IMPACT OF BUILT FORM ON URBAN FLOODING IN GURUGRAM

A DISSERTATION

Submitted in partial fulfilment of the

Requirements for the award of the degree

of

MASTER OF URBAN & RURAL PLANNING

by

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under the supervision of

DR. ARINDAM BISWAS

DEPARTMENT OF ARCHITECTURE AND PLANNING

INDIAN INSTITUTE OF TECHNOLOGY

ROORKEE - (INDIA)

JUNE, 2019

CANDIDATE'S DECLARATION

I **Nishant Agrawal** hereby declare that the work presented in this dissertation entitled "Impact of Built Form on Urban Flooding in Gurugram", in partial fulfilment of the requirement for the award of the degree of 'Master of Urban & Rural Planning' submitted to Department of Architecture & Planning, Indian Institute of Technology, Roorkee, India, under the supervision of Dr. Arindam Biswas, is an authentic record my work done during the Spring semester of 2018-19. I have not submitted the matter embodied in this report for the award of any other degree or diploma.

Date: 10th June 2019
Place: Roorkee **Nishant Agrawal**

This is to certify that the above statement made by the candidate Mr. Nishant Agrawal is true to the best of my knowledge.

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CERTIFICATE

This is to certify that, this report titled ''**Impact of Built Form on Urban Flooding in Gurugram**'', which has been submitted by Mr. Nishant Agrawal in partial fulfillment of the requirements for the award of the Post Graduate Degree in Master of Urban & Rural Planning, to the Department of Architecture & Planning, Indian Institute of Technology, Roorkee is the student's own work as per my knowledge and carried out by his, under my supervision and guidance.

The matter embodied in this dissertation has not been submitted for the award of any other degree.

Place: Roorkee

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Nishant Agrawal

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Aim

To study the effect of Change in Built-Form with time on Hydrological Cycle.

Objectives

1. To explore the relation between built form and urban flooding and how they affect each other.
2. To study and analyse change in built form and flooding scenario in Gurugram area for past 20 years.
3. Spatial analysis of change in Ground water level with respect to built-form for Gurugram.
4. Spatially map flooding scenario for study area under different rainfall and built-form conditions.
5. To assess the area and enlist probable causes of flooding.

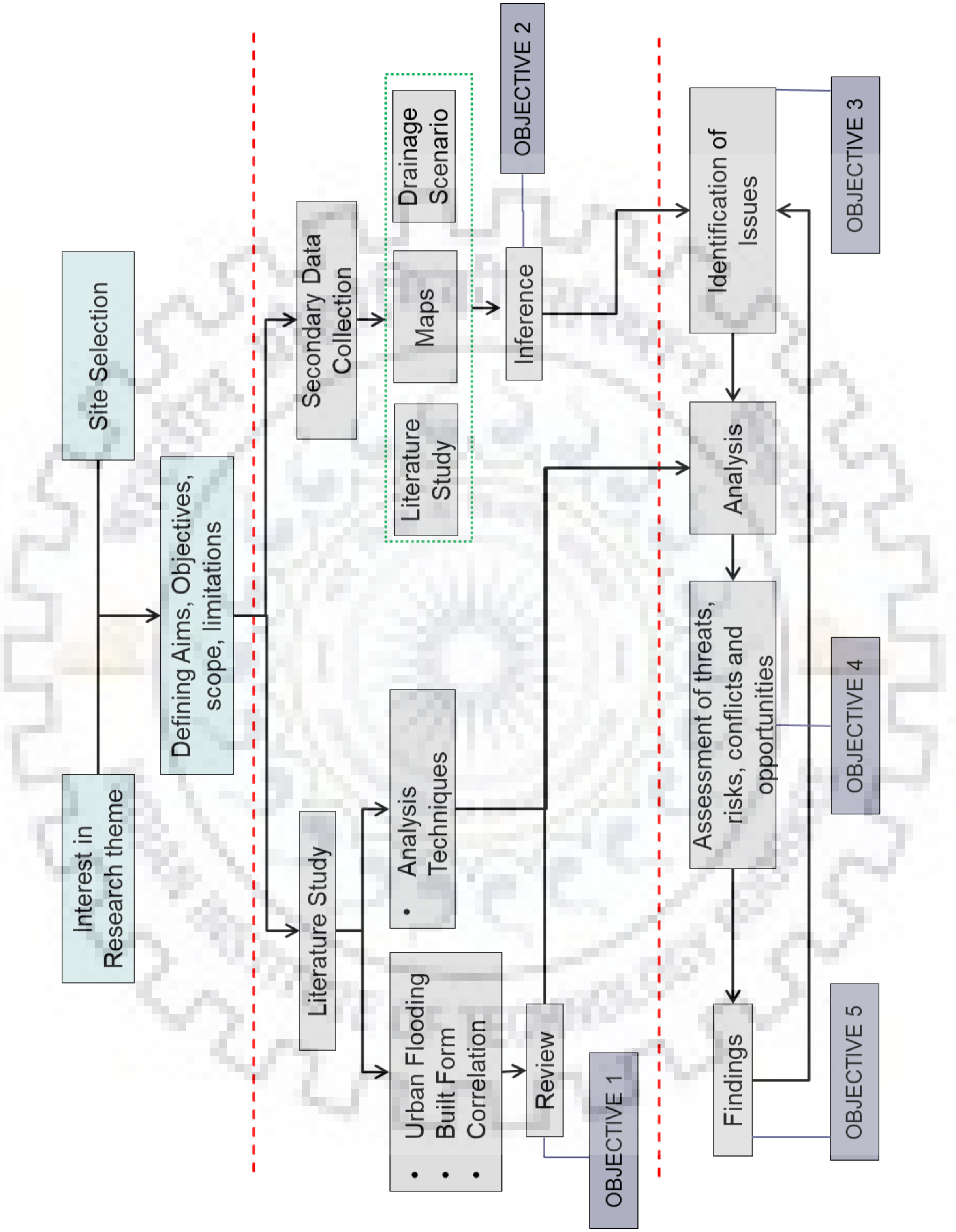
Scope

The scope of the study covers spatial and temporal characteristics affecting Urban Flooding. GIS based techniques would be used as these technologies provide efficient tools to manipulate and analyse variety of data.

Limitations

1. The study is limited to area under Gurugram Municipal Corporation.
2. Spatial Mapping has been done based only on available satellite images.
3. The analysis has been done based on information received from different government officials, published and unpublished government reports and news reports.
4. Due to lack of available Data, Cost factor cannot be determined.
5. News Reports have been considered for Flood Mapping.

Research Methodology



Literature Review

In this section, the project theme, need of study, study area profile and the techniques which could be used for analysis would be discussed.

