pradesh and Haryana. It has an area of 1,483 square kilometres with maximum length of 51.90 kilometres and greatest width of 48.48 kilometres. It is situated on the right bank of the river Yamuna at the periphery of the Gangetic plains. To the west and south-west is the great Indian Thar desert of Rajasthan state and, to the east lies the river Yamuna across which has spread the greater Delhi of today. The ridges of the Aravelli range extend right into Delhi proper, towards the western side of the city, and this has given an undulating character to some parts of Delhi. The meandering course of the river Yamuna meets the ridge of Wazirabad in the north; while in south, it branches off from Mehrauli.

1.1 PHYSICAL CHARACTERISTICS OF DELHI

1.1.1 Geomorphology

Delhi is bounded by the Indo-Gangetic alluvial plains in the North and East (as indicated in Fig. 1.1), by old alluvium in the West and by Aravalli hill ranges in the South. The terrain of Delhi is flat in general except for a low North East to South West trending ridge that is considered and extension of the Aravalli hills of Rajasthan. The ridge may be said to enter Delhi from the South West. The eastern part of the ridge extends up to Okhla in the South and disappears below Yamuna alluvium in the North East on the right bank of the river.

Fig. 1.1: Geomorphology of Delhi, 2016



Compiled by Author (2017)

1.2 Hydrology

In terms of hydrology, fresh water is available up to 60 metres depth below ground level (as indicated in Fig. 1.2) for over 90 per cent of the city, and the quality of water is also potable. For the 10 per cent of city limits comprising of the Ridge, that is not suitable for water recharge or aquifer; the remainder has saline and brackish waters. In terms of groundwater potential (as indicated in Fig. 1.3) of the city, area covered by younger alluvium has the potential to yield 800 litres per metre (lpm) to 3200 lpm. For areas under older alluvium, the yield is 400 lpm to 500 lpm. While for fringe areas, yield is low at 150 lpm to 300 lpm and for the Delhi quartzite or the area under Delhi ridge, the yield of groundwater is limited at 100 lpm to 150 lpm.

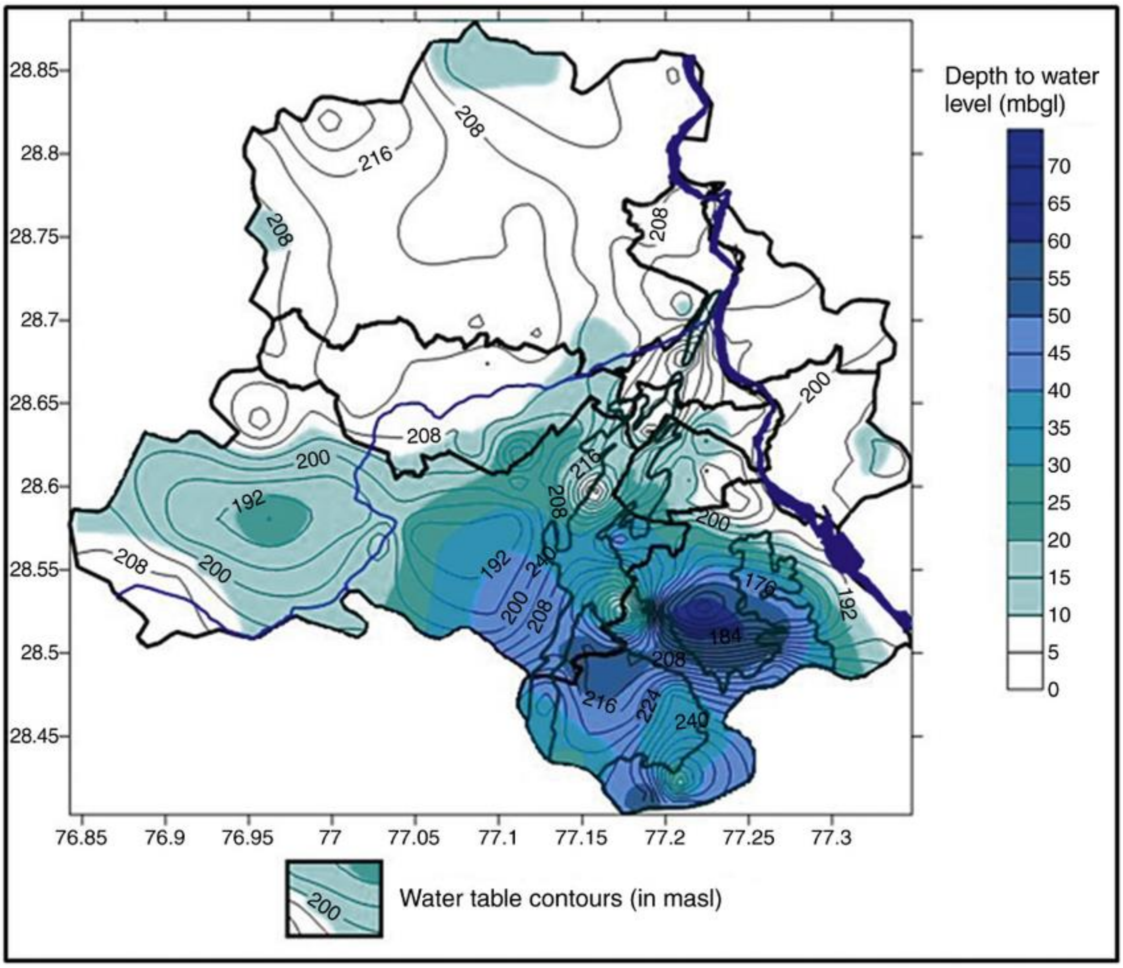


Fig. 1.2: Hydrology of Delhi, 2016

CGWB (2016)

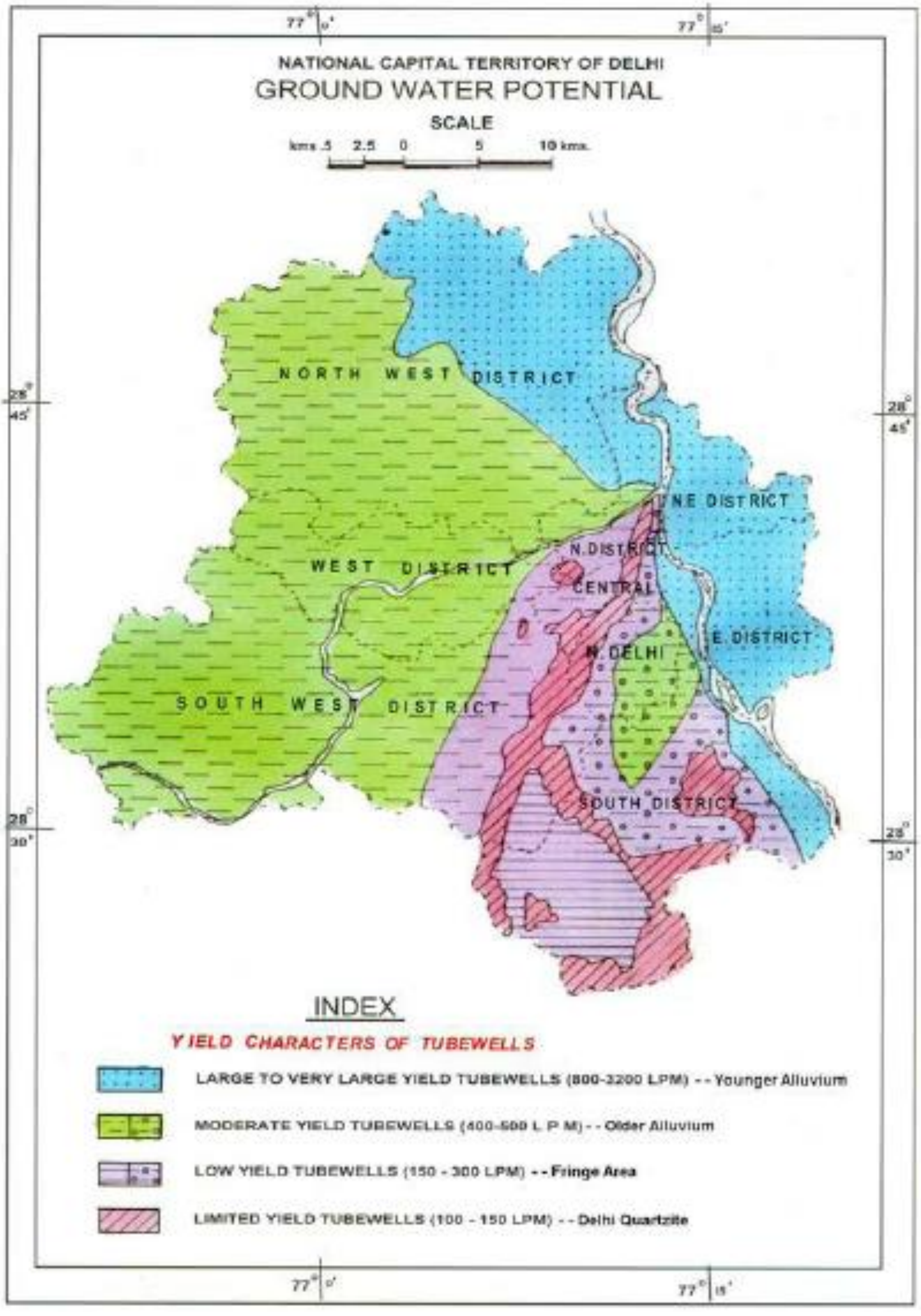


Fig. 1.3: Groundwater Potential of Delhi, 2016

CGWB (2016)

1.3 Land Use Pattern

The city of Delhi has been sub-divided into 9 use zones (as indicated in Table 1.1) as per the master plan of Delhi. At present, the city's land use is dominated by residential use (as indicated in Fig. 1.7) at 63 per cent followed by recreation at 21 per cent and transportation at 17 per cent of city's total developed area. With the phasing out of industries from Delhi post 1990s Supreme Court order, the industrial use has come down to 5.3 per cent while commercial use continues to grow and stands at 6.1 per cent.

