Climate risks and urban drainage: A case of the National Capital Territory (NCT) of Delhi

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Cities are victims as well as a primary reason for climate change. They account for over 70% of global greenhouse gas emissions and shelter over 50% of the global population (IPCC 2015). The paper is an attempt to highlight the interplay of urbanisation, natural environment and climate variability for the National Capital Territory (NCT) of Delhi, particularly their implication on the city's mobility. With the help of aerial imagery and meteorological data, the study is grounded in detailed spatial-temporal empirical analysis conducted at macro and micro levels for the period of 1986 to 2016.

Empirical analysis at macro-level notes that during 1986-2016 Delhi lost 94 hectares of its vegetative cover, 6 hectares of water bodies and 14.3 hectares of flood plains for every 100 hectare increase of built up area. Simultaneously, surface run-off increased 3 times leading to increased flooding, travel time and road length under water. The correlation model built from this analysis forecasts city flooding to increase more than 80% by 2041 with 90% of city limits becoming a concrete jungle- thereby, increasing travel time by 43 minutes and clogged road length to 38 kilometres, from urban flooding. Micro-level analysis of the most vulnerable population, including 141 villages with over 2,800,000 inhabitants, indicates increased losses from flooding, burdening the state exchequer with over 20.1 million INR [~0.3 million USD] annually.

This interplay therefore has multi-dimensional implications on urban mobility and makes it imperative for a liveable urban future to conceive the city in a holistic framework of climate resilience, guided by policies of land use-land cover and transport planning.

Keywords: *Urban Development Pattern, Urban Flood, Travel Time, Inundation, Affected Population and Area*

1. INTRODUCTION

Climate change is a global phenomenon and variability of climate over decades is attributed, directly or indirectly, to human activity which alters the composition of the atmosphere, thereby contributing to natural climate variability observed over comparable time periods. Emerging trends of climate change indicate a global rise in human induced warming, higher than the natural warming of the earth which will continue to increase at a much more rapid rate. The Intergovernmental Panel on Climate Change 2014 report (IPCC Fifth Assessment Report. 2014) highlights that while global population grew from 4 billion to 7 billion, a 75 per cent increase since 1970, greenhouse gas emissions increased by 82 per cent, with an annual increase of 2.2 per cent in the last decade alone.

The Paris Climate Agreement 2015 supports the cause of climate change mitigation and shifts it from a global scale issue to one of development at the urban scale. This is not a new finding. In 2008, urban development became central to the international discourse on climate change, when global urban population increased by 50 per cent while total GHG emissions increased by 70 per cent. Four cases for this situation were identified: land use and land cover change, transportation, building construction, and pollution related to industry. These four categories of activities coincide with areas affected by the role of urban planners and urban planning in terms of planned development, adapting to climate change and mitigating future risks. Essentially, cities and climate change are intertwined and urban planning plays a vital role in this equation.

2007-08 also saw the publication of a tremendous amount of literature and research on cities and climate change. In India a plethora of research has been produced which studies the impacts of climate change, the spatial distribution of greenhouse gas emissions, and urban drainage in relation to changing intensities of precipitation. However, only a few try to think beyond these topics and assess climate change in terms of urban development patterns. The need to study climate change and the impact of urban development on climate change becomes more important today since cities cover less than 3 per cent of the earth's surface but contribute over 70 per cent of GHG emissions and account for 75 per cent of global energy consumption (UN-Habitat. 2011). Moreover, this trend of urban growth is forecast to continue as rural population decline.

This paper is an account of a study of climate change and its relationship with urban development and urban mobility in Delhi during the period of 1986 to 2016; with 1986-96 marking the decade of economic reforms and the post-Asiad games construction boom, while 2006-2016 marks ripples of construction boom for the Commonwealth games and the notification of the Master Plan for Delhi-2021. Empirical analysis is conducted for the four time periods- 1986, 1996, 2006 and 2016 using two prime secondary sources, which include meteorological data from the Indian Meteorological Department and raw aerial LandSat imageries from the online portal of the United States Geological Survey, Global Land Cover Facility and Bhuvan India. GIS modelling and analysis of aerial imageries in relation to statistical data indicate a trend of human induced climate variability for the city.

The paper is structured into three broad sections. In the first section, Delhi's urban development trend is described in terms of increase of built up areas and loss of heat sinks. In the second section, climate change is assessed in terms of natural climate variability and reflected through precipitation variables. The third section assesses the implications of urban development and climate change on mobility patterns of the city. The fourth section scales down the assessment to micro level and examines implications on the vulnerable population of the city. In particular, an empirical analysis based on primary surveys and supported by secondary meteorological data is conducted to assess physical, social and economic impacts of climate change on the most vulnerable population in the city, identified as residing in the villages located in the flood plains of Delhi. This includes implications on their mobility patterns.

The last section concludes on a note of dire need of climate resilient urban strategies to achieve a sustainable urban future of the city.

