Multi-sector Exposure and Vulnerability to Urban Development and Climate Change in Indian Megacities: Case of National Capital Territory of Delhi, India

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Abstract

Cities are drivers and victims of climate change. Risks to climate change and induced disasters vary spatially and across a region's demographic spectrum. Building resilience to the changing climate requires exhaustive analysis of climate risks, their magnitude and implications along with a multiplier effect they have over each other and their secondary environment, sectors. The idea is to propagate the concept of climate resilience in India beyond international mandates and bold statements, enabled through utilization of open data. The research underscores need for climate responsive planning for mega cities in India, with an example of National Capital Territory of Delhi- the capital of India whose trends and policies often form a blueprint for others to follow.

Highlights

1. Urbanization crossed 50 per cent mark in 2008 and accounted for nearly 70 per cent of global greenhouse gas emissions- the latter being the result of 4 major activities-land use land- cover change, transportation, building and activities within, and industries.
2. The 4 categories of activities are areas where the role of urban planner and planning fits in terms of strategic planning, adaptation to climate impacts and mitigation of future risks.
3. Between 1986 to 2016, Delhi's built up increased at an annual rate of 1.3 per cent while the heat sinks (vegetative and water bodies) were lost at 1.4 per cent annual rate (Figure 1). Corresponding to the complex changes associated with this growth- the city's average annual surface temperature (Figure 2) increased 6 times the average annual air temperature during the time period.
4. Methodologies for evaluating the multiplier effect are still in their pre-final stage and there exist uncertainties and margin of error
5. Aligned with pre-tested methodologies, the research through extensive empirical and spatial-temporal analysis indicates severity and irreversibility of socio-economic and environmental losses
6. India has approximately 8,000 urban centers. Less than 2 per cent of these centers have a planning document. Less than 1 per cent of these documents acknowledge climate change as a phenomenon let alone a challenge to urban future. It is therefore a priority to address the challenge from a planning perspective for India

Note:

This is a work in its pre-final stage. Much more work is possible, given the time, funding and data support that adds to the analysis and improves strategic, policy recommendations. Findings presented in the paper are only for discussion purpose- to highlight what more needs to be done in India's actions towards climate change. The evaluation is subjective to variables identified and analyzed. Figures and values are likely to vary with inclusion of more variables in the on-going research.

1. Introduction

Climate change is a global phenomenon, emerging trends of which indicate a global rise in human induced warming, higher than the natural warming of Earth – a trend that is estimated to grow at significant rate. The Intergovernmental Panel on Climate Change (IPCC Fifth Assessment Report, 2014) highlights the growth of global population from 4 billion to 7 billion, a 75 per cent increase since 1970. During the period, greenhouse gas emissions increased by 82 per cent, with an annual increase of 2.2 per cent in past one decade.

The Paris Climate Agreement 2015 further supports and strengthens the cause of climate change mitigation and shifts it from a global scale issue to one of development at 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 urban planners and urban planning in terms of development, adaptation to climate change and mitigation of 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 study geographies of emissions, changing climate, impacts of climate change on agriculture, urban drainage, biodiversity, and regional temperature rise. However, only a few try to examine beyond these areas of study 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 as 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 declines, especially for the rapidly growing economy and demography of India.

In 2015, India emerged at the forefront of climate talks at the Convention of Parties and the Sendai Framework on Disaster Risk Reduction. At the national level, policy frameworks for climate action and disaster risk reduction were ratified. Much before this- in 2010, another policy framework– known as the National Action Plan on Climate Change (NAPCC) was notified by the Union Government. Under the provisions of NAPCC, each of the 29 states and 7 union territories of India had to prepare and implement a State Action Plan on Climate Change. In reality, less than 10 states prepared a State Action Plan, and less than 5 actually carried forward with its implementation. Post 2015 however, several cities and states started looking at climate action through heat action plans, transit-oriented development in the name of emission reduction whilst promoting market led high density developments along transit corridors, and electric mobility plans. In select cities of Surat, Pune, Chennai, Jaipur, Amravati- city resilient strategies for one or a range of challenges, are being formulated with the support of 100 Resilient Cities network. In past 5-6 years, a move to plan and envisage cities in context of climate change has been initiated in a big way in India- but the country is still far behind in examining and addressing global challenge of climate change and multidimensional implications associated with the it- in holistic, strategic fashion and actually implementing these solutions, strategies at all levels of space, time and governance.