Table :1.1 Land Use of Delhi, 2016

Land Use	Area (in sqkm)	%
Residential Use	549	37.0
Commercial Use	53	3.6
Industrial Use	46	3.1
Public Semi-Public Use	103	7.0
Recreation	182	12.3
Transportation	148	10.0
Utility	36	2.4
Government Use	55	3.7
TOTAL =	1,483	100

Compiled by Author (2017)

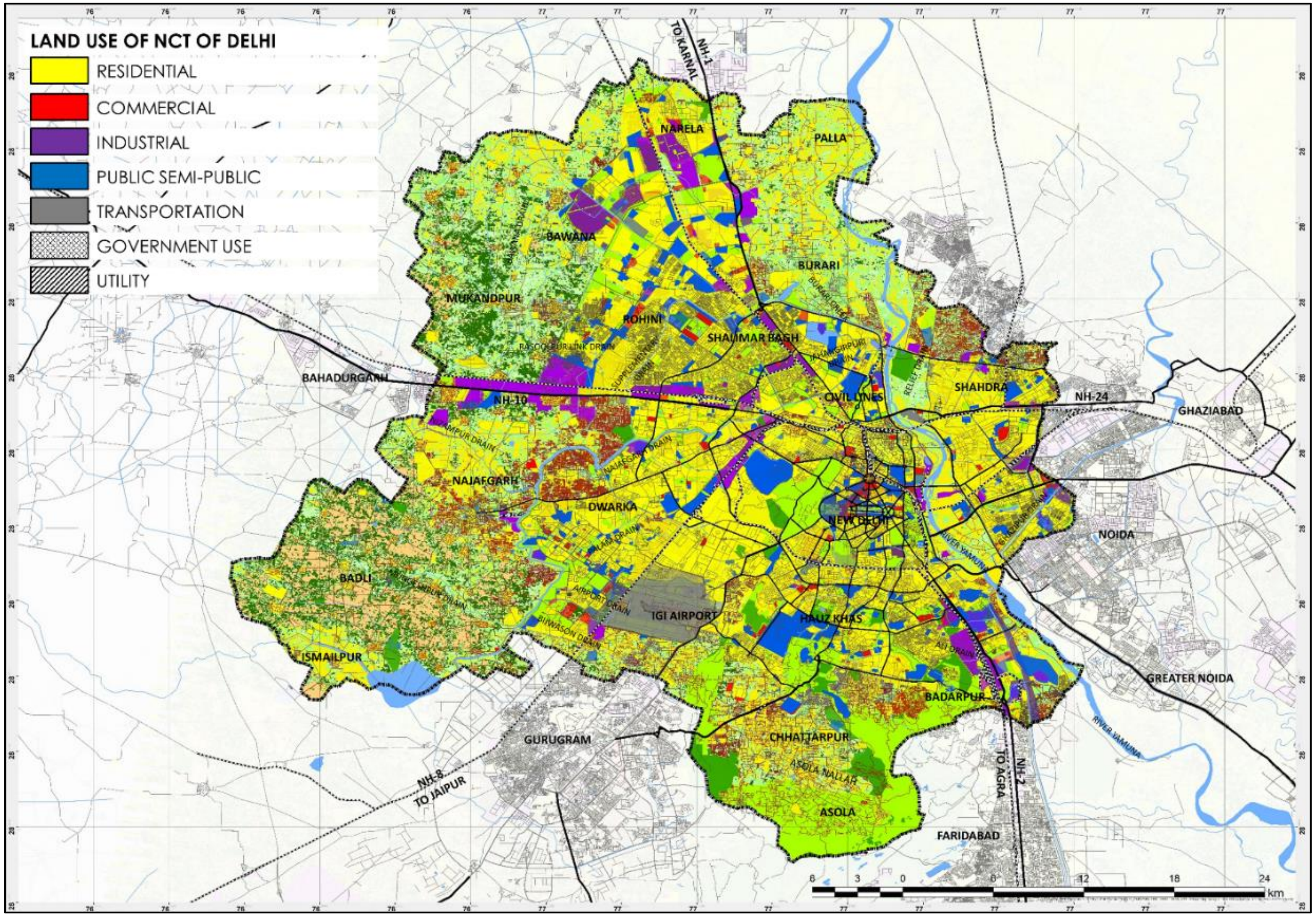


Fig. 1.4: Land Use of Delhi, 2016

Compiled by Author (2017)

A study conducted on Delhi metropolitan area measured growth between two time periods (1989 and 2011) using Landsat images of 1989 and 2011. This study is based on the detection of change in the urban land cover around Delhi using temporal data of Landsat TM 5 (Thematic Mapper 5). The results showed that there was rapid change in land cover/land use. It was found that there was a phenomenal change in the built-up area in watersheds, loss of forest cover and change in agriculture land.

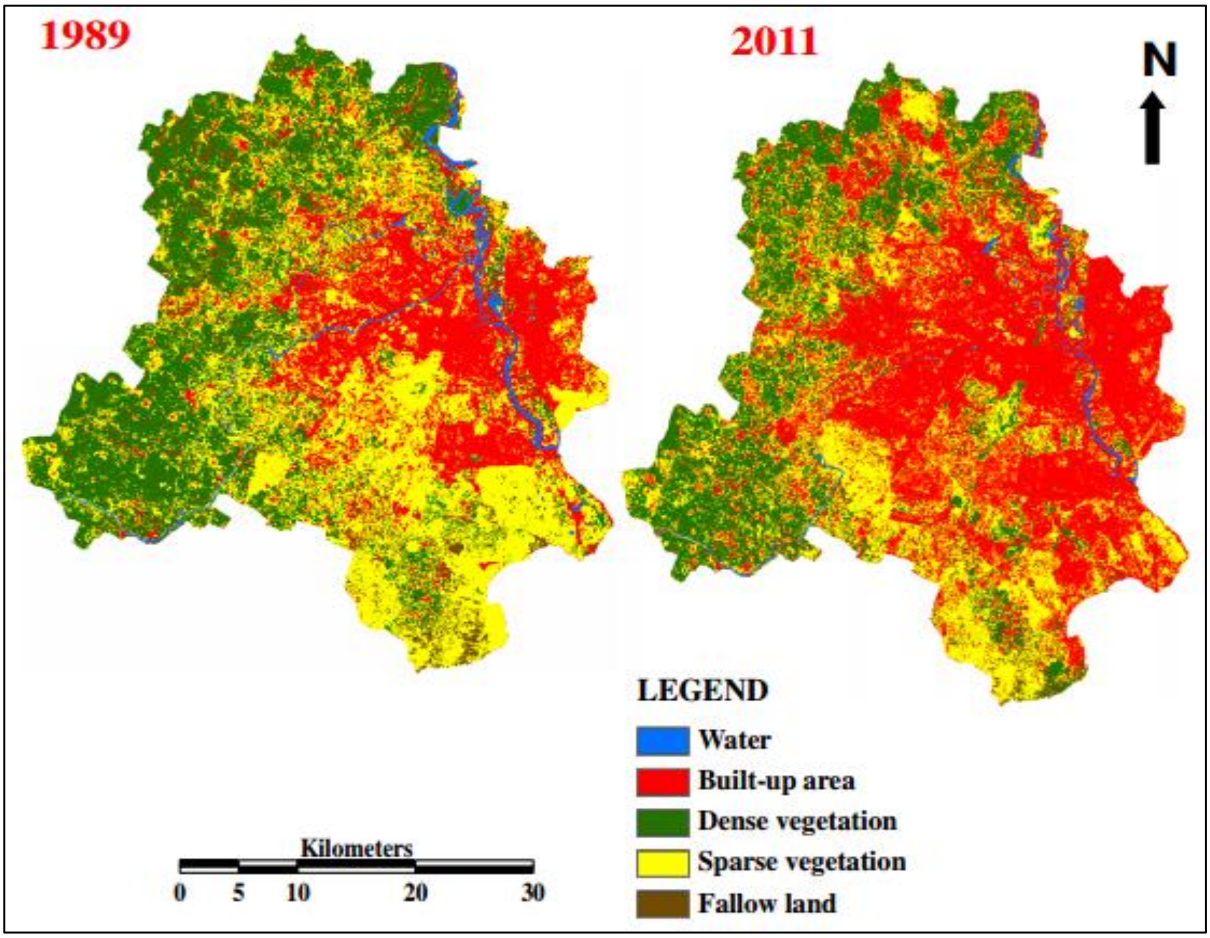


Fig. 4 Land use - land cover maps of 1989 and 2011 (Source: Mukhopadhyay, et al., 2013

Public semi-public use includes 12 per cent of city's developed area while area under utilities and government use equals to 4.2 per cent and 6.4 per cent respectively.