2. URBAN DEVELOPMENT PATTERN OF DELHI, 1986-2016

Delhi, capital city of India, is testimony of numerous changes and cumulative challenges. This section documents the changes which underscores the trend of urban development in the city. The change in land cover of Delhi (as indicated in Table 1) indicates that after 1986 the city spread around its core with infill developments. Moreover, developments from 1986-1996 amounted to 1.3 times the development of the preceding two decades. This may be attributed to the real estate growth that emerged after the 1980s Asiad games and economic liberalisation of the country's economy in 1990. Statistically, the city's developed area increased from 39.2 per cent of the overall city area in 1986 to 58.2 per cent in 2016.

Table1: Change in Land Cover of Delhi, 1986-2016

Land Cover	1986	1996	2006	2016	Decadal Change		
	Area (in sqkm)	Area (in sqkm)	Area (in sqkm)	Area (in sqkm)	1986-1996	1996-2006	2006-2016
Total Built Up	581.45	710.4	783.6	863.5	22.5	11.0	10.8
Forests	176.8	178.1	172.1	176.2	0.8	**-3.8**	2.6
Other Green areas	48.6	66.8	70.2	75.8	36.0	5.5	8.6
Water Bodies	41.9	34.4	29.6	25.4	**-21.7**	**-16.6**	**-16.9**
Agriculture Land	586.0	432.5	368.2	284.6	**-33.2**	**-17.7**	**-28.2**
Wasteland	48.3	60.8	59.3	57.6	25.9	**-2.8**	**-3.2**
TOTAL=	**1483**	**1483**	**1483**	**1483**			

Extracted by the author (2017) from USGS (1986, 1996, 2006 & 2016)

The increases in population and the built-up areas in the city resulted in the conversion of agricultural fields into non-agricultural use like residential, commercial and other non-permeable concrete 'jungles'. The city has witnessed a rise in its density as well. It is conjectured that for a population increase of 12.4 million during these three decades, there is a corresponding increase in developed area from 581.45 square kilometres in 1986 to 86,350 square kilometres in 2016. This is further accompanied by an increase of urban density of 2.6, an increase of developed area density by 1.8 and an increase in gross residential density by 2.14.

These developments have engulfed natural green areas and flood plains of the city, thus disturbing the city's microclimate and ecological balance. Both of these natural areas serve as heat sinks. Empirical analysis indicates that 57.5 per cent of the city's area acted as heat sinks in 1986 which declined to 37 per cent in 2016, with an annual rate of depletion equivalent to 1.4 per cent. Moreover, it is observed that heat sinks are depleting at a much faster rate (equivalent to 1.4 per cent) than the rate at which the built up area is increasing (equivalent to 1.3 per cent). Also, it is found that a 100 hectares increase of built up area corresponds to a loss of 94 hectares of vegetative heat sinks and 6 hectares loss of water based heat sinks.

3. CLIMATE CHANGE OF DELHI

The climate of NCT of Delhi is categorised into four seasons by the Indian Meteorological Department- winter, summer, monsoon and post monsoon. The winter season extends from December to February. Summer includes March, April and May while the monsoon season extends from June to September. The post-monsoon season includes October and November. The paper however assesses this change in climate for Delhi only through precipitation variables using meteorological data obtained from the Indian Meteorological Department, New Delhi and Irrigation and Flood Control Department, Government of NCT of Delhi.

3.1.1 Precipitation variability

The annual precipitation variability is assessed in terms of annual rainfall and annual number of rainy days for a time frame of 115 years, from 1901 to 2016. The trend of annual precipitation post-1901 (as indicated in Figure 1) shows that the average rainfall has increased by 210 millimetres and that the periods of drought have become longer than the periods of heavy rain.

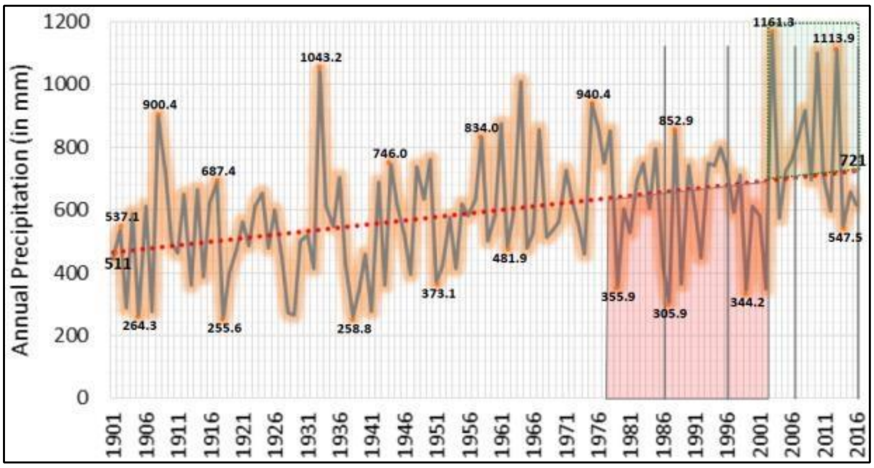

Figure 1: Change in Annual Precipitation for Delhi, 1901-2016
Source: IMD (2016)

Assessing the trend in the number of rainy days for Delhi (as indicated in Figure 2), in the same time period shows that the average number of annual rainy days has increased by 9 rainy days while the average precipitation per rainy day has increased by 2.5 per cent. Since the annual precipitation and number of rainy days are increasing, and given that the actual duration of precipitation has reduced, this resulted in a sharp rise in rainfall intensity from 13.2 mm/hour in 1986 to 22.9 mm/hour in 2016 (the latter leading to flooding of over 50 per cent of the city in three hours in 2016).