This paper is an account of select part of a comprehensive, exhaustive research study of climate change and its inter-relationship with urban development and environment at an urban scale- for the case city of National Capital Territory of Delhi. The analytical framework and city diagnostics are carried out for the period of 1986 to 2016. It is presented into three main sections. In the first section, methodology of research is discussed. In the second section, evidence of urban development and climate variability are highlighted. City's urban development trend is described in terms of increase of built up areas and loss of heat sinks while climate variability is reflected in terms of temperature and precipitation variables. Implications of alternative strategies and recommendations are documented in the third section. The paper concludes at the note of dire need of climate resilient urban strategies in India- to achieve a sustainable urban future.

2. Research Design

The research was conducted in 6 distinct, yet inter-related stages, which include: stage 1: literature review; stage 2: data collection; stage 3: data analysis at 4 levels – city, zonal, planning division and flood plains inhabited by climate vulnerable population with least adaptive capacity; stage 4: formulating alternative scenarios of future development; stage 5: evaluation of scenarios; stage 6: conclusions and recommendations.

The paper highlights implications of built environment on climate and vice versa, reflected through the climate variables of temperature and precipitation and spatial-temporal variation of built up intensity, greenhouse gas emissions, heat sinks, flood plains and groundwater table. Three forms of data sources are utilized in the work- aerial imageries collected from open source portals of United States Geological Survey, Global Land Cover Facility, National Oceanic and Atmospheric Administration and Bhuvan Portal; secondary data in the form of reports, meteorological data, flood levels, socio-economic data and information were collected over a period of 70-75 days from several departments of the Government of NCT of Delhi and Government of India; and primary data collection through stakeholder consultations and interviews.

The data for the research analyses trends for past three decades, extending from year 1986 to 2016. The decade of 1986-96 marks a period of economic turmoil followed by reforms and post-Asiad games construction boom, while 2006-2016 witnessed ripples of construction boom from Commonwealth games-2010 as well as the notification of Master Plan for Delhi-2021. Data collected was compiled, subject to GIS modelling and simulations and analyzed for relationships with statistical data- findings of which underline a trend of human induced climate variability for the city. From a macro city level analysis, the study advances to study the impact at area level and also examines climate risks to vulnerable population situated in flood plains of the city. A correlation model is developed comprising of multivariate equations between urban development, climate variability and urban environment.

Three alternative scenarios are developed- business as usual, master plan guided development and climate carrying capacity guided development. The study concludes with recommendations for climate resilient urban development of Delhi along with general guidelines for other mega cities.

3. Evidence

Modelling and simulation using open data in the form of aerial imageries has been critical and considerable input. Evidence of development pattern extracted from imageries is correlated to statistical data and climate variables obtained from several departments of Government of National Capital Territory of Delhi and Government of India.

3.1 Urban development pattern, 1986- 2016

Delhi, the capital city of India, is testimony of numerous changes and cumulative challenges. As far as history of planning in the city goes, population and developed area of Delhi has far exceeded anticipation of plan document for the period. The change in land cover of Delhi (as indicated in Table 1) indicates post-1986 city spread around its core with infill developments. Furthermore, developments during 1986-1996 amounted to 1.3 times the development of the preceding two decades.

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 Greens	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 Author (2017) from USGS (1986, 1996, 2006 & 2016)

This may be attributed to the real estate growth that emerged post-1980s for the Asiad games coupled with economic liberalization of country's economy in 1991-92. 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. Increasing population and built-up in the city resulted in conversion of agricultural fields and other vegetative cover (illustrated in Figure 1) to non-agricultural uses like residential, commercial and other non-permeable concrete 'jungles'. The city witnessed a rise in density as well. It is conjectured that for a population increase of 12.4 million during these three decades, there's a corresponding increase in developed area from 581.45 square kilometers in 1986 to 86,350 square kilometers in 2016.

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. Post 1986, city's heat sinks depleted at a faster rate (=1.4 per cent annually), than the increase in built up (=1.3 per cent annually).   Research also notes that for every 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.

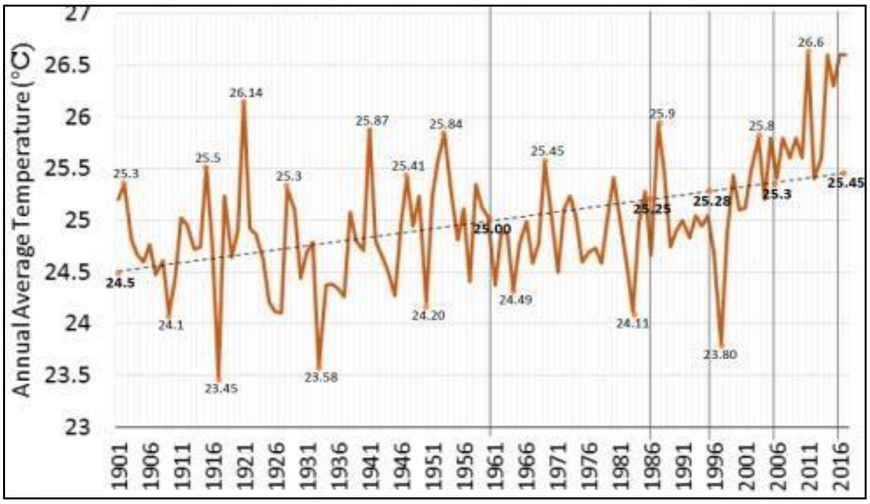
3.1 Climate Variability

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 research assesses change and variability in climate for Delhi only through temperature and 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 Temperature Variability