1.4 TRANSPORTATION NETWORKS

The National Capital Territory of Delhi comprises a vast network of hierarchical transportation network (as indicated in Fig. 1.9). The road network exists in a hierarchy of National Highways, arterial roads, sub-arterials, collectors and local roads at neighbourhood level. The length of road network has extended four times from 8,231 kilometres in 1985 to 34,012 kilometres in 2016, as indicated in Fig. 1.8 (GNCTD. 2016).

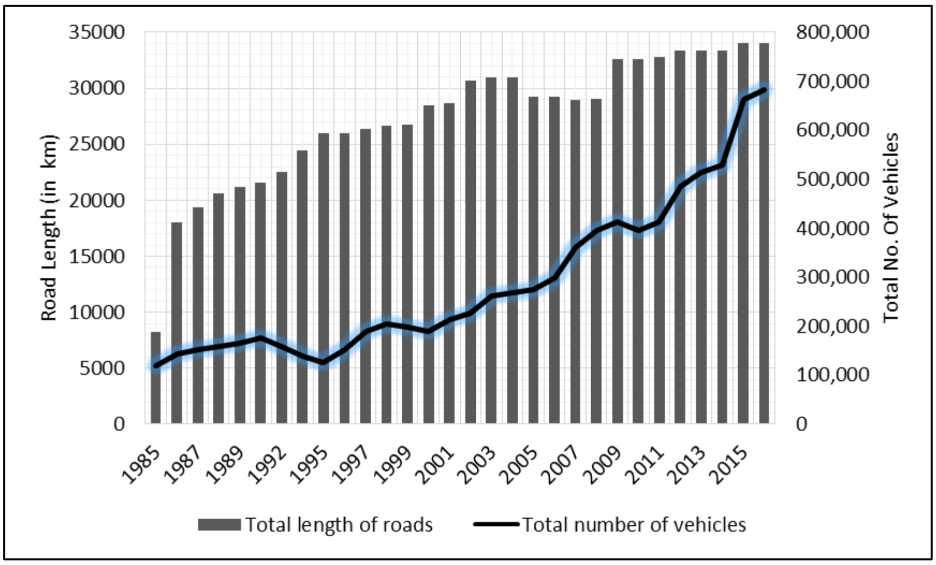


Fig. 1.5: Growth of road network and vehicles in Delhi, 1985-2016

Compiled from GNCTD (2016)

The city is connected by national highways (as illustrated in Fig. 1.9) connect the city with cities and regions beyond its administrative boundary. For instance, NH-1 connects Delhi to Karnal in north while NH-10 leads to Bahadurgarh and Rohtak in west, NH-24 connects city to Ghaziabad, Noida and Greater Noida in the east and NH- 2 connects city to Gurugram and leads to Jaipur in South. Apart from National highways, the intra-city connections are supported by network of arterial and sub-arterial roads which are fed by collector roads at community and local roads at neighbourhood level. The city mobility is also dependent upon its 213 kilometres of Metro network, which covers a considerable part of Delhi and also the suburbs. The city also has a fleet of Delhi Transport Corporation plied bus services, which has been an essential mode of mobility of Delhi, much before metro came into being. Apart from public transportation and road networks dominated by private vehicles, the city also has a system of para-transit which comprises of e-rickshaws, auto rickshaws and cycle rickshaws.

1.5 DRAINAGE PATTERN

Delhi comprises of 24,840 hectares of flood plains of which 68 per cent forms a part of river Yamuna floodplains. The city has three drainage basins based on the watershed of drains that includes North Basin with a basin area of 26,694 hectare; West basin with an area of 75,633 hectares and South and East Basin spread over an area of 45,973 hectares. As per the Supreme Court Order of 2014, flood plains of Delhi are delineated at 300 meters on either side of the river Yamuna, 100 meters on either sides of drains feeding Yamuna and 50 meters for tertiary drains and water bodies like lakes and ponds (as indicated in Fig. 1.10). However, the flood plains have reduced in width from an average 800 meters in 1986 to an average of 300 meters in 2016 as a result of construction and developments that came up on the flood plains and resultant loss of the eco-fragile ecosystem.

The drainage morphology of Delhi is defined in a large measure by the Aravalli foothills and connected outcrops and, under these influences, a principally easterly storm water movement is indicated from the higher elevations in the West towards Yamuna in the East. In contrast, the region to the east of Yamuna is low-lying and was originally a part of the Yamuna flood plain and, understandably, remained largely un-inhabited until after the partition of 1947. Following large scale migration of people from erstwhile West Pakistan and their re-settlement, this region, also known as the Trans-Yamuna area, is now home to about 30% of the total population of Delhi.

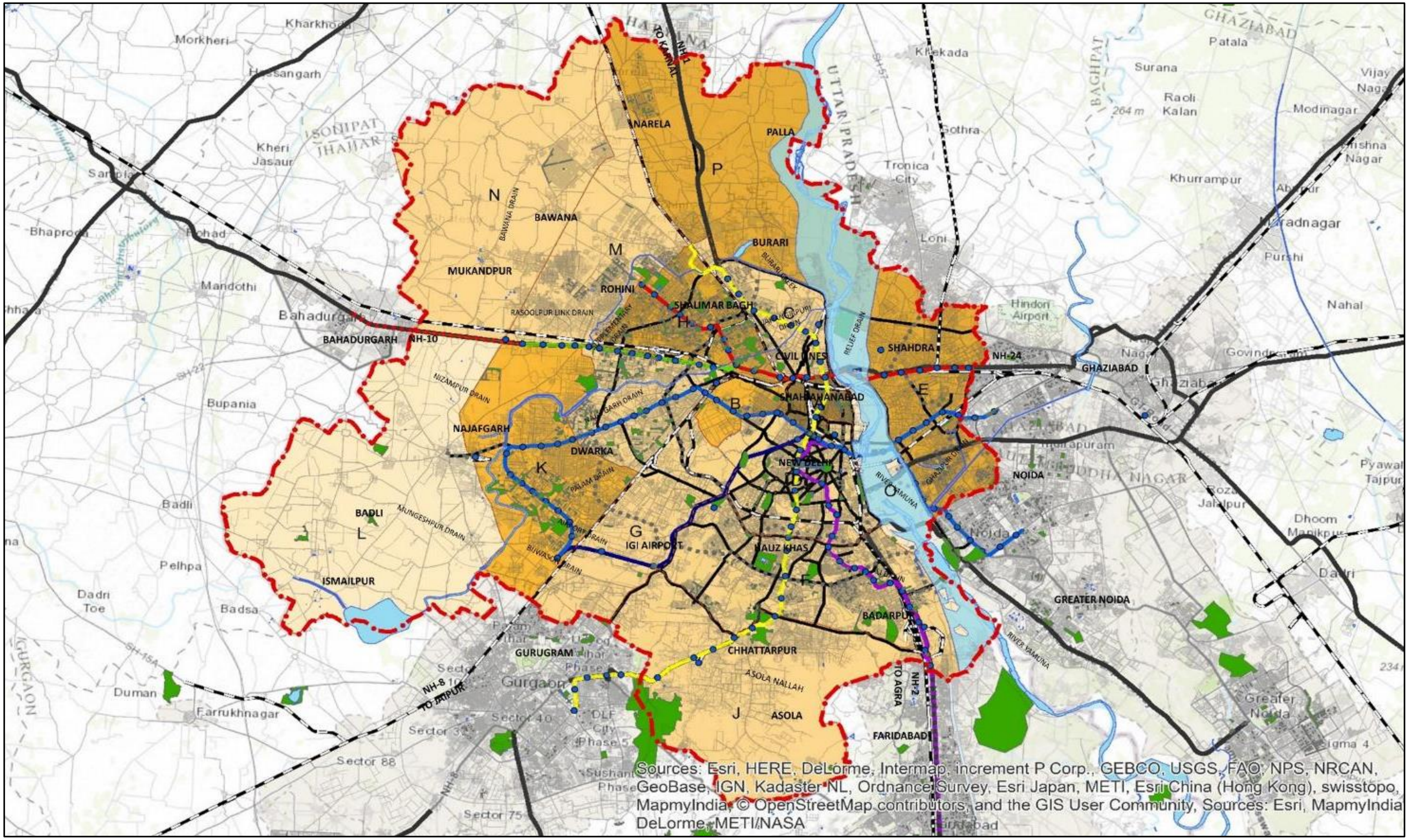


Fig. 1.6: Transportation System of Delhi, 2016

Compiled by Author (2017)