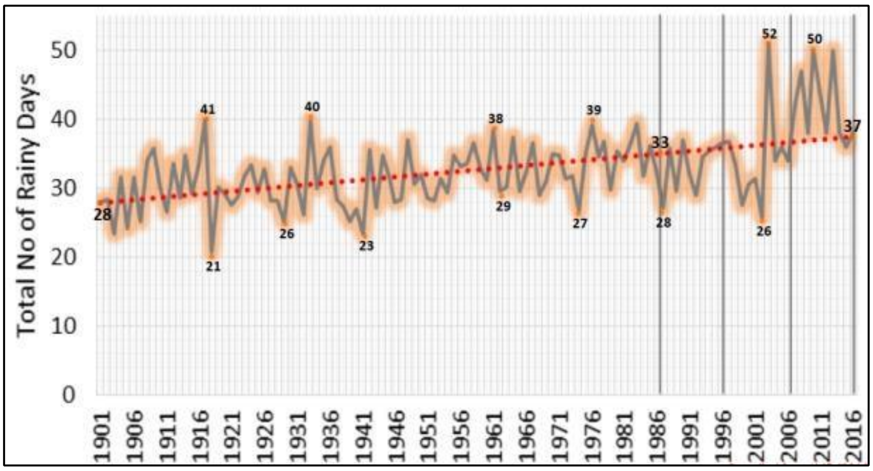

Figure 2: Change in Annual Number of Rainy Days for Delhi, 1901-2016
Source: IMD (2016)

The seasonal precipitation variability is assessed in terms of seasonal share of annual precipitation and rainy days for the timeframe 1901 to 2016. Analysis of the seasonal share of annual precipitation (as indicated in Figure 3) shows a trend of wetter summers and drier post monsoon periods. 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/hour in 2016. In 2016, 3 hours of rainfall at this intensity flooded over 50 per cent of the city, breaking down the city's mobility and livelihoods.

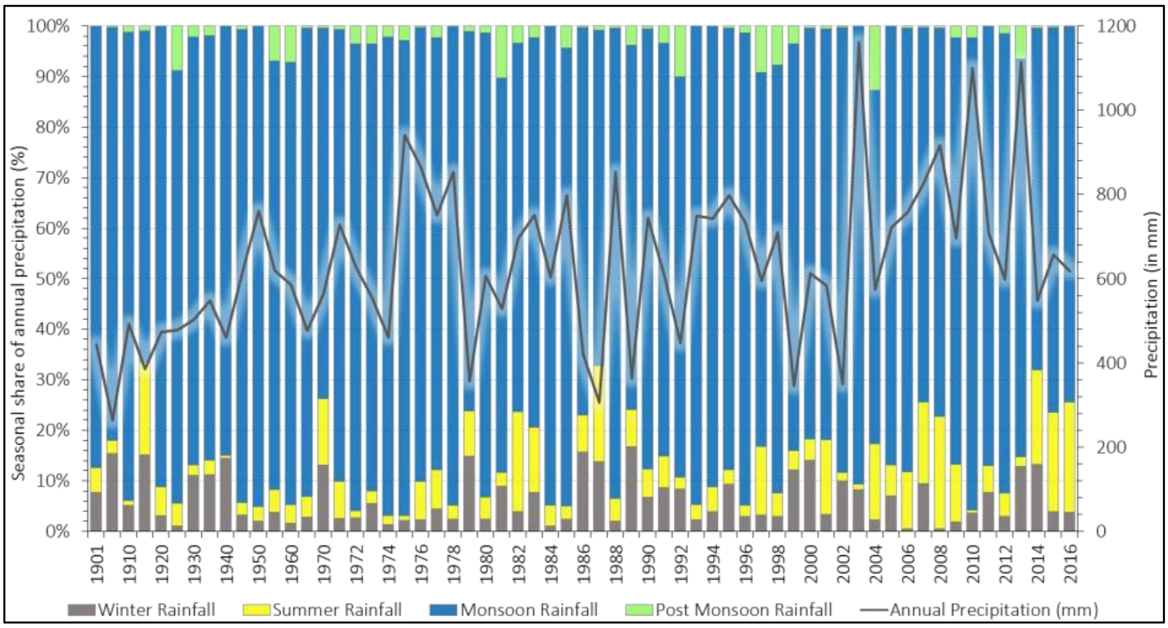

Figure 3: Seasonal share of annual precipitation for Delhi, 1901-2016
Source: IMD (2016)

4. Interplay of Climate Change and Urban Development with the Mobility Pattern of NCT of Delhi- 1986-2016

4.1 Contribution of the Transportation sector in total Green House Gas (GHG) emissions

The increase in GHG emissions for Delhi have been assessed at two levels. First, a spatial distribution of GHG emitters has been identified which included the built up area as well as wasteland. Second, the sectoral contribution of GHG emissions from the sectors of waste, transport, domestic and industries is estimated using the Tier II methodology formulated by the intergovernmental panel on Climate Change in 2007.