The variability of annual temperature for Delhi is assessed in terms of its annual average temperature, annual average maximum temperature and annual average minimum temperature. Assessing the average annual temperature of the city from 1901 to 2016 (as indicated in Figure 2), it is inferred that the city has experienced a 0.95°C rise in temperature, of which 0.2°C was experienced post-1986, which marks an era of economic liberalization and increased construction activities.

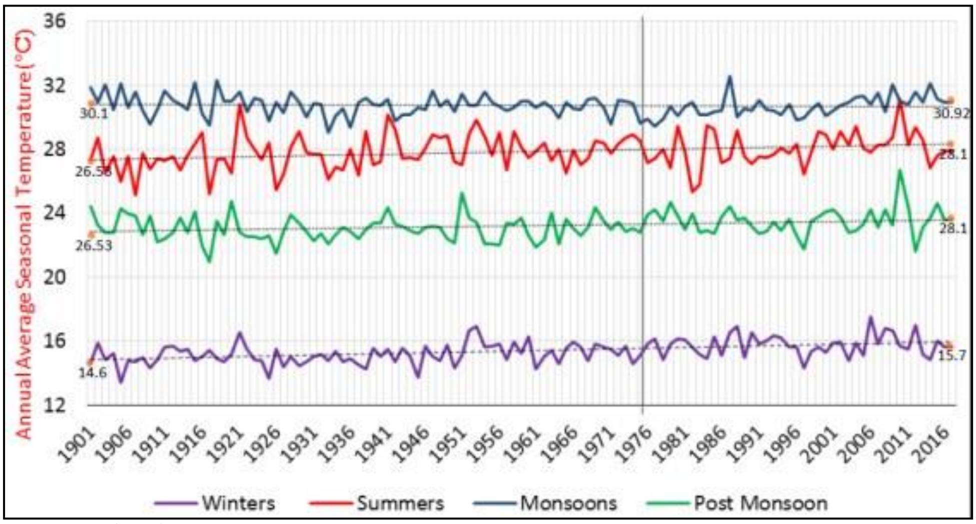
Figure 2: Change in Delhi's Annual Average Temperature, 1901-2016



Source: IMD (2016)

Assessing the average annual temperature for the four seasons (indicated in Figure 3) from 1901 to 2016, it is observed that the temperature for winter, summer, monsoon and post monsoon seasons have increased by 1.1°C, 1.5°C, 0.8°C and 1.3°C, respectively.

Figure 3: Seasonal Temperature variation for Delhi, 1901-2016



Source: IMD (2016)

What is worth noting is that the summer temperatures increase is twice that of monsoon.