Urban Flooding

Floods can be defined as "the submergence of usually dry area by a large amount of water that comes from sudden excessive rainfall, an overflowing river or lake, melting snow or an exceptionally high tide'" (Tamilarasu S, 2017). The MoUD noted the multiple effects of floods on human society. The primary effects incorporate causalities and property misfortune and the secondary effects incorporate sullying of water, misfortune in whole collect and spread of water borne ailments, while on other and the tertiary impacts incorporate financial hardship, the travel industry misfortune, deficiency of sustenance, cost of infra revamping, increment in costs. (Ministry of Urban Development, 2017)

Urban Flooding could be defined as floods due to local heavy rainfall are caused by insufficient or poor drainages (Tingsanchali, 2011). Urban flooding is explicit in the way that the reason is an inefficient drainage in area (Floodsite Projects, n.d.). In an urban area, when the capacity of sewerage and drainage system (including draining canals) is in-efficient to drain away the water received by heavy intensity rainfall then it can cause flooding.

The event of a flood occurs when water overflows or inundates land, normally dry. There are various ways in which it can happen. Out of these, the most common is when rivers or streams overflow their banks. The extreme level of rain, a ruptured dam, rapid snow melting, or even an beaver dam which is placed inappropriately can overwhelm a river and send it spreading over the adjacent land, called a floodplain. Coastal flooding happens when a huge tempest or tidal wave makes the ocean flood inland. (Geographic, 2017)

Most floods take hours or even days to create, giving occupants plentiful time to get ready or clear. Others create rapidly and with small cautioning. These blaze floods can be amazingly hazardous, immediately transforming a chattering creek into a roaring surge of water and clearing everything in its way downstream. (Geographic, 2017)

Floods present unequivocal challenges for emergency response as colossal districts of land are secured with water, making coordination extraordinarily irksome. Dealing with collaborations, transport and scattering of assistance stock is bewildered, since the state's framework is regularly hurt (IFRC, n.d.)

With growth in population, the demands for water will also increase. The major problem for today is the balance between water supply and water demand.

More than half of the Earth's population are occupied by Urban Areas and by 2050, this number is projected to increase to approx. 67% of the global population (United Nations World Water Assessment Programme, 2010). During the 20th century the population of urban areas increased by more than ten times which shows the rapid growth of urban areas and pressure on water resource due to high and sudden increase in demand. As the Urban regions continue to grow, over the next 25–50 years, assuring an adequate water supply will be a continuing issue in water resources and sustainability of urban areas. (Lyons, 2014)

Impact of Urbanization

As seen in the above section, it has been found that Urbanization plays a major role in elevating floods and we are required to study the components related to Urban Flooding affected by Urbanization.

Natural Drain

Drainage System consists of all the elements which carry water to water body. Natural drainage channel is the path of water carrying streams formed out of existing geographical and topographical features. Drainage basins consist of divided landscapes, which carry water to one particular stream. Each minor channel collects rainwater from its own drainage basin and discharges it to larger stream. The channel formation is a result of runoff from different built forms in the basin. (Urbanization and The Natural Drainage System - Impacts, 1991). The collection, movement and capacity of water through various drainage basins describe the hydrology of an area.

Encroachment or blockage of natural drains is one of the major causes of flooding, this may be due to identified or unidentified formation of structure. In the greater part of the quickly developing urban zones, normal water channels have vanished because of human-actuated progression on the name of advancement or infringement. (PRAHARAJ, 2014). Because of forthcoming structures, neither can the floodwater be depleted out appropriately, nor does it permeate in soil and these outcomes in waterlogging.

Ground Water

Groundwater is the water present underneath Earth's surface in soil pore spaces and in the breaks of rocks arrangements. In the past 50 years, direct and legal access to pumped wells has ushered in a worldwide “explosion” of groundwater exploitation for municipal, industrial, and agricultural supplies. Internationally, groundwater withdrawals all out 750– 800 km3/year. In numerous territories of the world, groundwater withdrawals for household and agrarian use are prompting falling groundwater dimensions of as much as 0.5 to 5 meters for each year (P.H. Gleick, 2001).

Groundwater consumption is inescapable and there have been common results of pulling back water from an aquifer. In instances of fossil or compacting aquifers, where energize is either inaccessible or unfit to refill depleted pore spaces, exhaustion successfully comprises changeless groundwater mining. Real districts of North Africa, the Middle East, South and Central Asia, North China, North America, and Australia, and restricted territories all through the world are influenced by Excessive groundwater consumption (Leonard F. Konikow, 2005).

Interrelation - Urban Flooding and Built Form

Urban form or Built form include built-up areas, the shape of built-up areas, size, density and arrangement of settlements. It tends to be considered at various scales: from local, to urban, neighbourhood, 'block' and road Built form intensification is a result of rapid urbanisation(James D. Miller, Hyeonjun Kim , Thomas R. Kjeldsen, John Packman, Stephen Grebby, 2014).

The physical qualities of constructed structure involve shape, size, thickness and design of settlements. This can have contemplations at different scales: from territorial, to urban, neighbourhood, square and road. Built form intensification is a result of rapid urbanisation (James D. Miller, Hyeonjun Kim , Thomas R. Kjeldsen, John Packman, Stephen Grebby, 2014).

Land use and other anthropological activities modify the way in which the rainfall and snowmelt are stored on and run off the land surface into streams and hence, influence the peak discharge of floods. The areas which are not developed including forests and grasslands, the rainfall and snowmelt collected and stored on vegetation, in the soil column, or in surface depressions (Konrad, 2003) and after filling up of storage capacities, runoff flows through soil as subsurface flow. In contrast with undeveloped areas, the urban areas where a major portion is developed and covered by impermeable surfaces of roads and buildings, are inefficient to hold rainfall and snowmelt. The improvement of structures, streets and so on frequently includes evacuation of vegetation, soil and miseries from the land use controls in the territory. The porous soil is supplanted by impermeable surfaces, for example, streets, rooftops, parking areas, and walkways that store little water, lessen invasion of water into the ground, and quicken overflow to streams.

With more rapid runoff and insufficient storage capacity of urban basins, the urban streams rise more quickly during storms by higher peak discharge rates as compared to streams flowing in rural areas (Konrad, 2003).

Further, Urban Flooding is associated with several losses that could be classified into Direct and Indirect losses. Direct losses are the immediate outcome of a natural disaster, mostly relate to the physical damage which occurs during and following an event and the loss of asset value. Primary and secondary losses are the two categories in direct losses. The primary direct loss is result from immediate destruction of buildings, lifeline systems and infrastructure caused by an event such as wind damage from a hurricane. Direct losses are the additional impacts, which are a result of physical destruction or degradation of property.

Disaster events have their residual effects which are termed as "indirect losses". These could be either decline in business, sales, local tax revenue or a combination of two or more. Also, disruption in transportation system is also one of the major indirect losses which highly affect the economy. Business disruption is one of the major problems in the aftermath of a storm or flood. The local businesses shut down and cause a rise in unemployment and loss in revenue as the communication and transportation networks take longer timer in repair.

By the above discussion, it could be inferred that there is a direct correlation between Urban Flooding and Built Form as the effect of one could be directly seen on the other.