In the first case, imageries indicate an increase in the total area of greenhouse gas emitters, which has a direct correlation with the densities of the developed area. Their empirical analysis indicates that the city had 42.5 per cent of its area under greenhouse gas emitters in 1986 which increased to 56.8 per cent in 2016. That is at an annual rate of increase equivalent to 1.3 per cent, with the result that the city's emissions are increasing rapidly. The increase is related to increases in densities of the developed area.

In the second case, GHG emissions from the sectors of waste, domestic, industries and transportation was calculated using the Tier II methodology formulated by IPCC in 2007. The method uses emission factors for energy consumption in each sector. Based on this, emissions for NCT of Delhi have been estimated. This table shows that the city's GHG emissions have increased 4.5 times since 1986. Moreover, the increase has been over 12 times for the transportation sector, 3.5 times for the domestic sector, 3 times for the waste sector and 2.9 times for the industrial sector.

Empirically, for every 100 hectare increase in built-up area between 1986-2016 was leading to an increase of GHG emissions by 0.078 million metric tonnes of CO2 equivalent.

4.2 Urban Floods and implications on urban mobility

The city comprises 24,840 hectares of flood plains of which 68 per cent forms a part of the river Yamuna floodplains. The city has three drainage basins (as indicated in Table 2) based on the watershed that includes the North basin with a basin area of 26,694 hectare; the West basin with an area of 75,633 hectares; and the South and East basins spread over an area of 45,973 hectares.

Assessing the development pattern of Delhi, it is observed that the city has lost over 41 per cent of its flood plains and the loss has increased by 1.4 times since 1986 (as indicated in Figure. 4). The city's flood plains have reduced in width from 800 meters in 1986 to 300 meters in 2016 as a result of construction and developments located in flood plains.

Table 2: Loss of Flood Plains in Delhi, 1986-2016

Basin	Area of Basin (in sqkm)	Area of Flood Plains (in sqkm)	Loss of Flood Plains (in sqkm)				Loss of Flood Plains, 1986-2016 (in sqkm)
			1986	1996	2006	2016	
North Basin	266.94	20.02	3.96	4.91	5.17	5.83	1.86
West Basin	756.33	113.45	33.01	39.48	41.07	44.81	11.80
South and East Basin	459.73	114.93	56.91	72.37	83.03	84.97	28.06
TOTAL=	1824.1	248.4	93.9	116.8	129.3	135.6	41.7

Extracted by the author (2017) from USGS (1986, 1996, 2006 & 2016)

Summing up, the National Capital Territory (NCT) of Delhi witnessed a ~~paradoxical~~ dramatic ecological change over the past three decades. For every 100 hectare increase in its built up area it felt adverse repercussions of corresponding hard coverage of 94 hectares of green sinks and 6 hectare of water bodies.

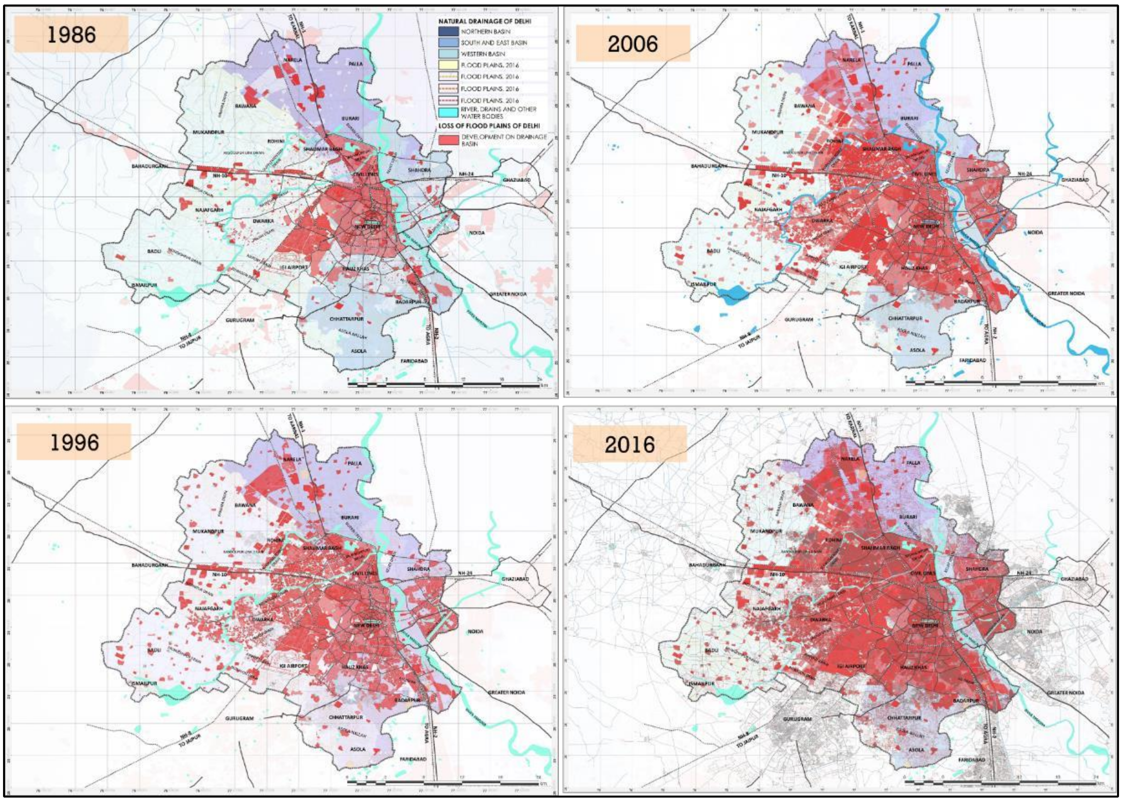

Figure 4: Loss of flood plains in Delhi, 1986-2016
Extracted by the author (2017) from USGS (1986, 1996, 2006 & 2016)