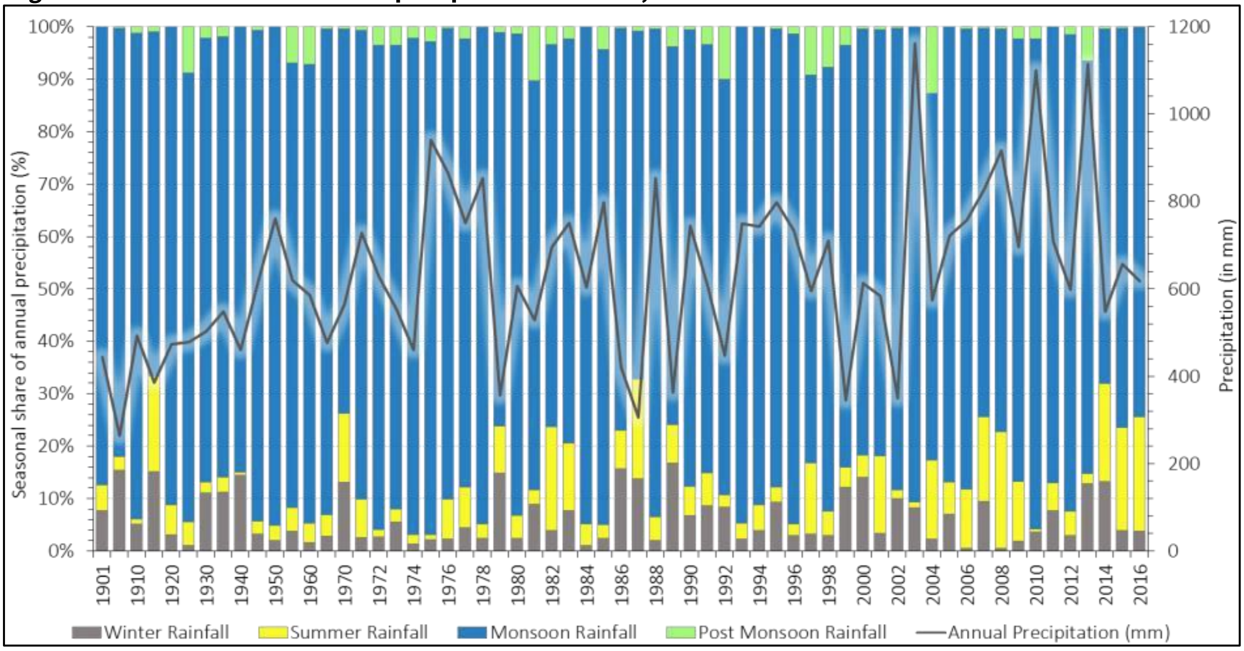
3.2.2 Precipitation variability

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 is indicative of increase in average annual rainfall by 210 millimetres (as indicated in Figure 4) while periods of drought have become longer than the periods of heavy rain.

During the period, average number of annual rainy days has increased by 9 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.

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 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.

Figure 4: Seasonal share of annual precipitation for Delhi, 1901-2016



Source: IMD (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.

4 Results

Literature from across the world provide plethora of evidence in favor of climate change aggravated and influenced by urban development and implications thereof. The research discussed in the paper elaborates contribution of urban development on temperature variability at surface and in air, loss of flood plains and resultant flooding in conjunction with rainfall intensity and precipitation at city level. The work also briefly highlights variation of the above across the city and demography.

4.1 Interplay of Urban Development and Temperature

Development of cities in the 21st century is often equated to expansion of transportation system, vehicular fleet, skyscrapers and other buildings. Little does one account for the repercussions associated with this kind of development, the former including shrinking greens, agriculture land, drainage basin and network, declining aquifer, increasing emissions and resultant pollution and associated manifestations. One of the most obvious impact of urban development is increasing emissions from carbon emitters with simultaneous decline of heat and carbon sinks.

For Delhi, 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 (indicated in Table 2). This table shows that the city's GHG emissions have increased 4.5 times since 1986.