Review

S.No.	**Citation**	**Learnings**
1.	(Christopher, 2003)	Impermeable Surface accelerates Runoff; Land Use change effects flood vulnerability; the settlement in flood-prone areas is more vulnerable to flood hazards
2.	(Huong & Pathirana, 2013)	Urban development affects the hydrological and hydro meteorological conditions which increase flood risk and hazard; Urbanisation significantly impacts urban rainfall intensities
3.	(Pelling, 1998)	Community Participation in decision making for sustainable management, local support, resource

		allocation
4.	(Barroca, Bernardara, Mouchel, & Hubert, 2006)	vulnerability study is to limit weakness and integrate flood risk into urban development
5.	(Johanna Antonia Elisabeth ten Veldhuis, 2010)	The quick urbanization has offered ascend to increment in manufactured thickness in zones defenseless against inclined territories; the development of impenetrable surfaces adding to the inflow into existing urban drainage systems and accordingly to the likelihood of flooding.
6.	(Hua-peng Qin, Zhuo-xi Li, 2013)	Cover structures (LID designs) are progressively compelling in flood decrease amid the heavier and shorter precipitation occasions
7.	(Suriya & Mudgal, 2012)	Understanding Hydrological Effects of Urban growth is essential for Urban Planning. GIS adds a great deal of versatility to hydrological analysis.
8.	(James D. Miller, Hyeonjun Kim , Thomas R. Kjeldsen, John Packman, Stephen Grebby, 2014)	Routing of storm runoff through high proportions of impervious layer into the concretized drainage system can lead to flashier and adverse impacts as compared to the ones attributed by land use land cover change or increase in impervious cover.

CASE STUDY – CHENNAI FLOODS

There are several cases in India where Urban Flooding could be seen. Almost all of the Metropolitan areas in the country are experiencing waterlogged areas and flooding situation during monsoon. Only if we see for the year 2018, Bangalore (Debroy, 2018), Chennai (Nath, 2018), Delhi (Sharma, 2018), Mumbai (Staff, 2018), Kolkata (Express News Service, 2018). One of the Cases of Chennai Floods has been discussed in detail in the next section.

Introduction

In Tamil Nadu, Chennai and various other parts were impacted by the devastating floods during November and December in year in year 2015, claimed about 400 lives and caused economic damages enormously. The event mentioned above created a challenge to the scientific community in developing a comprehensive understanding for the events like this. Therefore, answers to the crucial questions linked with the circumstances prevailing during and after flooding phase which are essential to evolve this understanding. These include: (a) what were the air conditions that caused the high power precipitation, (b) how was the precipitation circulated spatially and transiently, (c) what amount of stream happened in the three waterways going through the city– the Kosasthalaiyar River, the Cooum River and the Adyar River - and the Buckingham channel, (d) how were the two repositories upstream of the city, viz., the Chembarambakkam repository and the Poondi supply, worked, (e) what amount overland stream was created in the city because of precipitation over the city alone, (f) how did the tempest water waste framework react, (g) which zones in the city were immersed and for to what extent, (h) how did the waters subside after the downpours stopped, (I) what were the wellbeing ramifications of the occasion, (j) did the land use change in the city throughout the years fuel the flooding, and, in particular, (k) what moves should be made so that for comparative precipitation designs rehashing in future, the city would not face such an overwhelming storm?

Impact of Global Warming and Urbanization

The theories and models given by various scientists suggest the rise in tropical cyclones in former decades. However, these suggestions are not proved from the recorded number (counts) of cyclones (Balaji Narasimhan, 2016).

Be that as it may, the conceivable ruinous tendency of tornados, characterized as "the all out dissemination of intensity, coordinated over the lifetime of the typhoon has expanded, is expanding and will increment in a warming domain (Emanuel, 2005) and this is principally connected with the warming" (Knutson, 2004).

The global warming is a potential reason of the significant event over which Chennai is hypothesized. However, this is not proven and need to be proven by an event based attribution (King, 2010) study. The other factor which is observed is the urbanisation, which has intensified the very intense precipitation.

This is either from making of convection because of Urban Heat Island (UHI) or through the uneven urban landscape bringing about wake dissemination and choppiness (Shastri, 2015)

This is observed that the extremes in Southern and Central Region of India are affected during summer monsoon season (Shastri, 2015) but this is also true that the specific impacts during the monsoon of winter and cyclones have not yet been explored. This city is analysed to have significant urban heat island (Swamy, 2016) and there is a possibility of such UHI-extremes link.

This is noticed that inappropriate urbanisation may also to the encroachment of the waterways. This kind of encroachment will reduce their vent way. The improvement of Mass Rapid Transit System (MRTS) along the Buckingham waterway and in certain areas in this channel is a practical case of above case. In other case, the new Runway of Chennai city's airplane terminal is based on the Adyar River. In the comparable way, ducts given on different new streets have lacking ability to pass the stream from one side to other.

Magnitude of Floods – Loss of life and property

The floods of December 2015 were enormous although, there are reports upon the various losses like total casualties, extent of flooding and total economic loss.

On December3, 2016, the Government of India informed that the rains and floods claimed 269 lives in Chennai alone (The Indian Express, 2015a) (Balaji Narasimhan, 2016). The unfortunate news was of death of 18 patients in MIOT International Hospital. The hospital is located close to the Adyar River and the power units supplying power to the ventilators were damaged by flood waters (The Hindu, 2015b). The passing numbers were ascend to 347 (in the whole province of Tamil Nadu) by December 25, 11, 2015, according to the announcements of the State Government (The Hindu, 2015c). The Chief Minister of state affirmed that a sum of 470 lives were lost in the province of Tamil Nadu amid the North East storm (The Hindu 2016a).

Due to this flooding event, more than 18 lakh (1.8 million) population was displaced. About 30.42 lakh (3.042 million) families were suffered with partial or full damage to their houses; due to flooding, a total of 3,82,768 lakh hectares of agricultural crops and were damaged and 35,471 hectares of horticultural crops; roughly 98,000 livestock animals and poultry were died (The Hindu, 2016b). Due to floods, a total of more than 100,000 structures were damaged. Almost 30% of Chennai households have each faced losses between Rs.2 lakh and Rs.20 lakh (DNA, 2015)

Study area Profile

Introduction

Gurugram is a part of National Capital Region and is located in Haryana State in the north west of India.