4.2.3 Impact of the built environment on surface run off

Increasing development of drainage basins and the resulting loss of flood plains, coupled with the increase in impermeable surfaces has led to an increase in surface run-off from the city. Due to an interplay of urban development and natural climate variability, the city's surface run-off has increased from 211 million litres per day (MLD) in 1986 to 622 in 2016, that is a 2.9 times increase over the last 30 years. Also, it is observed that with the loss of every 10 hectares of green cover, the surface run off increases by 0.014 MLD. Annually the surface run-off is increasing at 3.7 per cent while the loss of heat sinks is 1.4 per cent. That is, surface run-off is increasing at a much faster rate than the loss of permeable surfaces in the city. The entire chain of events becomes crucial in the light of strong interdependence between loss of heat sinks- both vegetative and drainage basins, increase of impermeable surface, urban expansion and changing precipitation pattern.

5. IMPLICATIONS ON URBAN MOBILITY OF DELHI

5.1 Macro-Level Implications

At the macro level or city level, the empirical study indicates critical linkages between the urban development pattern, climate variability and urban mobility. The two major linkages identified are – first, increasing greenhouse gas emissions with change in urban development which adds to climate change at a regional level, and second, the impact of urban floods on road networks of the city and consequently on the average travel time.

First, in terms of greenhouse gas emissions, recapitulating earlier facts, emissions for NCT of Delhi increased 4.5 times since 1986. However, the increase has been over 12 times in transportation sector alone, owing to rising vehicular traffic and increased congestion on roads. Second, increasing surface run-off and impermeable surface, along with increasing intensity of rainfall has led to increase in the area flooded by precipitation in Delhi (Figure 5).

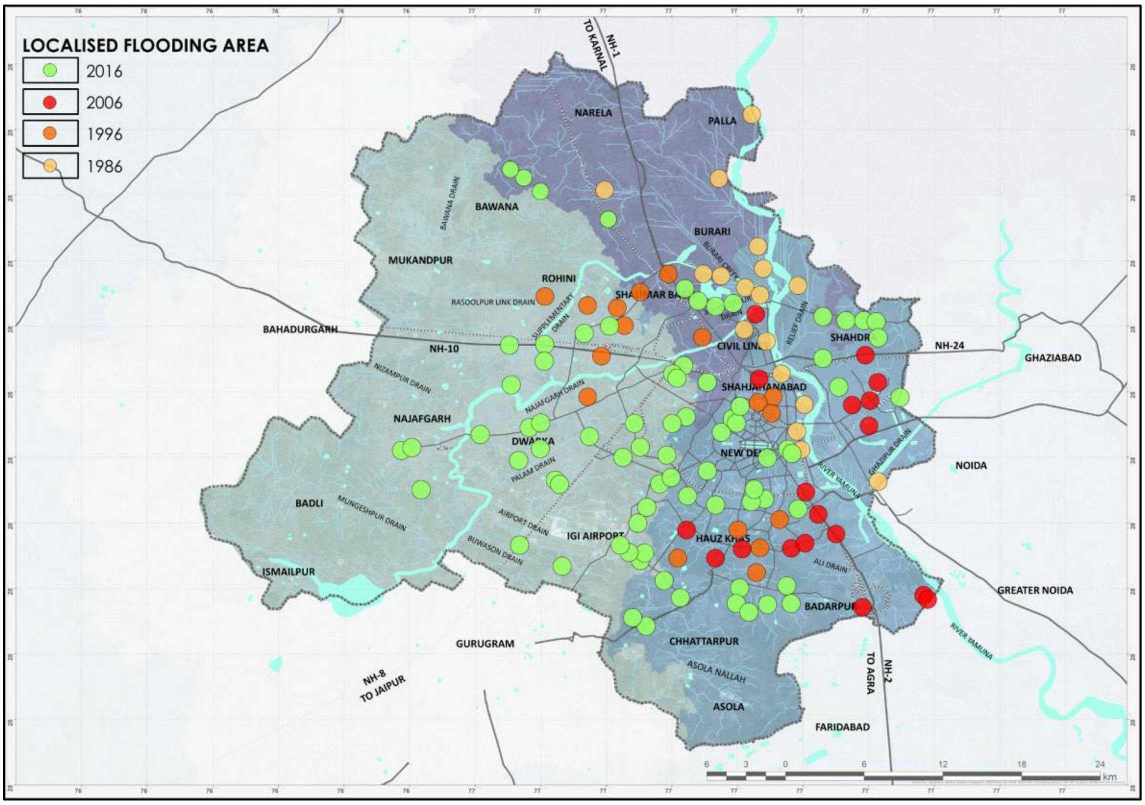

Figure 5: Change in waterlogged/ flooded area in Delhi, 1986-2016
Extracted by Author (2017) from USGS (1986, 1996, 2006 & 2016)

While the period witnessed an annual growth of surface run-off by 3.8 per cent, it led to increase in flooding by 2.5 per cent. Moreover, for every increase in surface run-off by 1 MLD [million litres per day], flooding increased by 85 hectares, the road length affected increased by 68 meters, while vector borne diseases increased by 7.8 per cent. The problem is aggravated by extraction and increasing reliance on groundwater to meet the water demand supply gap.