Table 2: Sectoral contribution of GHG emissions in Delhi, 1986-2016

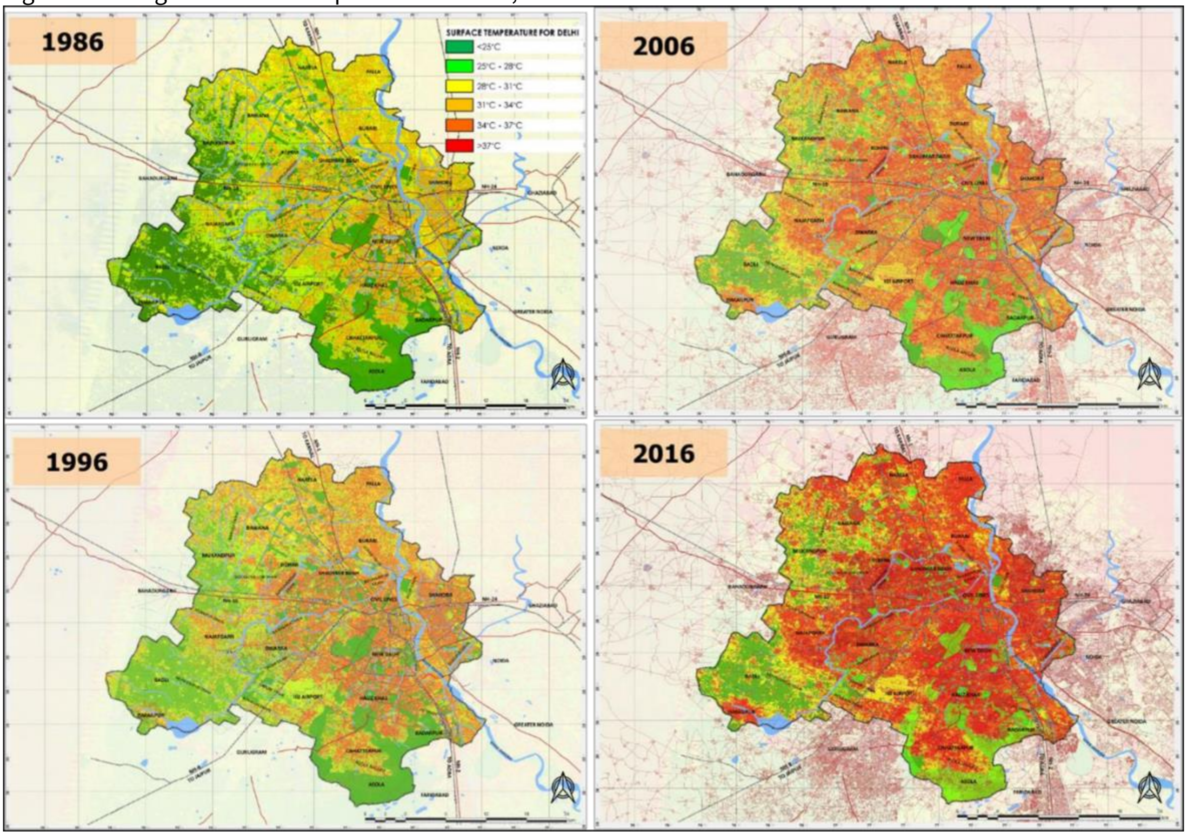
Year	WASTE SECTOR		DOMESTIC SECTOR			INDUSTRIAL		TRANSPORTATION		NET GHG EMISSIONS (in MMT)
	Waste Generation (in million kg)	GHG EMISSIONS (in MMT) (EF=0.13)	Area (in hectare)	Population (in million)	GHG EMISSIONS (in MMT) (EF=0.06)	Energy Consumption (in million units)	GHG EMISSIONS (in MMT) (EF=0.15)	Fuel Consumption (Petrol, Diesel, CNG) (in '000 MT)	GHG EMISSIONS (in MMT) (EF=0.09)	
1986	2.8	0.36	54600	5.8	3.51	1,085	0.16	948	0.57	4.60
1996	4.3	0.56	65640	8.6	5.20	1,537	0.23	1,718	1.03	7.02
2006	6.8	0.88	67780	11.9	10.74	2,518	0.38	2,028	1.83	13.82
2016	8.4	1.09	70520	13.6	12.25	3,135	0.47	7,693	6.92	20.73

Estimated by Author (2017) from GNCTD (2016) and IPCC (2007)

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 hectares increase in built-up area between 1986-2016, the area under vegetative heat sinks reduces by 94 hectares and water bodies deplete by 6 hectare, leading to an increase of GHG emissions by 0.078 million metric tons of CO_2 equivalent.

With the increasing development and emissions thereof, the city has experience significant changes in its land surface temperature. The latter has been modelled for each of the four time-periods (as illustrated in Figure 5). Empirical analysis of the land surface temperature of the city indicates that the average city level surface temperature has increased from 32.8°C in 1986 to 35.9°C in 2016.

Figure 5: Change in surface temperature of Delhi, 1986-2016



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

This change is equivalent to an annual increase in surface temperature by 0.31 per cent, which is 1.6 times the increase in air temperature. Also, it is inferred that more area is getting affected by higher temperature ranges while areas with lower temperatures, particularly in the city's periphery are gaining temperature, primarily due to conversion of heat sinks into wasteland and barren land.

Summing up, the period 1986-2016 witnessed a loss of heat sinks by 292 square kilometers and a rise in surface temperature by 3.1°C and air temperature by 0.2°C. That is, for every 100 hectare of heat sinks lost to development, surface temperature of the city increases by 0.01°C which is 1.6 times the rise in air temperature of the city.

4.2 Interplay of Urban Development and Precipitation

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 3) 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.

Table 3: 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)