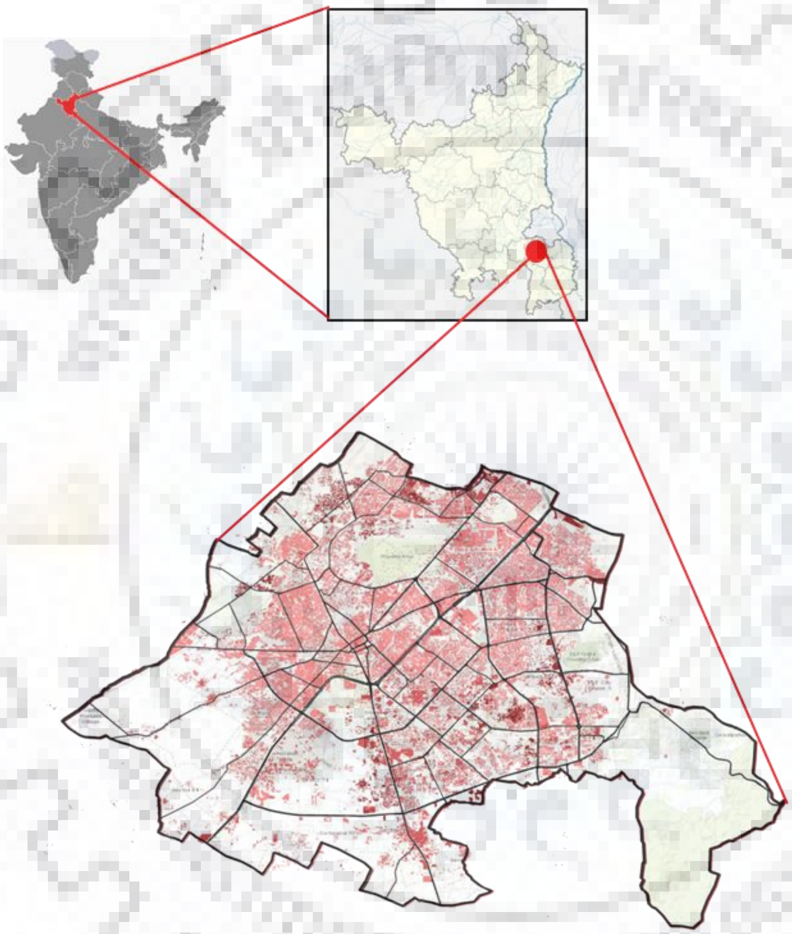


Figure 1 Location Map of Gurugram (Source : GMDA, Author)

Gurugram is a leading financial and industrial hub, holding the third-highest per capita income in India. It has achieved a sudden growth in economic development status. Its monetary development story began when the main Indian vehicle maker Maruti Suzuki India Limited built up an assembling plant in Gurugram (at that point Gurgaon) during the 1970s. Today, This City has nearby workplaces for in excess of 250 Fortune 500 organizations.

Present Scenario of Gurgaon development

In 1966 when the state of Haryana was formulated, Gurugram was designated as one of its districts. Formerly, the city was based on an agro-based economy. The town was intercepted under the Urban Estates Department, Haryana in 1966 from where, the its planned urban development was started. The decade of 1970s mark the journey of its development. However, the city faced huge influx in population which moved into Gurugram since 1990’s onwards which gave it a growth spurt. The reason behind this phenomenal change in city was the outcome of new liberal system introduced in India in 1990’s. The advancement and globalization made the city as a home to various employment choices before the finish of the 1990s with GE being the first to set up its redistributing unit in Corporate Park in Gurgaon in 1997. This actuated the tremendous populace development and Gurugram turned into the Millennium city. Because of differential development experience between two times of pre 1990s and post 1990s, the city has seen two qualities. In the time of pre-advancement, the development of the city and the coming up of new parts has been neighboring the old states of Gurgaon, towards Delhi along the Old NH-8. The segments created at then incorporate till division 23 and are situated to one side of NH-8 (while proceeding onward NH-8 from Delhi towards Jaipur). These comprise Old Gurgaon. The Old Gurgaon was grown generally by the administration with the exception of two pockets that have been worked by the private designers (Old DLF Colony by DLF close segment 14 and Palam Vihar by Ansals in part 21 to 23).

Since 1990s, the development began spreading outwards with the coming up of NH-8. Parts 24 to 57 (aside from division 31 to 38) have all come up post-1990s, that is, in the post-advancement stage. These segments have come up post 1990s and to a great extent been worked by the private engineers. This development and the areas are situated to one side of NH-8 (while proceeding onward NH-8 from Delhi towards Jaipur) and establish New Gurgaon. Therefore, two characteristics of development can be observed in city.

Demographics

The demographic transformations in Gurugram show the sharp increase in the population thus city has also faced cultural changes as well. Gurgaon was a class III town till the beginning of 1970s decade. The main specification of the number of inhabitants in Gurgaon was done in 1868 when this town had 2,643 individuals. The town had a populace of 9,935 people in 1941. The Table given beneath demonstrates the expanding populace quantities of city. The number of inhabitants in Gurgaon had raised quick from 18,613 individuals in 1951 to 37,868 of every 1961. This expansion was primarily because of the development of industry in and around Gurgaon and its proximity to NCT of Delhi.

The city had a population of more than 1 lakh over a period of 30 years from 1971 to 2001. In last decade from 2001 to 2011, it was with 15,00,000 (1.5 million) population numbers. The lofty development of populace amid 2001 and 2011 that is the first decade shows enormous scale in-movement of individuals from neighboring states specifically. This change in populace pattern was because of work openings produced in an arrangement. The underlying open doors were that of the Maruti plant in 1980s and pursued by auxiliary plants coming up. Toward the finish of 1990s and start of 2000, there was countless focuses, BPOs, KPOs – all working in movements with a great deal of taxis, subsequently creating in-office employments as well as occupations for drivers, watches. The trend was followed by coming up of more IT companies and corporate office jobs influencing in migration of people simultaneously with low income generating jobs to support higher income groups. This city as well as the present urban villages has inferred distinctive nature of working alternatives, for example, giving on lease shared cars, driving shared cars or beats, giving on lease set of rooms, shops.

In the time of 1971-81, when the populace development in city was 56%, the rustic populace became just by 35.3%. Be that as it may, this pattern changed amid 1981-91 when the towns in city have appeared higher development rate than this town, the normal being 64.71% amid 1981-multi decade contrasted with 36.32% for the city. Out of these, four towns have demonstrated a development rate of over 70% amid that decade. The assessments show that the rate of populace development in these towns is probably going to be higher as yet amid 1991-2001 because of mechanical, private and business spaces made in the city locale because of numerous components, for example, globalization, key job of private engineers and pursued by acquiring of corporate employments. Additionally, these evaluations demonstrate the rate of development of populace in these towns is probably going to be higher as yet amid 1991-2001 by virtue of mechanical, private and business spaces made in the city district because of different factors, for example, globalization, key job of private designers and pursued by getting of corporate employments. Presently, it tends to be seen that, populace has been on increment yet is driving towards the physical extension of Gurgaon from Old Gurgaon or center town. Likewise, over the most recent two decades, the populace development has moved to the encompassing fringe towns accordingly prompting difference in these towns into urban towns and the obtained spaces of these towns into New Gurgaon.