6. Impact of Climate Change and Urban Development on the Mobility Pattern of Vulnerable population of NCT of Delhi- 1986-2016

Having established the correlation between urban development and climate change at city and spatial levels, this section analyses the impact of climate change on vulnerable population. For this purpose, the flood plain of the river Yamuna is identified and the population at risk recorded. The village population is identified for detailed analysis and surveys among the cohort of climate risk population located in the flood plains, as it has the least adaptive capacity.

4.2.1 Profile of the Flood Plains of the River Yamuna in Delhi

The flood plains of the river Yamuna make up for over 68 per cent of the city's total flood plains. Over a period of time, the river has undergone a change in the course of its flow. Since 1986, studies have indicated that the flood plains have reduced in area and width by 800 metres on either side of the river in 1986 to less than 300 meters in 2016. The land cover on the flood plains of the Yamuna river have undergone major changes in the past three decades.

The land use on the flood plains of the Yamuna river have undergone major changes in the past three decades as well (as indicated in Figure 6). The trend indicates that of the total built up area, residential use has increased by over 200 per cent in the past 3 decades, followed by a 92 per cent increase in commercial and a simultaneous reduction in industrial use. To support the development, utilities and transport infrastructure have grown at the rate of 37 per cent and 14 per cent respectively. That is, the no man's land has become a favourable site for real estate despite the environmental senstivity of the region.

It is because of this increasing built up area alone, that the flood plains and its environmentally sensitive ecosystem have undergone a rapid depletion, accentuating the climate risk as well as frequency and intensity of floods in the river Yamuna.

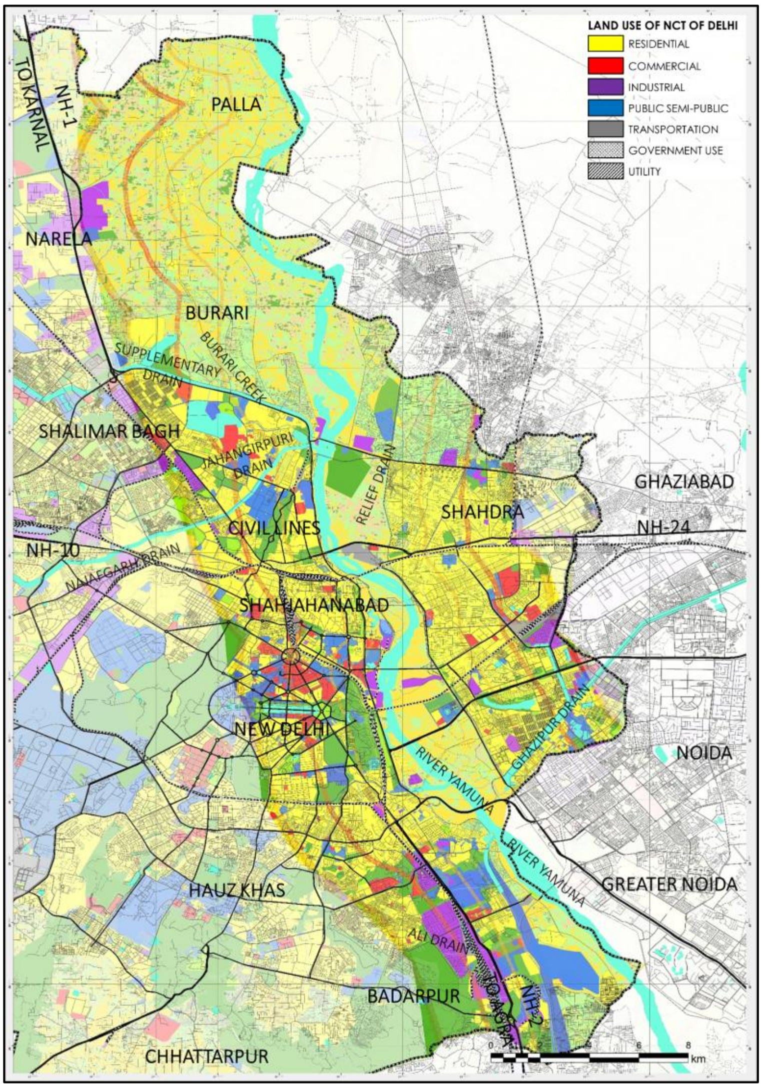

Figure 6: Land Use in flood plain of river Yamuna in Delhi, 1986-2016
Extracted by the author (2017)

5.2.2 Vulnerable Population

Climate resilient urban planning highlights the necessity for assessing the impact of climate on vulnerable population. With increasing developments on the flood plain of the Yamuna river, particularly residential development, the vulnerable population has increased by more than 2.4 times in the last 3 decades. Amongst the three categories of vulnerable population, maximum increase has been in the number and area occupied by unauthorised colonies while villages have reduced in number due to their conversion into census towns but increased in total population due to natural increase. Over time, planned colonies such as the Commonwealth games village have also come up. However, for the purpose of assessing climate risk on vulnerable population, villages are identified separately from the cohort owing to their limited adaptive capacity.