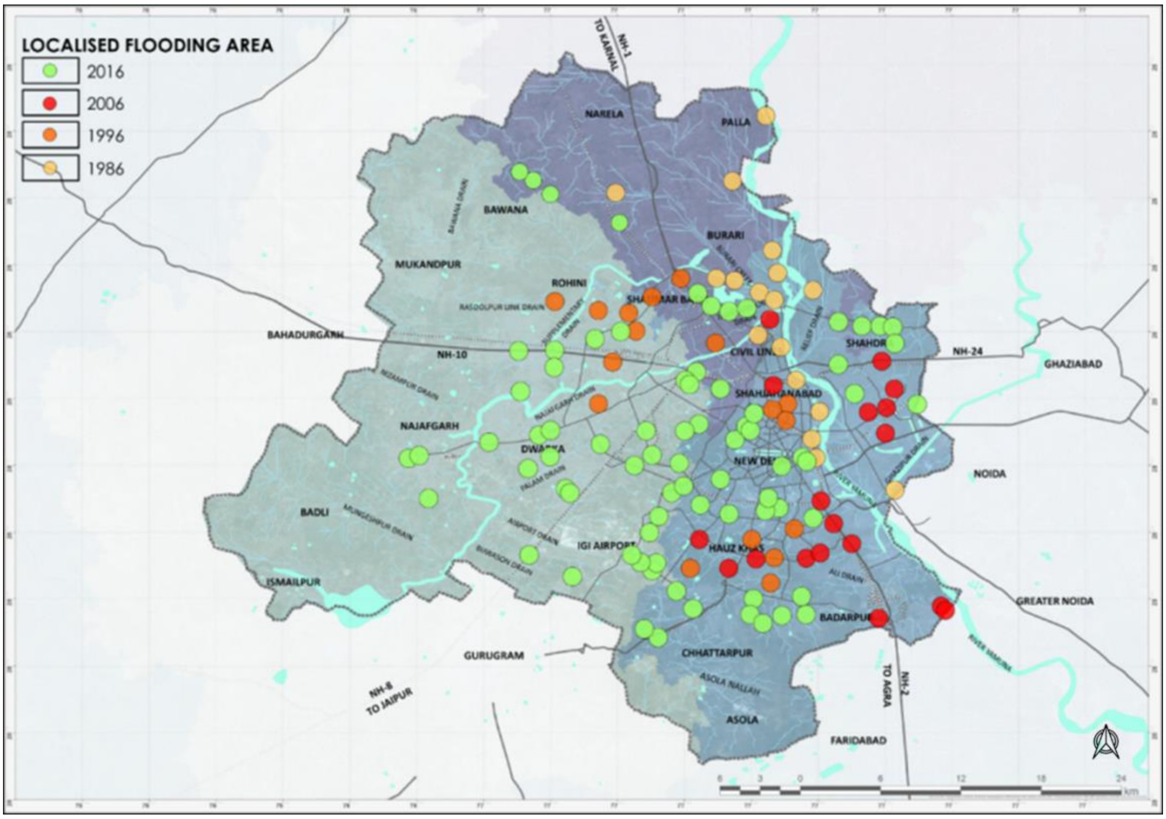
Assessing the development pattern of Delhi, it is observed that the city has lost over 41 per cent of its flood plains and the loss has increased by 1.4 times since 1986. The city's flood plains have reduced in width from 800 meters in 1986 to 300 meters in 2016 as a result of construction and developments located in flood plains. Delhi witnessed a dramatic ecological change over the past three decades, whereby for every 100 hectares 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.

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, which is 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 and aquifer recharge zones- both vegetative and drainage basins, increase of impermeable surface, urban expansion and changing precipitation pattern.

This increase in surface run-off and impermeable surface area, along with increasing intensity of rainfall has also resulted in increase in the area flooded by precipitation in Delhi (as indicated in Figure 6). 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. 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.