Table 1 Population Growth 1941-2011

Year	Population
1941	9,935
1951	18,613
1961	37,868
1971	57,151
1981	1,00,877
1991	1,35,884
2001	2,29,243
2011	15,14,000

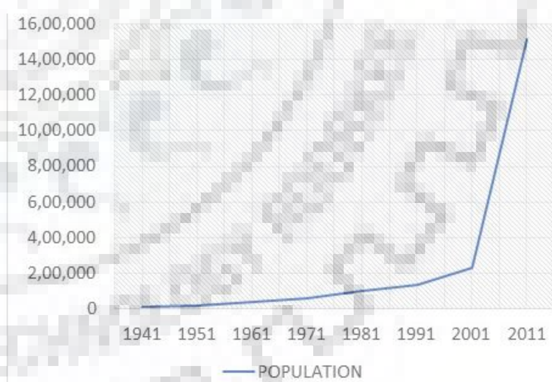


Figure 2 Population Growth Curve

Ward Wise Population

Table 2 Ward Wise Population

Ward_No	Area	Households	Population	Population Density
1	592	5528	26429	45
3	328	10001	45861	140
2	1127	9152	41499	37
4	151	9595	43754	290
11	179	6821	27725	155
12	1056	5225	21454	20
10	113	6250	26512	235
9	359	9325	40975	114
15	207	5393	22791	110
14	220	3572	13676	62
8	104	8781	40581	390
7	93	6575	29142	313
6	328	7709	35958	110
18	143	2473	9072	63
17	100	3809	13586	136
16	80	5562	19336	242
21	96	4887	19179	200
13	447	4757	16731	37
23	306	4940	16890	55
22	56	4301	16133	288

20	122	6315	28088	230
19	558	4859	22265	40
27	552	3921	14895	27
28	316	5650	23106	73
24	2306	6198	24358	11
25	1916	5421	20398	11
26	1805	5924	21746	12
5	947	8411	40048	42
35	549	349	2128	4
29	1039	5747	23114	22
31	277	7085	32348	117
30	3390	6733	28036	8
34	1130	1054	5913	5
33	242	8329	39699	164
32	1762	7348	31584	18

Spatial Dynamics of the City

The dynamics of demography bring spatial expansion and transformations in the city. As the city has seen a sharp spurt in population in last two decades which is proportional in parallel way by growth in area of city . The need to accommodate the growing population has caused this increase in area. This growth in area has influenced the land uses and land covers in the city. The city has its limited boundary hence, the encroachment of the peripheral villages can be observed. Consequently, there has been landscape change in the city.

Areal Growth and Spatial Transformation of the City

The growth in area of Gurgaon with the passage of time is given in the graph which shows the increase in the city's area. The increase in expansion of area has been only marginal before year 2001 and after that there has been a sharp rise in the increase in area occupied by settlement of the city. This has been largely due to the influx of huge population in the city.

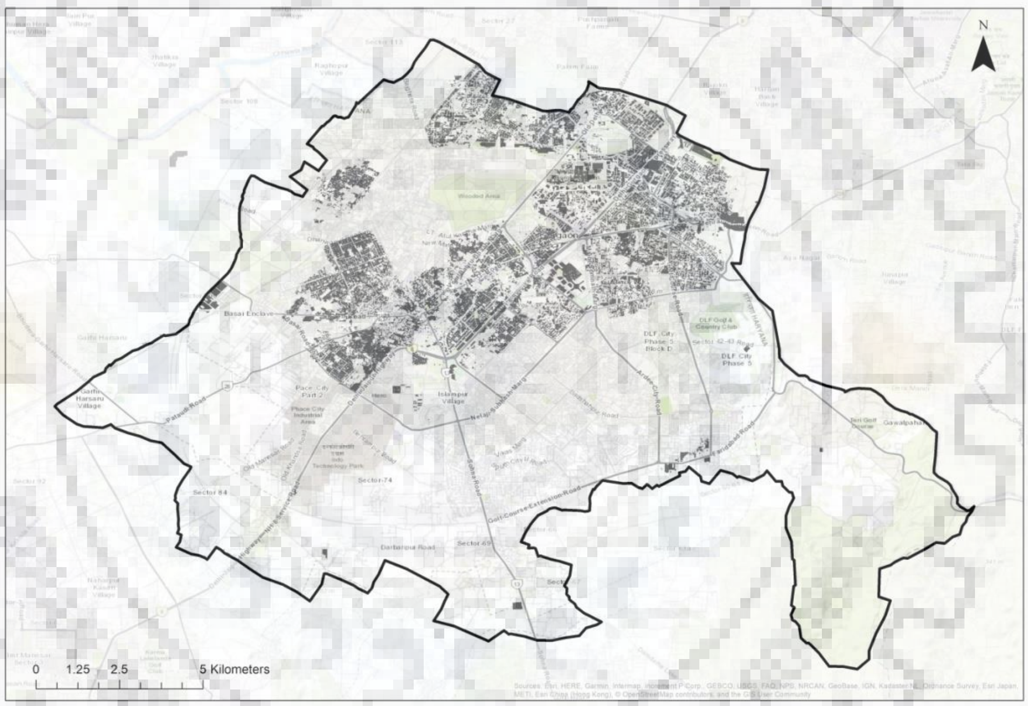


Figure 3 Developed Land Year - 1990 (Source : Composed by Author)

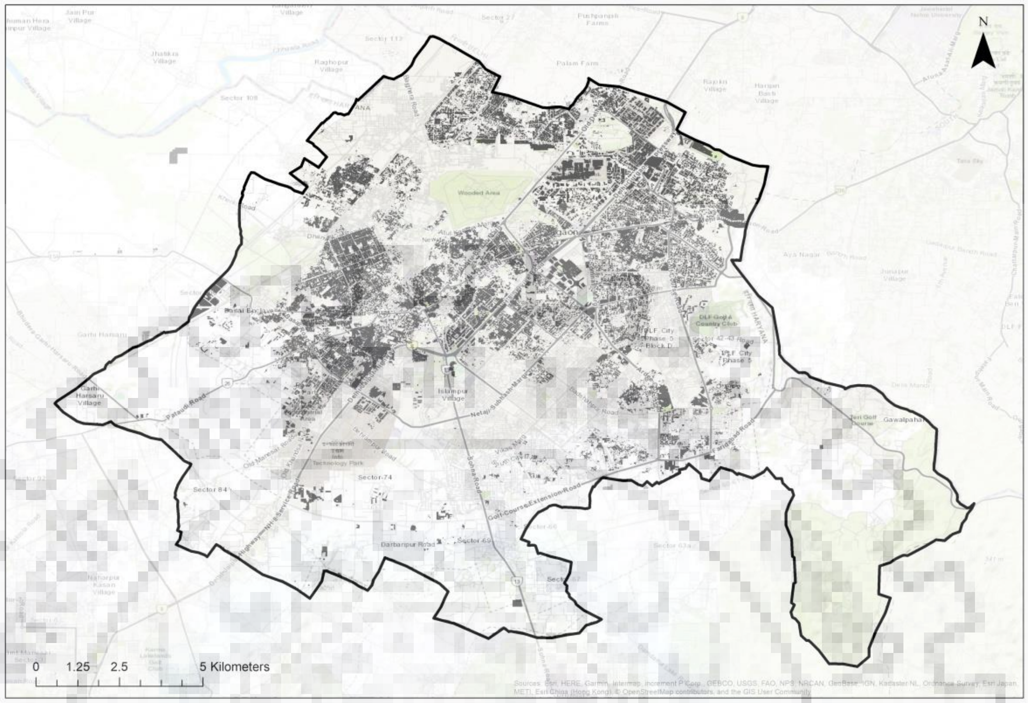


Figure 4 Developed Land Year - 1999 (Source : Composed by Author)