144 villages exist within the flood plains of Delhi that are prone to flooding. These villages are categorised annually by the Irrigation and Flood Control Department of Delhi, Government of National Capital Territory of Delhi into two categories – most vulnerable/totally exposed area villages and moderately vulnerable moderately exposed area villages. However, owing to constraints of time and human resource, only 3 villages (indicated in Figure 7) were selected for impact assessment, which include Badarpur Khadar, Usmanpur and Garhi Mandu in the upstream river Yamuna, north of the Wazirabad barrage.

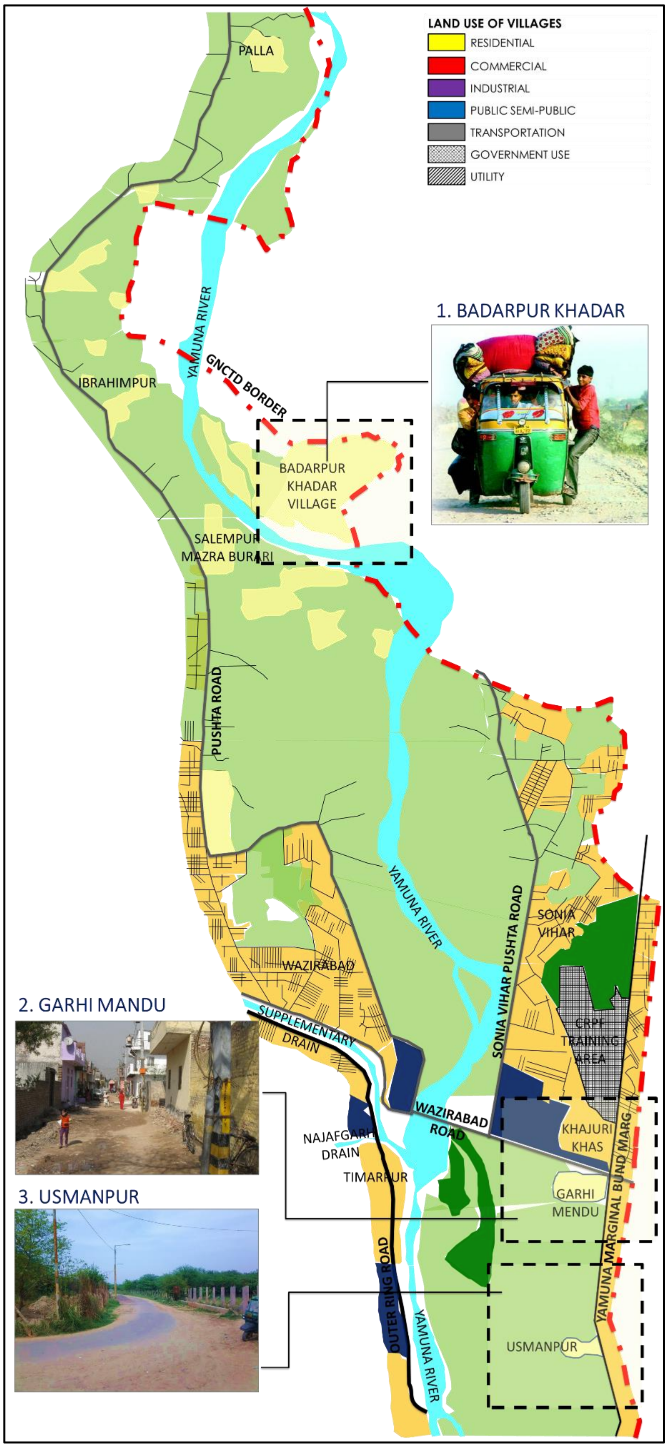

Figure 7: Location of Case villages in the upstream of river Yamuna flood plains, 2017
Compiled by the author (2017) from I&FC (2017)

The impacts were assessed in terms of physical loss, social impact and economic impact.

- **Physical impact -** The physical impact of floods is felt in terms of temporary loss of habitation by way of entry of flood waters into houses and loss of connectivity to the outside world, thus impacting access and connectivity of the settlement with the outside world. To cope with it, prior to flood warnings issuance villagers vacate to higher ground or are resettled to relief camps set up by the Delhi government.
- **Social impact** - Owing to the loss of connectivity and inundation by flood waters, access to education facilities is disrupted for an average of 10 to 12 days. Also, incidences of increasing vector borne diseases, like malaria, dengue, chikungunya and snake bites, have been recorded.

  Economic impact- Due to loss of connectivity to the outside world, a worker loses 10 to 12 working days and tends to lose over 25 per cent to 30 per cent of monthly income. It varies from Rs 250 (~4 USD) per day per capita to Rs 415 (~7 USD) per day per capita.