Table 1: Engineered Storm runoff system of Delhi

S. No.	Zone	No. of Drains	Total Length of Drains (km)
1.	Central	41	47
2.	South	127	102
3.	Sadar-Paharganj	10	4.5
4.	Karol Bagh	47	23
5.	City Zone	10	8.6
6.	Civil Lines	77	339
7.	Shahadra South	174	134
8.	Shahadra North	197	135
9.	Narela	84	83
10.	Rohini	142	180
11.	West	185	410
	Najafgarh	202	228
	TOTAL	**1,296**	**1,694.1**

Source: Irrigation and Flood Control Department, GNCTD (2017)

The Irrigation and Flood Control Department, Government of NCT of Delhi demarcates the city into six drainage zones namely (i) Northern Zone, (ii) Western Zone, (iii) Central North West and South East Zone, (iv) Central South and South East Zone, (v) East Zone and (vi) South Zone (as indicated in Fig. 1.11). Delhi is also divided into 12 municipal zones (Table 1.2) to manage the storm runoff emanating from the entire urban expanse of Delhi and is carried by a total of 350 km of natural drainage lines and a cumulative length of 1700 km of engineered storm water drains.

With regard to the management of the storm water drainage system within NCT of Delhi, there is, conspicuously, no single institution that bears an overall responsibility of the total system. To the contrary, the administrative authority of the capital's drainage system is quixotically distributed amongst numerous civic bodies and various constituent departments of Government of NCT of Delhi as well as Government of India. These include (i) Irrigation & Flood Control, Delhi, (ii) Delhi Jal Board, (iii) various Municipal Corporations of Delhi, (iv) Urban Development, Delhi, (v) Ministry of Urban Development, GoI, (vi) New Delhi Municipal Council, (vii) Delhi Development Authority, (viii) Delhi Cantonment Board, (ix) Delhi State Industrial Development Corporation, and (x) Public Works Department, Delhi. Other departments of the Government and civic bodies whose jurisdiction does not entail any direct responsibility pertaining to the state of the capital's drainage system but nevertheless effectiveness is indeed a matter of interest includes (i) Irrigation & Flood Control, Government of Haryana, (ii) Traffic Police, Delhi, (iii) Geo Spatial Delhi Ltd., (iv) Central Water Commission, GoI, (v) Indian Meteorological Department, (vi) Various Resident Welfare Associations (RWAs), (vii) Central Pollution Control Board of Ministry of Environment and Forests, GoI, (viii) National Green Tribunal, (ix) National Highway Authority of India, (x) DIAL and (xi) Civil society activist groups. That is, the drainage system of the city and issues related to it, especially during monsoons, remain entangled in the blame-game.

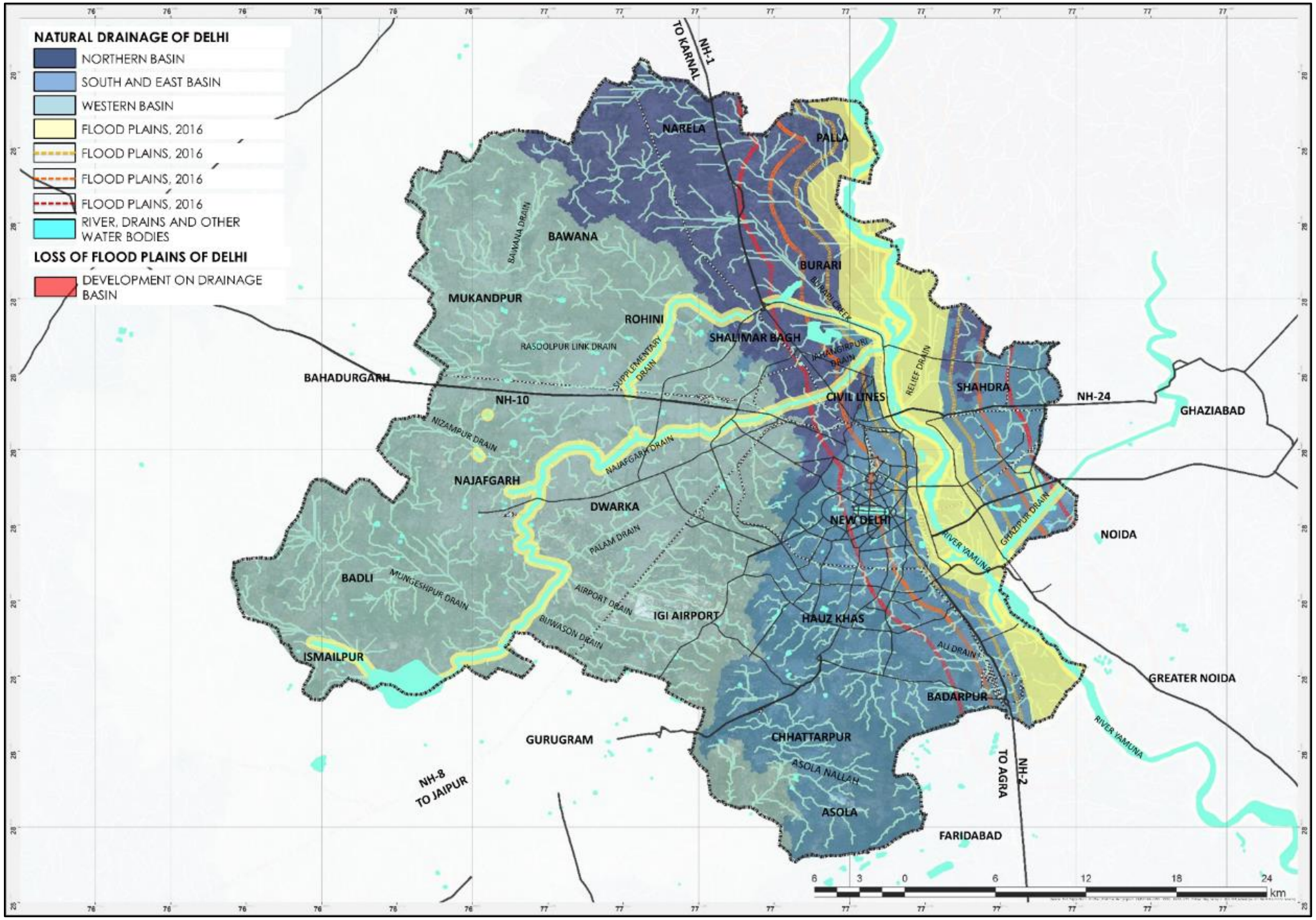


Fig. 1.7: Drainage pattern of Delhi and its Flood Plains

Extracted by Author (2017) from USGS (2016)