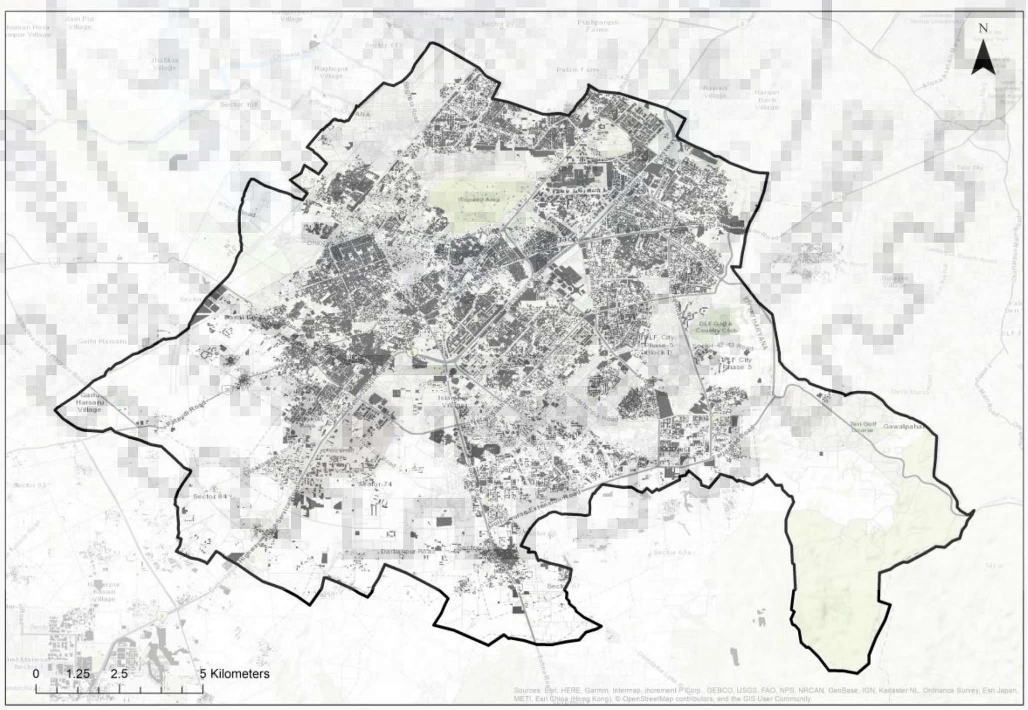


Figure 5 Developed Land Year - 2009 (Source : Composed by Author)

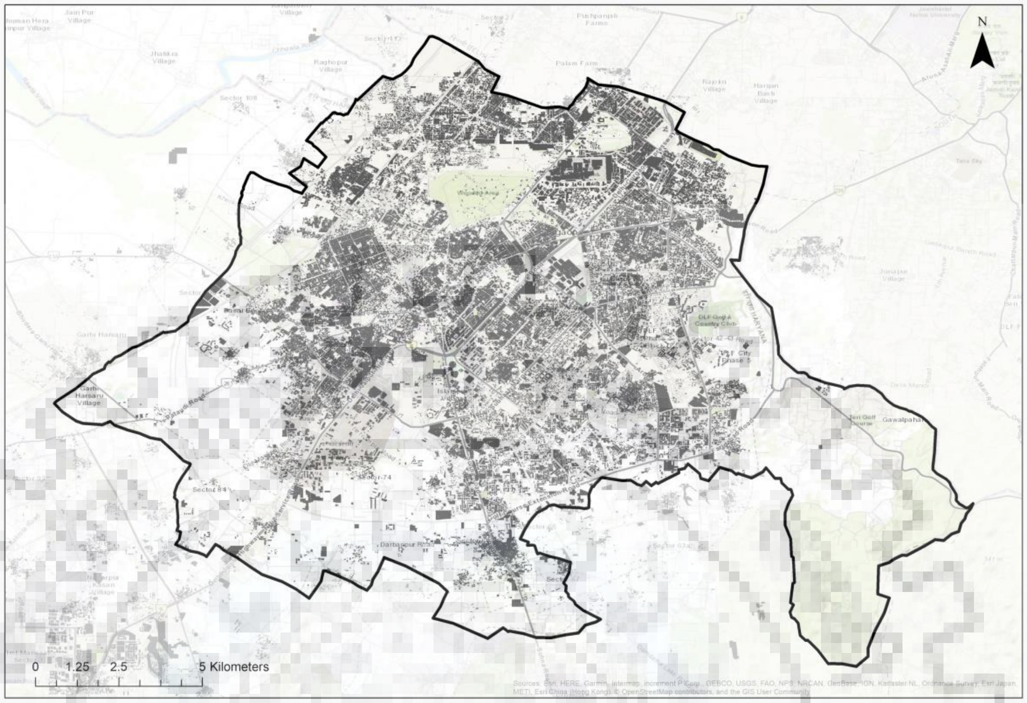


Figure 6 Developed Land Year - 2019 (Source : Composed by Author)

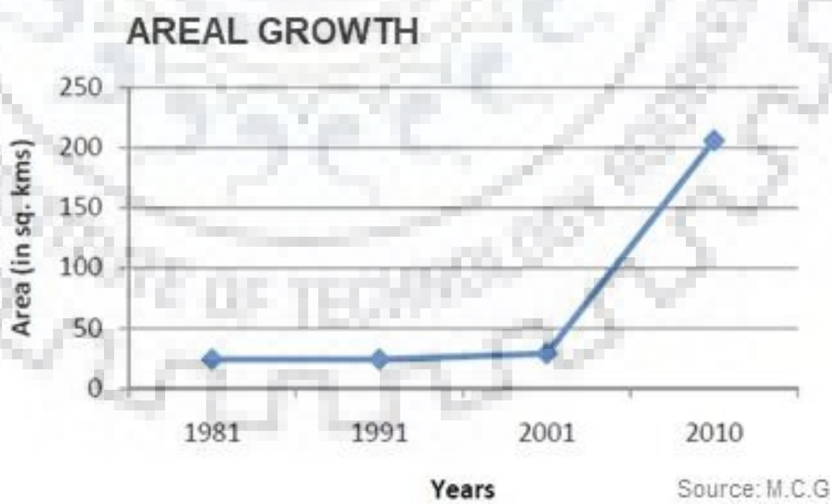


Figure 7 Areal Growth of Gurugram from 1981 - 2011

As examined over, this flood is impacted by the various activity ages in the city and joined by the gigantic scope of lodging offered by the private engineers. The areal increment of the city is come about into the changed scene and land use change in the city is gigantic. The most extreme has been the change of agrarian land into the developed zone and the resultant changes are uncovered by unequivocal contrasts in the land use change throughout the years.