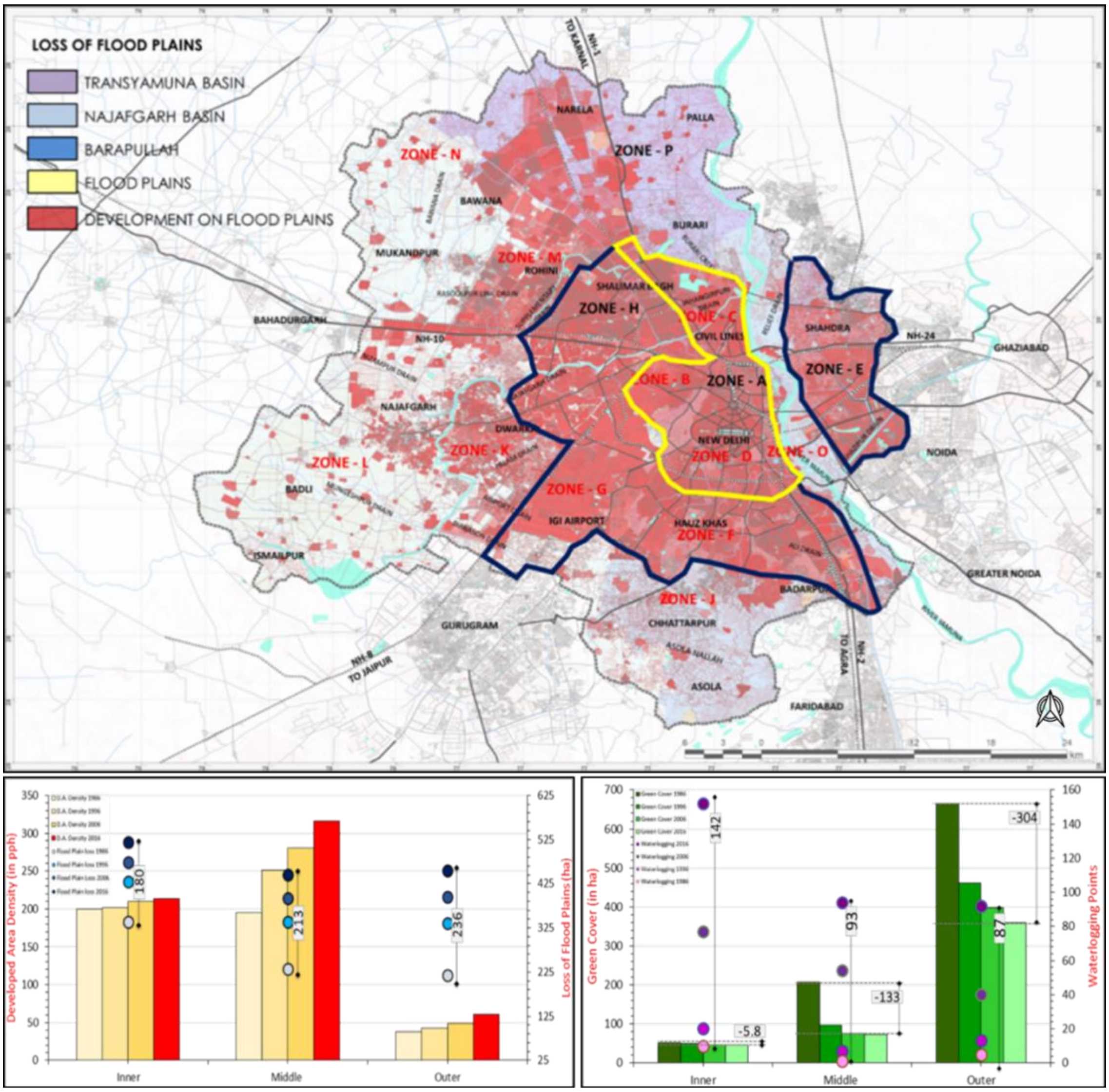
Figure 6: Change in waterlogged/ flooded area in Delhi, 1986-2016



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

Similar to variable cause and effect relationship between urban development and temperature, urban development and precipitation have a relationship that varies across space (as indicated in Figure 7). The problem is aggravated by extraction and increasing reliance on groundwater to meet the water demand supply gap at one end; and rising population vulnerable to the risk of flooding within the flood plains of river Yamuna, particularly for the cohort with lease adaptive capacity, which includes urban villages and their inhabitants.

Figure 7: (top) Loss of flood plains across spatial zones of Delhi as defined for research; (bottom left) relationship between developed area density and loss of flood plains across spatial zones; (bottom left) relationship between green cover and inundation area across spatial zones



Extracted by author (2017)

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 -land use of the flood plains of the Yamuna river have undergone major changes in the past three decades. 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. Ironically, once known as 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.

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. 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.