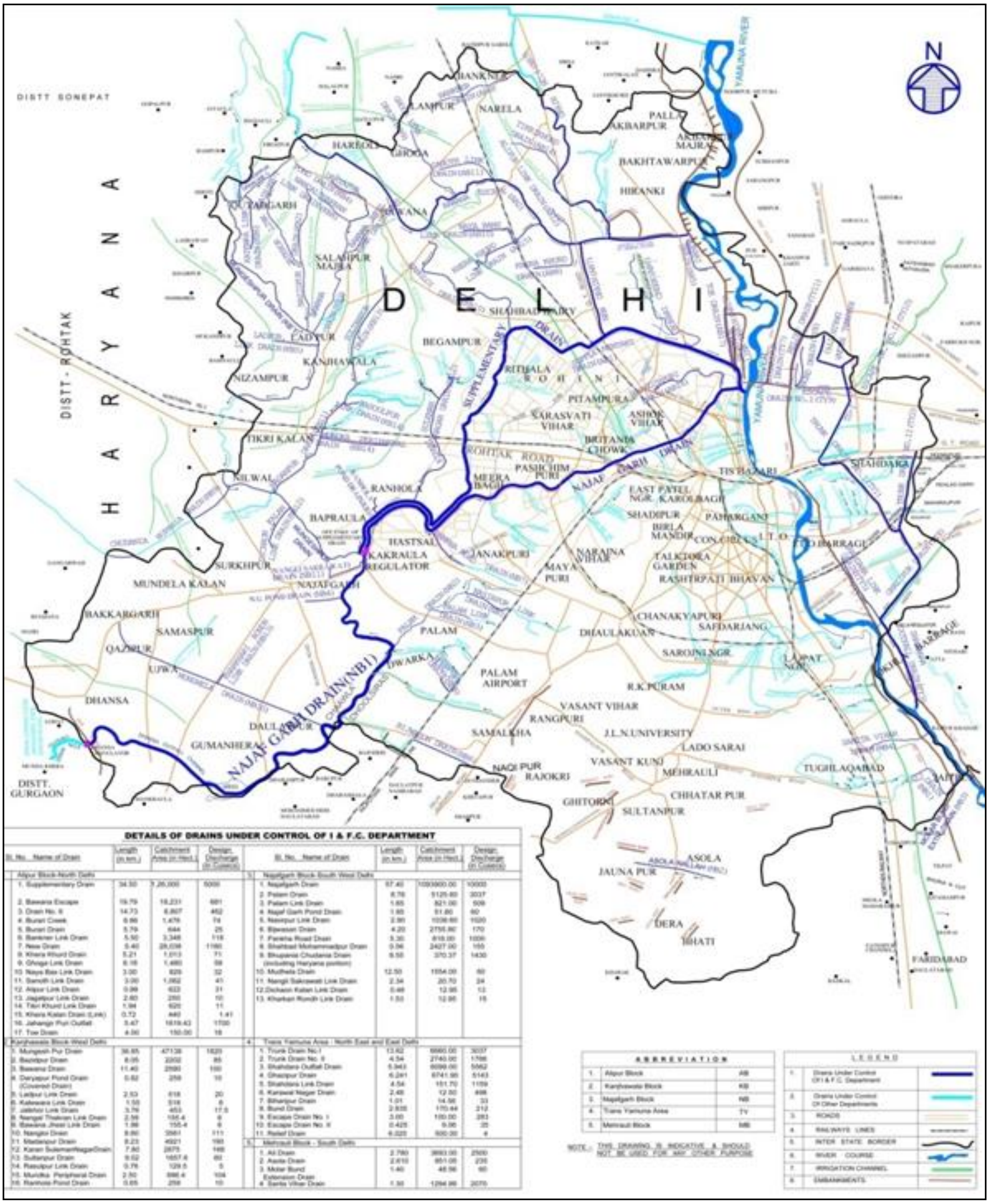


Fig. 1.8: Drainage pattern of Delhi as per the Drainage Master Plan of 1976

Source: Irrigation and Flood Control Department (1985)

2 FLOOD PATTERN OF DELHI

2.1 Trend of Annual Precipitation

The annual precipitation variability is assessed in terms of annual rainfall and annual number of rainy days for a time frame of 115 years, which is 1901 to 2016. The trend of annual precipitation post 1901 (as indicated in Fig. 1.12) indicates that the average rainfall has increased by 210 millimetres but the periods of drought have become longer than periods of heavy rain.

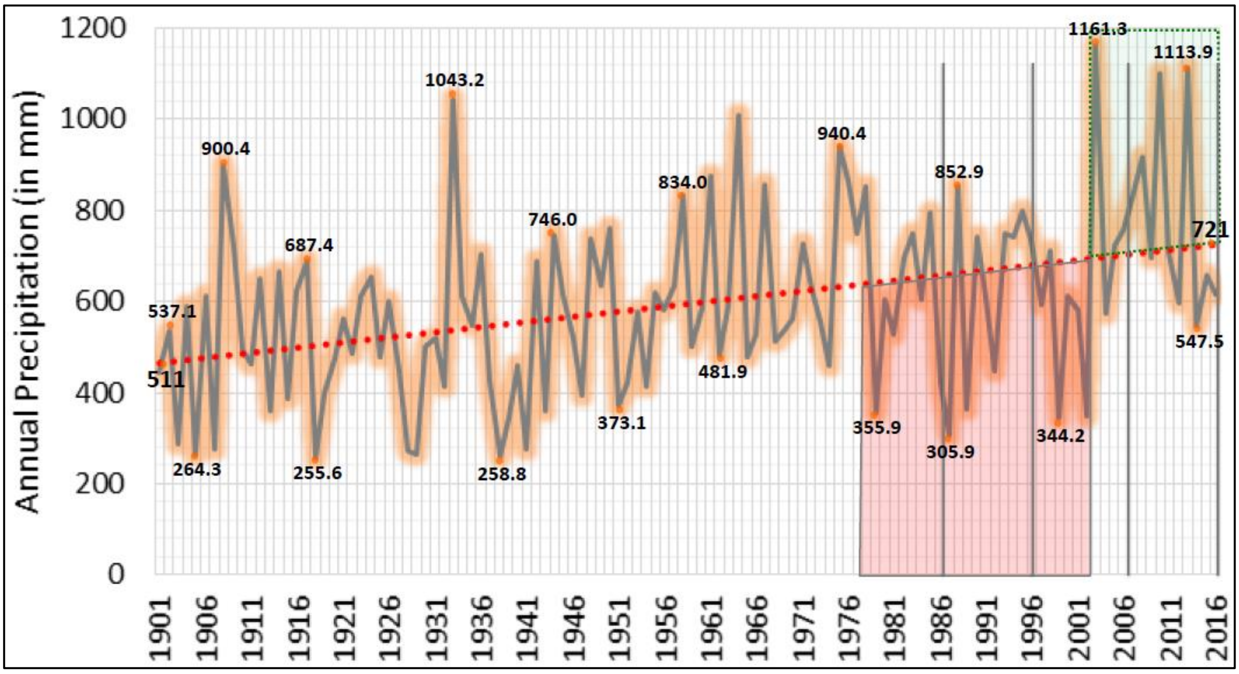


Fig. 1: Change in Annual Precipitation for Delhi, 1901-2016

Source: IMD (2016)

Assessing the trend of number of rainy days for Delhi (as indicated in Fig. 34) in the same time period indicates that the average number of annual rainy days have increase by 9 rainy days while the average precipitation per rainy day has increased by 2.5 per cent.

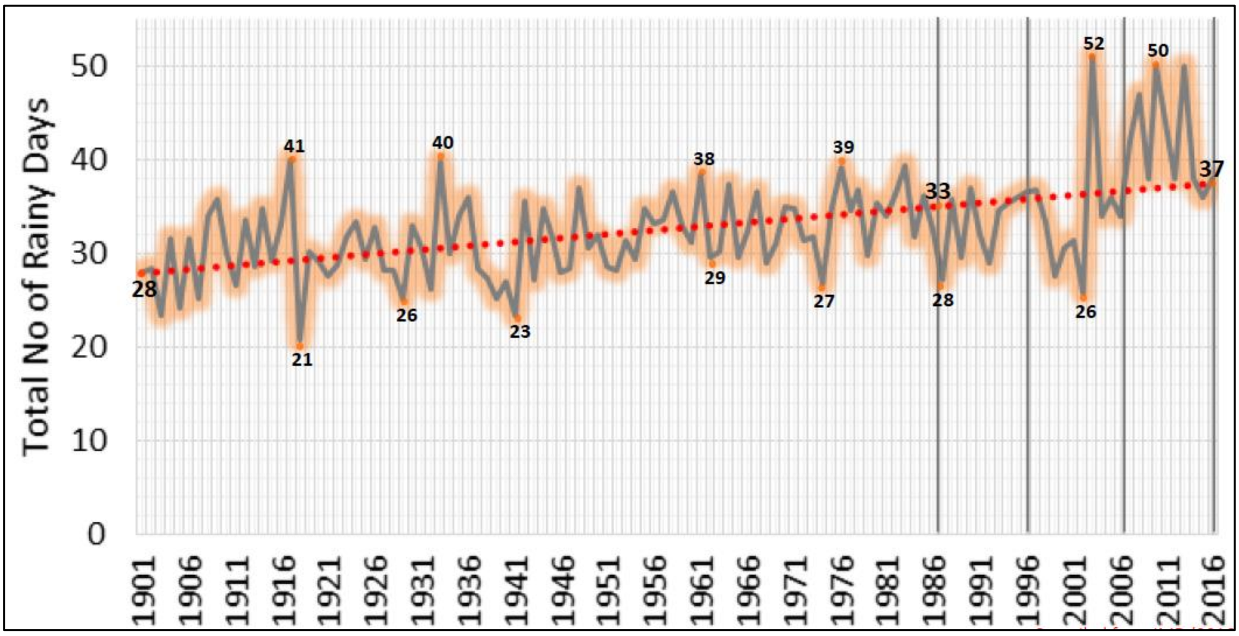


Fig. 1.13: Change in Annual Number of Rainy Days for Delhi, 1901-2016

Source: IMD (2016)

Summing up, it is evident that the annual precipitation and number of rainy days are increasing; the actual duration of precipitation has reduced leading to a sharp rise in rainfall intensity from 13.2 mm/hour in 1986 to 22.9 mm/hour in 2016, the latter leading to inundation of over 50 per cent of city in 2016 in three hours.

2.2 Seasonal Precipitation Variability

The seasonal precipitation variability is assessed in terms of seasonal share of annual precipitation and rainy days for the timeframe of 115 years (1901-2016). Analysis of seasonal share of annual precipitation (as indicated in Fig. 1.14) indicates a trend of wetter summers and drier post monsoons.