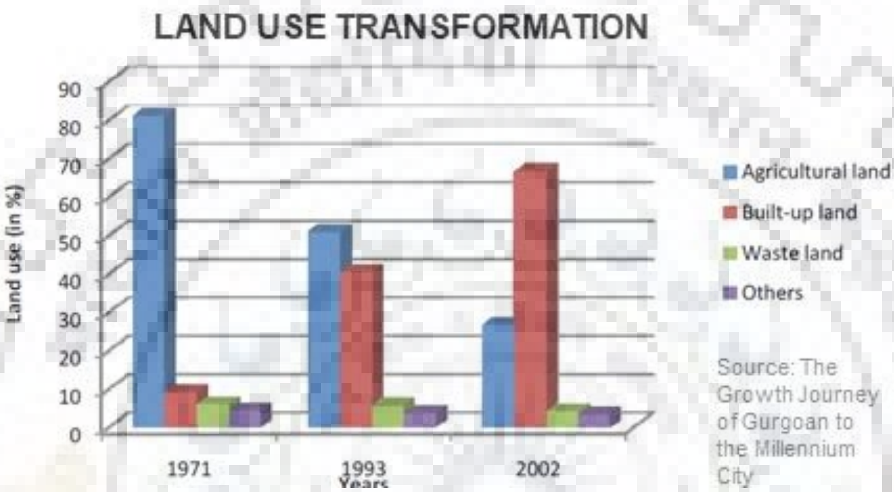


Figure 8 Land Use Transformation in Gurugram

This is due to the transformation of land from agricultural use to the use of built-up category in past decades. This is because of the change of land from rural use to the utilization of developed class in past decades. Out of the 126 sq kms. in 2002, as absolute territory of Gurgaon city/area, almost 81 % was under agribusiness in 1971 i.e., under towns. It was diminished to around 51% (50.67%) in 1993 and to 26.5% in 2002. The rate of decay was higher amid the most recent decade. Since 1971-93, 38.43 sq kms. of rural land was lost while from 1993 2002, 30.65 sq kms. of farming area was lost. Since this region has been generally put to the developed class, the 'developed land' classification expanded considerably from 11.36 sq kms. in 1971 to 84.2 sq kms. in 2002, the rate share having expanded from 8.96 in 1971 to 66.42 in 2002.

Climate

Gurugram city encounters a rainstorm affected composite atmosphere. It encounters four seasons - spring (February - March), summer (April - August), fall/harvest time (September - October) and winter (November - January), alongside the rainstorm season setting in towards the last 50% of the late spring. The period of summers beginning from early April to mid-October, are ordinarily sweltering and muggy, with a normal day by day June high temperature of 40 °C (104 °F). The season encounters heat lists effectively crossing 43 °C (109 °F). Winters in the city are cold and foggy with couple of bright days, and with a December daytime normal of 3 °C (37 °F). The Western Disturbance acquires some downpour winters that further adds to the chill. Spring and harvest time are gentle and lovely seasons with low mugginess. The rainstorm season as a rule begins in the primary seven day stretch of July and proceeds till August. Rainstorms are normal amid the Monsoon. The normal yearly precipitation is around 714 millimeters (28.1 in).

Climate data for Gurgaon [hide]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C (°F)	21.1 (70)	24.2 (75.6)	30.0 (86)	36.2 (97.2)	39.6 (103.3)	39.3 (102.7)	35.1 (95.2)	33.3 (91.9)	33.9 (93)	32.9 (91.2)	28.3 (82.9)	23.0 (73.4)	31.4 (88.5)
Average low °C (°F)	7.3 (45.1)	10.1 (50.2)	15.4 (59.7)	21.5 (70.7)	25.9 (78.6)	28.3 (82.9)	26.6 (79.9)	25.9 (78.6)	24.4 (75.9)	19.5 (67.1)	12.8 (55)	8.2 (46.8)	18.8 (65.8)
Average rainfall mm (inches)	20.3 (0.799)	15.0 (0.591)	15.8 (0.622)	6.7 (0.264)	17.5 (0.689)	54.9 (2.161)	231.5 (9.114)	258.7 (10.185)	127.8 (5.031)	36.3 (1.429)	5.0 (0.197)	7.8 (0.307)	797.3 (31.389)
Average rainy days	1.7	1.3	1.2	0.9	1.4	3.6	10.0	11.3	5.4	1.6	0.1	0.6	39.1
Mean monthly sunshine hours	213.9	217.5	238.7	261.0	263.5	198.0	167.4	176.7	219.0	269.7	246.0	217.0	2,688.4

Figure 9 Average Climate Data of Gurgaon

Rainfall

Rainfall pattern for the area has been studied from IMD data to identify the total and maximum rainfall each year. It has been done to be superimposed with Flooding map and identify the critical areas of flooding.

Table 3 Annual Rainfall Statistics (Source : IMD)

Year	Annual Rf (mm)	Max Rf (mm)
1991	676.5	120
1992	422	45

1993	1030.5	118
1994	824	85
1995	926.3	127
1996	966	90
1997	882	80
1998	1300	124
1999	485	72
2000	673	87
2001	573	72
2002	451	82
2003	799	132
2004	528	52
2005	486	62
2006	288	47
2007	603	98
2008	955	82
2009	677	128
2010	1244	162
2011	563.5	52
2012	711	102
2013	799	102
2014	297	50
2015	466.8	122
2016	449	96
2017	308	58
2018	425.8	153

Catchment Area

Gurugram and NCT Delhi are for the most part arranged in the Najafgarh Basin which is a sub-bowl of the Yamuna River and is spread over conditions of Rajasthan, Haryana and Delhi. The rough catchment zone in the constituent states is as following :

• Catchment in Rajasthan : 6889 sq.km. [Sahibi waters through Outfall Drain No.8 – aggregate catchment upto Dhansa]

• Catchment in Haryana : 3074 sq.km [northern floodwaters through Outfall Drain No.8 – 1016 sq.km. + Manesar and Badshapur Nallahs – 464 sq.km.]

• Catchment in Delhi : 648 sq.km.

Gurugram Floods

Gurugram has been experiencing urban floods from past more than 10 years, the evidence could be seen from news of Dainik Jagran, Amar Ujala, etc. stating reports of Waterlogging and Flooding in several sectors of Gurugram. The data for Flooding has been collected from Newspaper reports and have been marked in the Table to identify recurrences of Flooding.