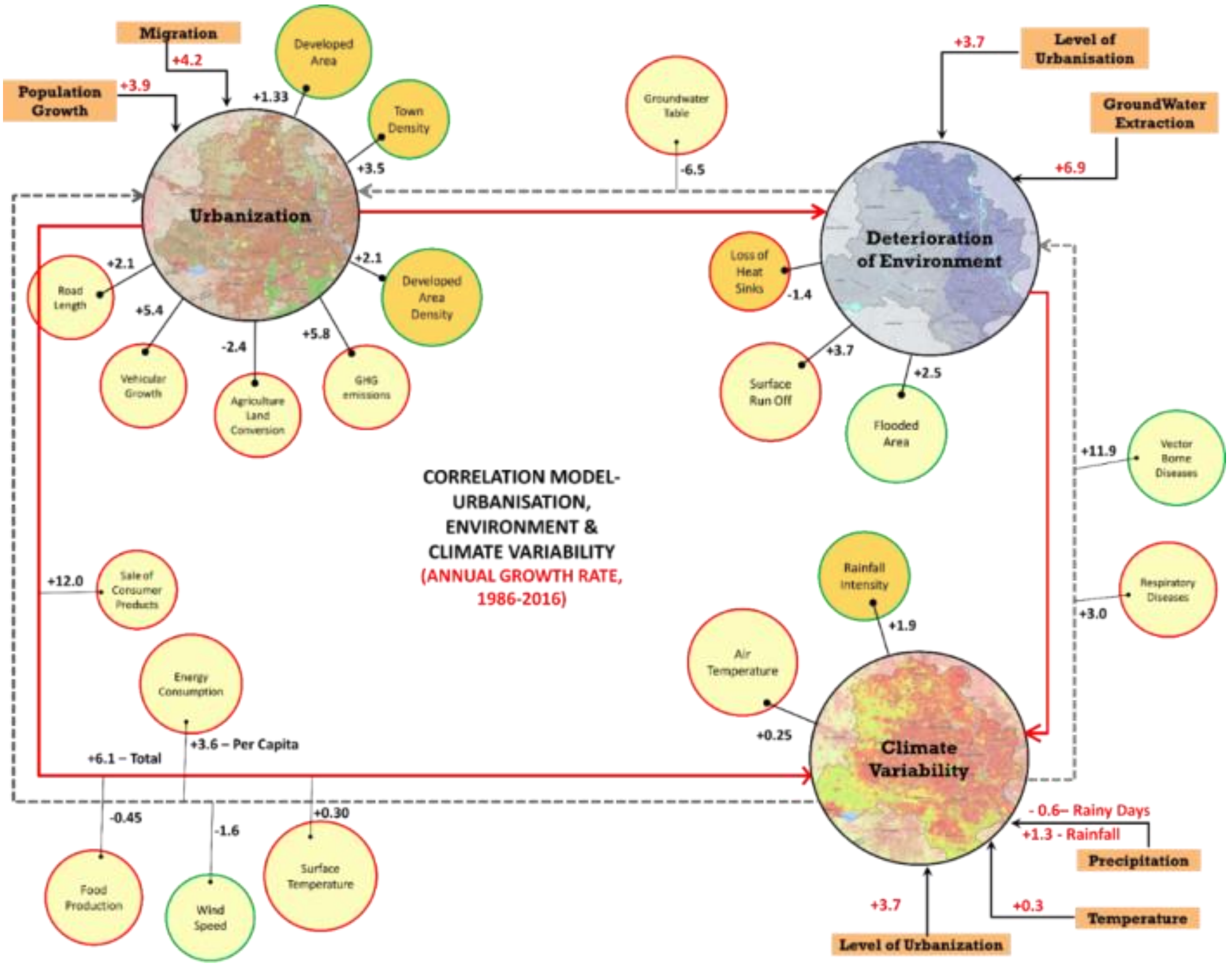
Summing up the survey findings at micro level, it is found that apart from temporary loss of habitat and connectivity to the outside world or suspension of school and increase in vector borne diseases and snake bites, the average economic impact incurred by the villagers is equivalent to 30 to 35 per 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.

5. Conclusion

Modelling and forecasting for 2041 as the horizon year, the research emphasises on propagating a carrying capacity guided development, as a wake-up call to the business as usual scenario. In the business as usual scenario, the assumption is that status quo would be maintained till 2041 in terms of development pattern and growth rate and its impacts on environment and climate. The analysis and correlation model indicate that for a population of 28.7 million and the rate at which current urban development exists, if continued unabated till 2041 will lead to a further rise in surface temperature by 2.8°C, subjecting Delhi to an average surface temperature of 38.71°C. Also, over 80 per cent of the city would inundated and GHG emissions would increase by 84.6 MMT while heat sinks would be further lost by 15,600 hectares. To sum it up, over 80 per cent of the city would be covered with built impermeable surface.

The research presented here highlights the interdependence of urban development, climate change and the natural environment, as well as a multiplicity of implications (as indicated in Figure 8) 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.

Figure 8: Relationship between urban development, environment and climate variability for National Capital Territory of Delhi, 1986-2016



Model by Author (2017)

The study emphasises a 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.

First and foremost, **the master plan of Delhi needs to include 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.

6. Recommendations for future researchers

In the ongoing research, correlation between urban development and climate variability at city, spatial and planning division level; are explored. It also examines the impact of climate variability on vulnerable population and forecasts multidimensional risks for horizon year of 2041. With the alternative scenarios, it is understated that Delhi needs to start implementing climate resilient urban development strategies for a livable urban future, at an accelerated pace.

However, there is much scope for further research in areas of wind and humidity variables of climate. Also, we can do back casting of the correlation model and strategies and assess as to how the city would have developed had we come to terms with the fact that climate change is ubiquitous and a challenge to urban development and requires climate resilient urban development strategies, say in 1990s before the second master plan was being revised or in early 2000s when the third plan document was being drafted. Thus, there exists a few yet important areas of research that can be regarded.

The research is currently exploring few more dimensions in the relationship model. Simultaneously, it is working out the relationship for other megacities, which apart from its population size and area, exhibit a completely different manifest.

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