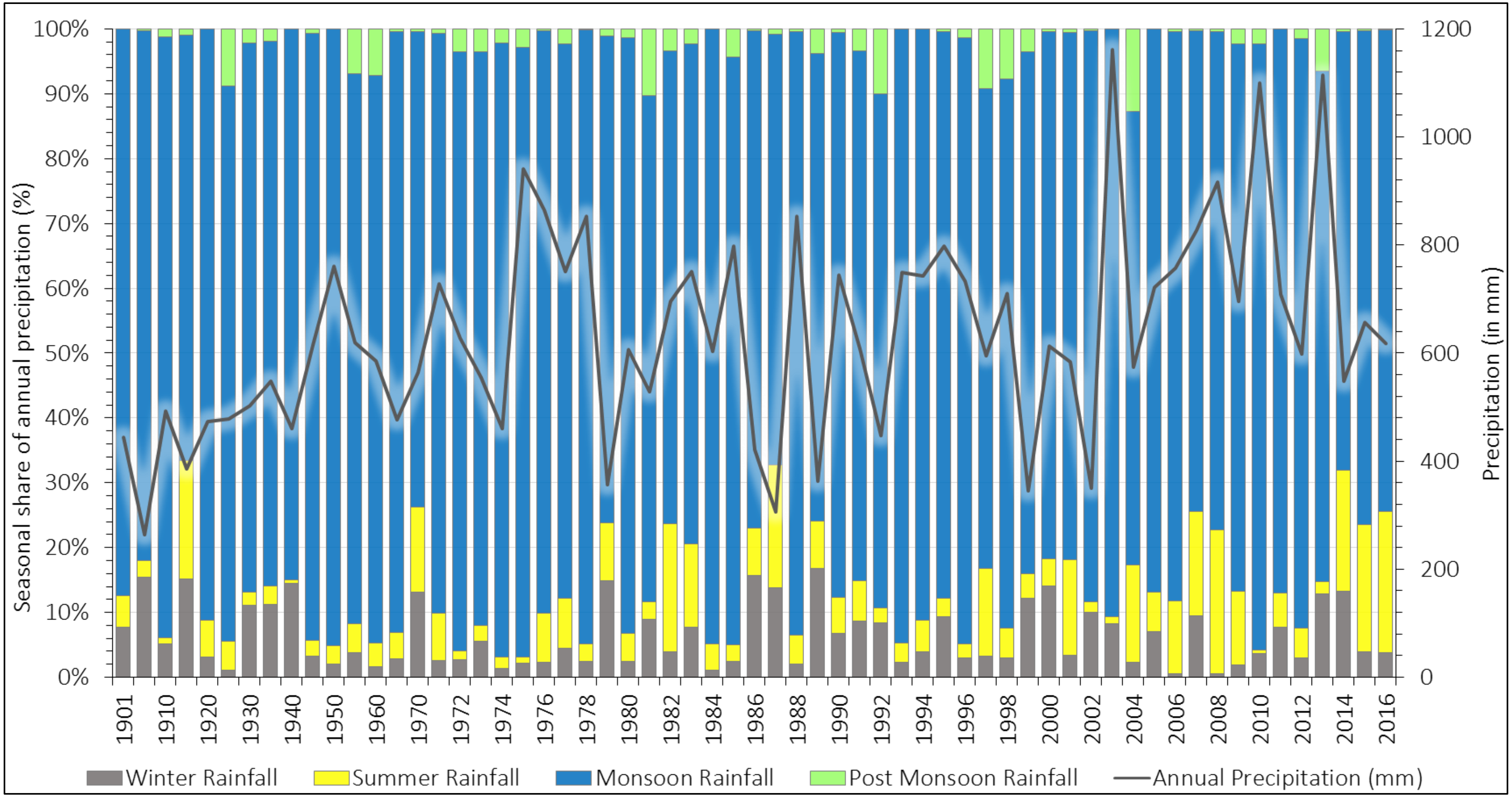


Fig. 1.14: Seasonal share of annual precipitation for Delhi, 1901-2016

Source: IMD (2016)

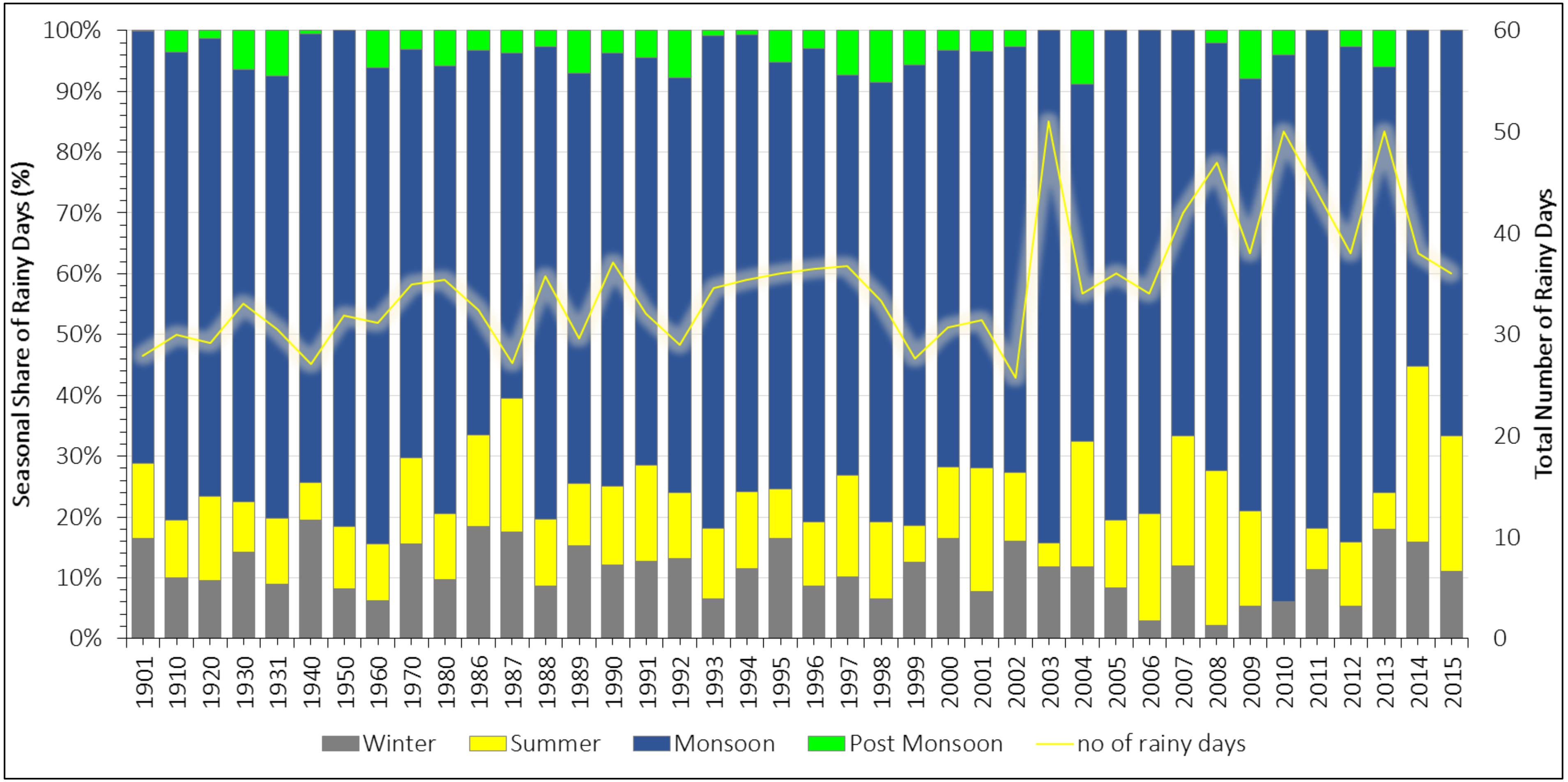


Fig. 1.15: Seasonal share of annual number of rainy days for Delhi, 1901-2016

Source: IMD (2016)