Summing up the survey findings at micro level, it is found that apart from temporary loss of habitat and connectivity to the outside world or suspension of school and increase in vector borne diseases and snake bites, the average economic impact incurred by the villagers is equivalent to 30 to 35 per cent of their monthly income, equivalent to 10 to 12 working days. Apart from the costs incurred by villagers, government spending on resettlement and relief camps is an annual burden on the state exchequer. The overall monetary loss due to floods in the Yamuna river flood plain is valued at 0.3 million USD per annum which includes 0.23 million USD as the cost incurred by government. Thus, the need to enhance resilience of vulnerable population becomes imperative.

6. Conclusion

The research presented here highlights the interdependence of urban development, climate change and the natural environment, as well as a multiplicity of implications arising from these interdependent phenomena. The need for planners and cities to deal with them in the planning system becomes critical, with cities being guzzlers of over 3/4 of overall resources and generators of about 3/4 of waste and pollution, while accommodating a little over half of the global population. Innovative thinking, planning principles and design within an appropriate framework to set strategies and priorities will be of the essence.

The study underscores the need for a climate resilient urban development for Delhi which means to start envisioning and planning the city according to its carrying capacity. The city’s expanse and political as well as socio-economic importance has led to its relentless growth in area, population, vehicles as well as pollution and degradation of natural resources. For that reason, there is a need to put a break on the increasing trend of city development. This requires strong mobilisation of political support for fruitful planning strategies and policies. An example is the recent initiative of *Clean India Mission, famously known as Swachh Bharat Abhiyaan* by Prime Minister Narendra Modi. It has brought about a wave of behavioural change at every level of governance across India and given sanitation a political priority at the centre. Thus, political nexus and push, as well as bureaucratic support play a binding role in ensuring success of planners’ efforts.

One of the priority proposals to be rolled out with central support is to initiate decongestion of the city, which can be supplemented by the upcoming Regional Rail Transit System connecting Delhi to surrounding towns of the National Capital Region. Delhi would continue to exist as an employment hub. However, a pressing current need is to start containing the development of the city. create heat sinks at an accelerated rate and redistribute population along more ecological principles. This could take the shape of land use-transport integration, redistribution of population densities and opening up public space, earmarking aquifer and recharging zones for no development among others.

Enhancing the climate resilience of population and infrastructure becomes indispensable to counteract the impacts which have arisen from years of past developments. Moreover, urban planning needs to widen its scope beyond the administrative boundaries of NCT of Delhi and start working at the level of Delhi Metropolitan region. This is particularly important for a climate resilient urban future. This would encompass making it a mandatory provision for all spatial plans to have a chapter on climate change and its implications on urban development. In particular, it should become a statutory requirement for the urban planning processes and plan documents to have a chapter with explicit mention of, and focus on climate change and its relation to urban development in Delhi. It is also proposed that any spatial plan shall have a chapter on climate change and policies for climate resilience, before it can be approved or notified in the official Gazette. The master plan document would have to elaborate climate strategies at city level and provide details at spatial level as well.

It is long overdue that planners start looking beyond the jurisdiction of the National Capital Territory of Delhi and start working and assessing climate and its relation to urban development for a region beyond the state boundary. That is, the urban planning jurisdiction should extend to the Delhi Metropolitan region. This recommendation is further supported by the fact that the predominant climate of the city is determined within 60 kilometres in radius of the city.

Apart from spatial development strategies including transit oriented development, redistribution of population and densities, protection and conservation of the city's drainage pattern, recharging the ground water aquifer and enhancing the green infrastructure, certain other spatial development and planning strategies should be compulsory as well.

Firstly, the master plan of Delhi has to have a comprehensive and clear non-disputable policy for relocation and rehabilitation of climate vulnerable population. Unambiguous provisions for the resettlement of population at risk of climate change have to be included in writing in all spatial plans. Resettlements within the same planning area have to be given priority. In case this is not possible due to space constraints, the resettlement location must not exceed 5 kilometres from the original stay.

Another strategy of paramount importance relates to enhancing the climate resilience for existing immovable infrastructure. There are three approaches to ensure that. First, roads could be aligned according to high flood risk level, or put out of use during the monsoon season. The second approach relates to the 'asset management approach', whereby planners, engineers and professionals from other disciplines would move from road design to planning and maintenance. That is, this approach is a departure from a reactive patch-and-mend approach to a preventive management approach. Lastly, it is necessary to opt for 'user behaviour management', whereby signage will guide users to alternative routes which are less or not affected by climate risk.

In this paper strategies for climate resilient urban development have been proposed for the National Capital Territory of Delhi. New guidelines for climate resilient urban development are also envisaged more generally for any megacity in India with similar attributes and evidence to that of Delhi. They include: land use and urban planning measures; planning for drainage including floods and solid waste management; management of water demand and conservation systems; building and enhancing resilient housing and transport systems; and strengthening of ecosystem services. These five categories of guidelines are directly related to spatial planning and development strategies, that need to be included and comprehensively detailed in spatial planning documents. Beyond that, another 5 categories of guidelines are proposed which are more related to institutional capacities and multiple sectors, affected by climate change and induced risks. They include: diversification and protection of livelihoods; encouraging institutional coordination mechanisms; establishment and strengthening of emergency and warning systems; improved technology and information systems; and enhancing education and capacity building of citizens.

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