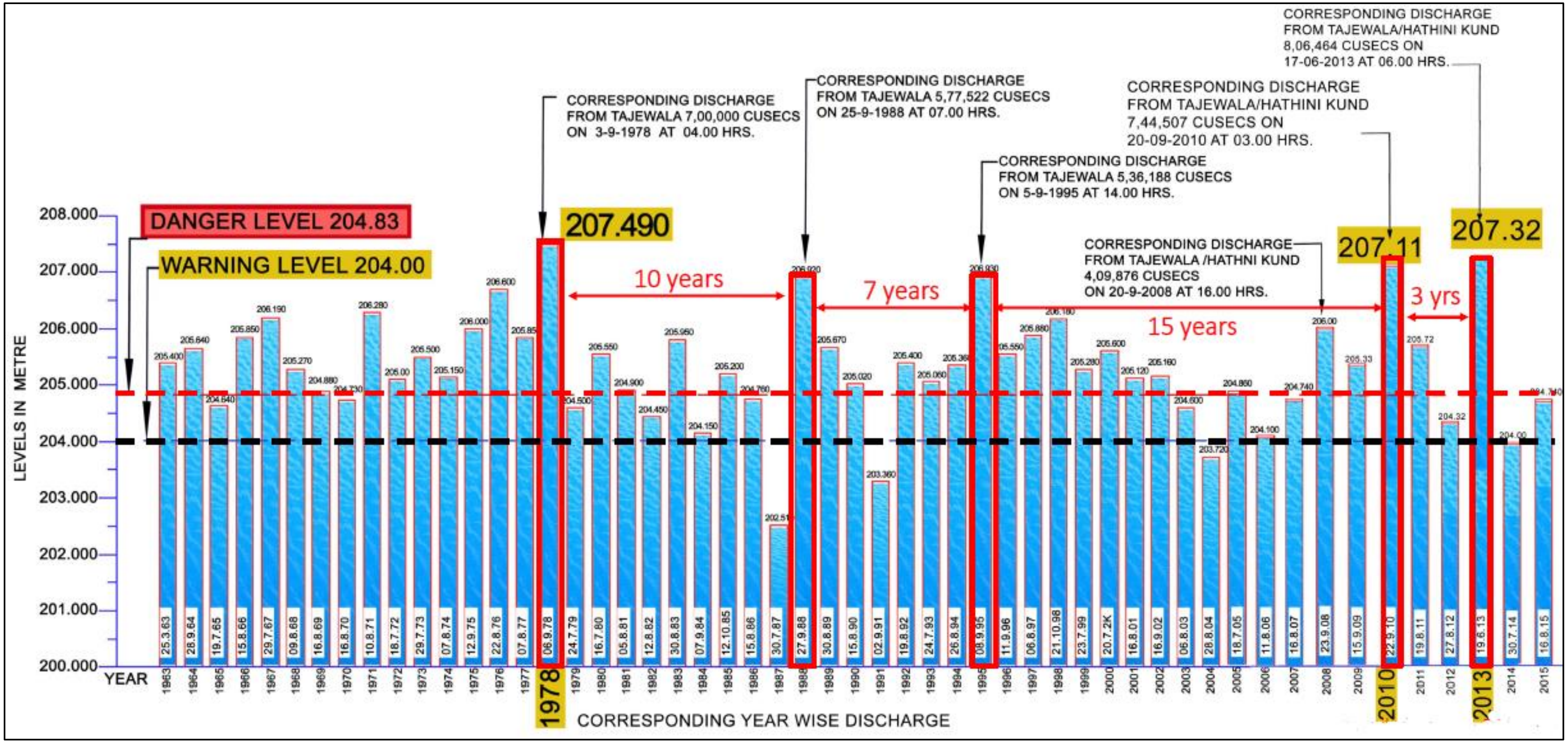


Fig. 1.16: Seasonal share of annual number of rainy days for Delhi, 1901-2016

Source: Irrigation and Flood Control Department, GNCTD (2017)

Similarly, change in seasonal share of annual number of rainy days (as indicated in Fig. 1.15) highlights that the summer wet days are increasing whilst post-monsoon rainy days are slowly diminishing.

To sum it up, seasonal variation of precipitation indicates that the summers are getting wetter, while winter and post monsoon rainfall is decreasing. Also, rainfall and rainy days are increasing but the actual duration of precipitation is reducing leading to increase in rainfall intensity from 13.2 mm/hour in 1986 to 22.9 mm/hr in 2016. In 2016, 3 hours of rainfall at this intensity flooded over 50 per cent of the city, breaking down city's mobility and livelihoods.

2.3 Past trends of Floods in Delhi

According to TERI Report " Floods in Delhi : Causes and Challenges " Increasingly, the city has become especially vulnerable to climate related hazards such as floods caused by unpredictable rainfall patterns. The city has been experiencing floods of various magnitudes in the past due to floods in the rivers Yamuna and Sahibi (through Najafgarh drain). The flow of Yamuna within Delhi is by and large influenced by discharge from Tajewala Headwork 240 km upstream. In the event of heavy rain in the catchment area excess water is released from Tajewala. Depending upon the river flow level downstream, it takes about 48 hours for Yamuna level in Delhi to rise. The rise in water level also causes backflow effect on the city's drains. The city also experiences floods due to its network of 98 drains whose catchment area extends well beyond the city limits.

Since 1900, Delhi has experienced nine major floods in the years 1924, 1947, 1976, 1978, 1988, 1995, 1998, 2010 and 2013 when the Yamuna River crossed its danger level of 204.83 m. The Table 2 shows that year 1978 witnessed the worst ever flood in Delhi when water level in Yamuna River in Delhi reached at 207.49 m with discharge 2.53 lac cusec at old railway bridge (7.0 lac cusec discharge was released from Tajewala) when 130 villages and 25 urban colonies in Delhi were submerged in water. The river has crossed its danger level 20 times in the last 33 years (DDMA, 2014-2015).

Table 2 Major flood events in Yamuna River in Delhi (Source: Irrigation and Floods Control Deptt.)

Year	Gauge (m)
1976	206.70
1978	207.49
1988	206.92
1995	206.93
1998	206.36
2010	207
2013	207.32

District North-East, East, Central, and South East of Delhi are most affected by floods in the city. Most settlements situated along the Yamuna River are prone to the flood hazard. A study on ''Urban Flooding and its Management'' by the Irrigation and Flood Control, Government of NCT of Delhi identified East Delhi under the flood plain region and vulnerable to floods (Pareva, 2006). During the monsoon, low-lying areas adjacent to Yamuna receive floods. Delhi was flooded in September 2010 and most of the areas along the Yamuna River were flooded, and a heavy damage to life and property was recorded. Hundreds of informal settlements were submerged under water, and 169 relief camps were set up by the Delhi Government to tackle the flood in the capital city.

2.4 Discharge in River Yamuna

Meteorological data assessment indicates a rise in total precipitation, number of rainy days which when coupled with reduction in duration of rainfall per day, the rainfall intensity and consequently the surface run off has increased significantly. Cumulative impact is felt on the discharge levels of river Yamuna which receives its water from Hathnikund barrage in the state of Haryana as well as drains and surface run-off from the city of Delhi. With increasing surface run-off, the actual amount of water that reaches the river has reduced either due to increasing impermeable surface or loss of continuity in flow of water. As a result, actual quantum of discharge is gradually decreasing while the intensity of flooding and precipitation is increasing (as indicated in Fig. 1.16).

2.5 IMPACT OF FLOODS

The un-even distribution of rainfall coupled with mindless urbanisation, encroaching upon and filling up natural drainage channels and urban lakes to use the high-value urban land for buildings are causing the increase in flood incidences in the city. The illegal filling of urban water bodies in city like Delhi is a rampant. The number of water bodies in Delhi accounting for about 800 had now remained 600 and rest vanished. Thousands of illegal colonies have emerged in city and planning has been thrown to the winds resulting in narrowing of natural drainage which is posing a serious threat to health of the city and invitation to urban flooding (TERI)

Various impacts of floods on urban development parameters are described in Table below:

Table 1.2: Relationship of Urban Development with Drainage and Flooding in Delhi, 1986-2051

Parameters	Indicators	Year of Enumeration				CAGR (2016-1986)	Projected Change - BAU	
		1986	1996	2006	2016		2031	2051
Urban Development	Developed area (in Ha)	58,145	71,040	78,360	86,350	1.33%	105,248	137,030
	Developed Area Density (pph)	107	133	177	194	2.01%	261	389
	Agriculture Area (in sqkm)	586	433	368	285	-2.38%	198	123
	Built Up (in sqkm)	581	710	784	864	1.33%	1,278	3,214
	Vegetative Heat Sinks (sqkm)	853	712	640	562	-1.38%	456	345
	WaterBodies (sqkm)	42	36	30	25	-1.65%	20	14
	Surface Run off (in	211	424	594	622	3.71%	1,074	2,223

Parameters	Indicators	Year of Enumeration				CAGR (2016-1986)	Projected Change - BAU	
		1986	1996	2006	2016		2031	2051
	MLD)							
	Loss of Flood Plains (in ha)	552	640	723	777	1.14%	921	921
	Groundwater Table (mbgl)	- 6	- 12	- 25	- 40	6.54%	- 103	- 179
Sectoral Impacts	Flooded Area (in sqkm)	326	420	571	676	2.46%	973.68	1,584
	Road Length Affected (in km)	13	26	116	233	10.25 %	1,008.08	7,098
	Average Travel time increase due to localised flooding (in minutes) *	10	15	32	42	4.92%	86.35	226
	Per Capita Expenditure on Health (in Rs.)	324	419	625	2,999	7.89%	9,366.39	42,760
	Vector Borne Diseases (in '000)	4.9	6.4	76.4	127.4	12.03 %	700.30	6,794

Source: Authors (2017)

2.6 Impact of Flood on the road network & Travel Pattern

Form the various newspapers and recent studies; water logging areas within the study area has been identified and it is observed that after 5MM of rainfall, increase in every 1MM rainfall there will be 2mins additional travel time increases in the network and same is adopted for the study to understand the travel pattern during the flood time. The below table shows the identified few routes where rainfall and travel time is available.

Identified Routes	Normal Day (TT in Mins)	Rainy Day (TT in Mins)	Rainfall (in mm)
Lajpat Nagar - Ashram	30	90	26
Faridabad from Connaught Place	42	90	22
ITO from South Extension	40	90	26
Average	37	90.0	25
Impact of Rainfall on TT		**2.41**	
1mm Rainfall Will Increase TT by		**2.11**	1MM
5MM	48		

Identified Routes	Normal Day (TT in Mins)	Rainy Day (TT in Mins)	Rainfall (in mm)
10MM	58		
15MM	69.0	1.85	

2.7 Results on impact of flood in Delhi

2.7.1 Background

The base year calibrated travel demand model for Delhi has been applied for estimating the future year network performance evaluation for the year 2050 during the flood time at average rainfall of 15mm. This process enables an assessment of impact of changes in travel pattern during the water logging in transportation network in horizon year under Business As Usual Scenario (BAU). The process involves running the travel demand model based on projected trip forecasts and future transport network.

2.7.2 Network

In BAU scenario, waterlogging areas were identified and additional time has been added to the network to estimate the change in the travel patterns during the flood in the study area. The map below shows the water logging areas in Delhi.

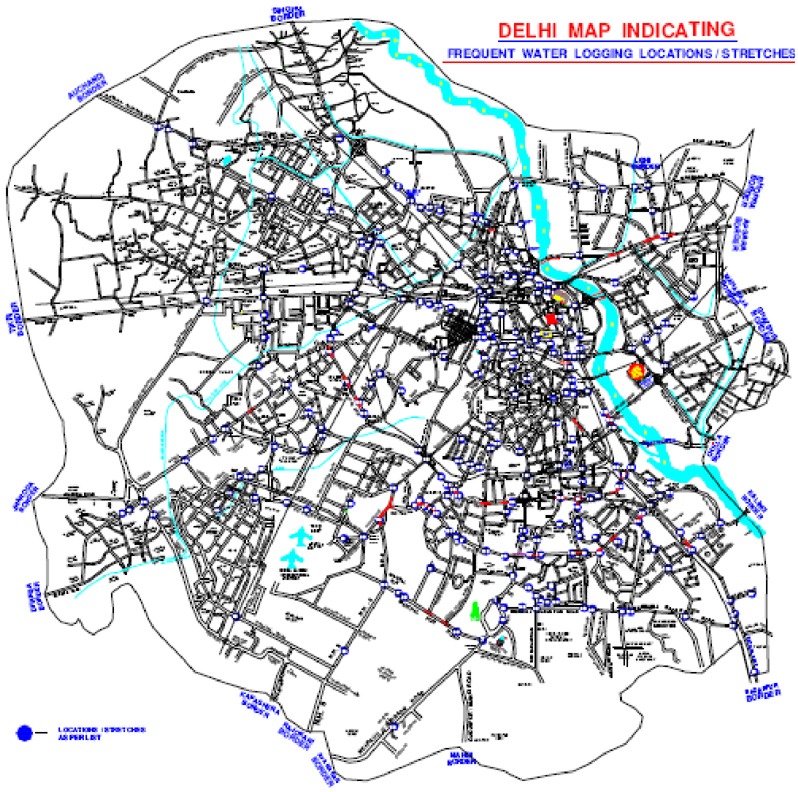


Figure 2-1: Water Logging areas in Delhi

2.7.3 Population and Employment Forecast

From the planning forecast described in earlier section under BAU scenario the population will increase to 24.8 million and 32.55 million while employment will increase to 8.91 million and 11.95 million in 2030 and 2050 respectively.

2.7.4 Modal Split

Base year calibrated parameters coupled with horizon year public transit network attributes are used to develop and estimate the future year 2030 and 2050 modal share. The estimate shows that there is a change in Home based work public transport share from 32% in 2030 to 43% under increase in transit scenario. Similarly the share increase from 24% in 2050 to 50% respectively .Table 2.1 shows the mode wise percentage share of trips in the cardinal years 2030 and 2050.

Table 2.1 Comparison of mode split in BAU and Increase in Transit - 2030 & 2050– Per Day

Mode	BAU - 2050	%	Flood time 2050	%
Mode choice AP_HW x C	5523972	26%	4329676	20%
Mode choice AP_HW x PT	5059888	24%	9142335	43%
Mode choice AP_HW x P_Auto	460525	2.1%	367139	2%
Mode choice AP_HW x TW	10438613	49%	7643849	36%
Total	**21482998**	**100%**	**21482998**	**100%**
Mode choice AP_HNW x C	5896294	23%	4579288	18%
Mode choice AP_HNW x PT	13452639	52%	16863900	66%
Mode choice AP_HNW x P_Auto	2760262	11%	2019157	8%
Mode choice AP_HNW x TW	3605302	14%	2252152	9%
Total	**25714498**	**100%**	**25714498**	**100%**

Table 2.2 shows the comparison of modal share in BAU and Increase in Transit scenarios. It is observed that Increased transit policy scenario shows a higher modal share in comparison to BAU scenarios ie. Increase from 45% to 54% in 2030 and from 39% to 61% in 2050 respectively

Table 2 .2 : Comparison of mode split in BAU and Increase in Transit-2030 & 2050– Per Day

Mode	BAU - 2050	%	Flood Time - 2050	%
Car	11420266	24%	8908964	19%
Put	18512527	39%	26006235	55%
Auto	3220787	7%	2386296	5%
Tw	14043915	30%	9896001	21%
Total	**47197496**	**100%**	**47197496**	**100%**

2.8 Trip Assignment

The horizon year trips for 2050 has been assigned on the proposed transport network and congested links were identified as shown in the figure 2.4 and 2.5 below:

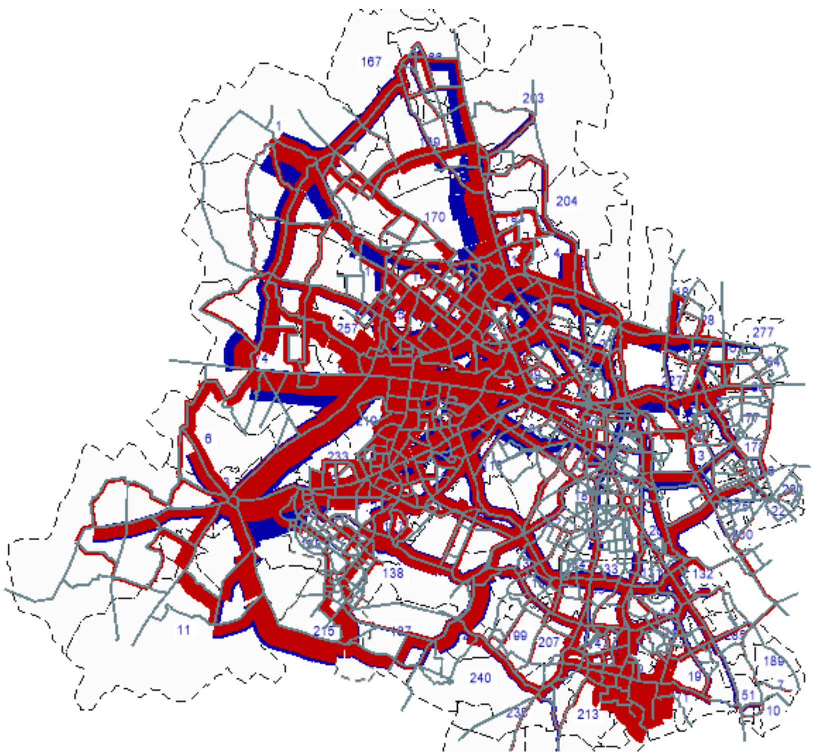


Figure 2.5 Trip Assignment for the horizon year – 2050

The comparative evaluation of alternative networks has been carried out from the point of view of passenger transport demand for the horizon year and ability of the various networks to cater to this demand. Table 2.3 shows the evaluation of BAU and increase in transit scenario

Table 2.3 : Comparative evaluation of BAU & Increase in Transit scenario- 2030 & 2050 – Peak Hour

Transport Network Scenario	Veh Dist Travelled (in Km)	Veh Travelled Hours	Average Speed (Kmph)	% PT+IPT Share	Pax (in No's)	Pax Travelled Km	Pax Travelled Hours	Co2 (in Kg)
Base Year	2,465,650	165,583	14.89	50%	434,197	3,426,571	101,350	230
BAU - 2050	19,821,085	13,671,726	1.45	39%	1,385,215	12,974,539	402,913	1,642
Flood (Water logging) - 2050	13,025,799	14,613,525	0.89	55%	1,942,500	18,350,106	574,502	1,210

It is observed that the average speed shall decrease from 14.89 kmph and 0.89 kmph in BAU with flood impact network. The share of public transport (bus, metro, IPT) increases from 39% in 2050 – BAU and 55% in 2050

Acknowledgements

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