Table 4 Gurugram Flooding Recurrence Year 2009 - 2014 (Source : Amar Ujala epaper)

Area Name	2009	2010	2011	2012	2013	2014
Agrasen Chowk						
Agrawal Dharamshala Chowk						
Fawwara Chowk						
Gurudwara Road						
Hero Honda						

Chowk						
Iffco Chowk						
New Railway Road						
Old Railway Road						
Rajeev Chowk						
Sabzi Mandi Chowk						
Shankar Chowk						
Bakhtawar Chowk						
Sector 42 Chowk						
DDO Chowk						
More Chowk						
Mahavir Chowk						
Basai Road						
Jharsa Road						
Medicity Road						
Civil Lines road						
Mata Road						
Sector 17 to MD Chowk						
Khandsa Road						
Devilal Nagar						
DLF Phase 1						
DLF Phase 2						
DLF Phase 3						

Gandhi Nagar						
Hans Enclave						
Heera Nagar						
Jacobpura						
Jyoti Park						
Kirti Nagar						
Laxman Vihar						
Laxmi Garden						
Madanpuri						
Mayfield garden						
Mianwali						
Model Town						
Om Nagar						
Patel Nagar						
Prem Nagar						
Rajeev Nagar						
Rajendra Park						
Ram Vihar						
Sector 12						
Sector 14						
Sector 15						
Sector 18						
Sector 29						
Sector 31						
Sector 32						
Sector 34						
Sector 38						
Sector 39						
Sector 4						
Sector 40						

Sector 42						
Sector 44						
Sector 45						
Sector 46						
Sector 49						
Sector 52						
Sector 7						
Sector 7 Extn						
Sector 9						
Shanti Nagar						
Sheetla Colony						
Signature Tower						
Sushant Lok						

Ground Water

The ground water statistics have been collected from CGWB and analyzed. The table below analyses one of the sites in centre of Gurugram and it has been found that with passing year and increase in development, ground water recharge has reduced drastically and from the year 2016 to 2018, Pre-monsoon (May) statistics show that there is a decline of approx. 7 mtrs. in just 2 years. This is a result to high Volume of extraction and low recharge.

Table 5 Gurgaon Location Ground Water analysis (2001-2018)

Site	Year	Jan	May	Aug	Nov
Gurgaon	2001	31.32	32.7	33.01	33.42
	2002	32.55	-	-	33.31
	2003	33.56	34.05	33.91	34.05
	2004	33.29	-	33.55	-

	2005	33.65	-	33.96	-
	2006	-	-	32.37	-
	2007	-	-	32.05	32.37
	2008	-	32.47	32.05	31.95
	2009	31.32	31.95	31.77	32.07
	2010	31.64	32.7	32.44	32.13
	2011	31.74	31.85	-	33.4
	2012	32.4	33.45	-	33.26
	2013	-	35.35	-	35.75
	2014	-	35.97	-	38.12
	2015	-	39.89	-	39.75
	2016	40	40.98	-	41.45
	2017	-	-	-	-
	2018	46.5	47.65	-	-

The data collected lacks enough information for computation of exact ground water at all locations, so the available data has been interpolated based on the points and timeline on Arc GIS software to attain map of Ground water scenario for the year 2018/

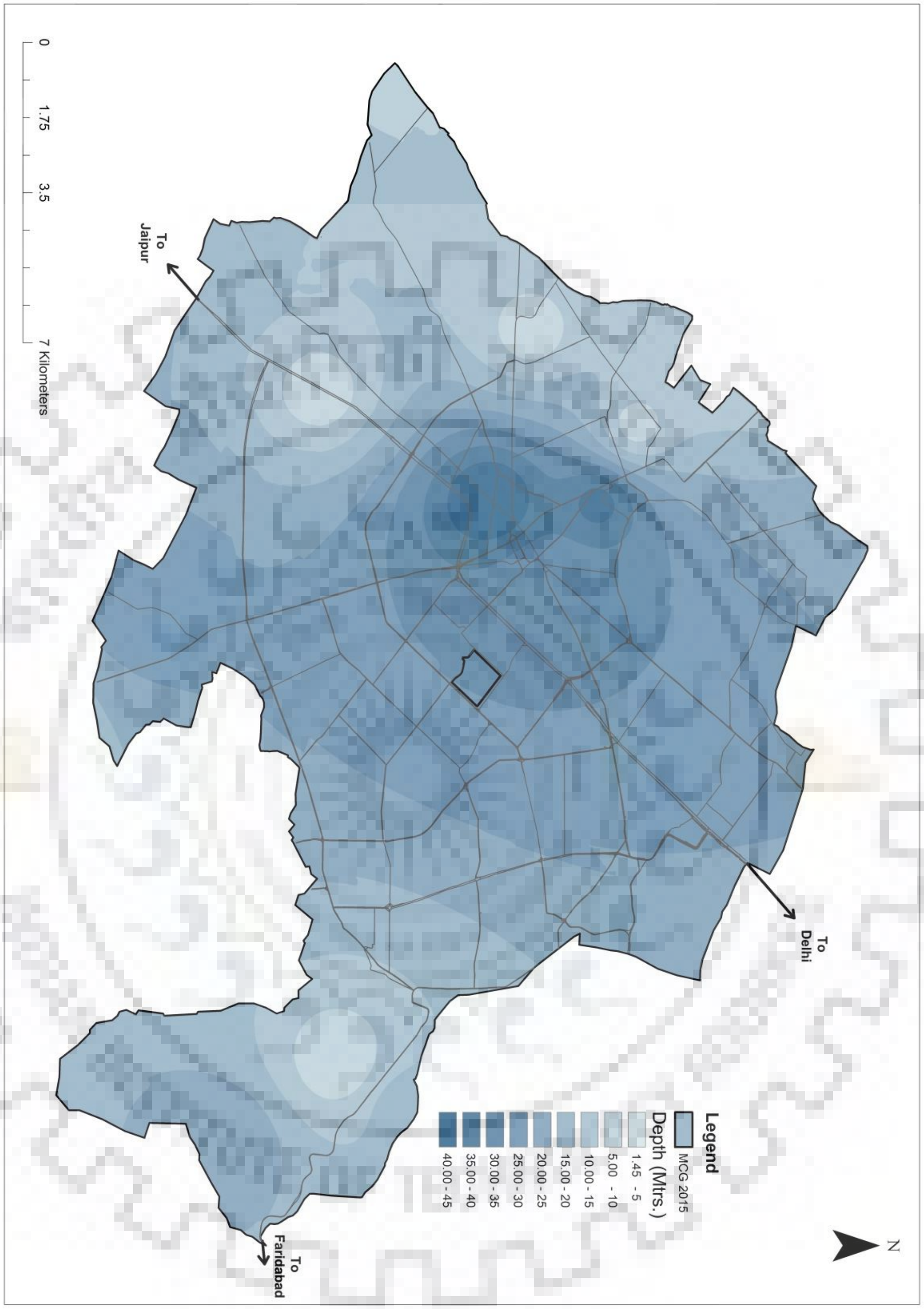


Figure 10 Current Scenario of Ground Water Table in MCG area year 2018 (Source : CGWB, author)

Geographical and Topographical Features

As the study considers both natural and manmade feature of the city, so in this section we have mapped the Geographical and Topographical Features of the City based on Satellite data from USGS Glovis, Google Earth Imagery, Central Ground Water Board Report.

Soil Characteristics and Gradient

The area has Majorly Loamy soil with part of the area covered with Coarse Loamy Soil, another part having a mix of Fine and Coarse Loamy Soil and third part is covered with rocky soil that lies in hill part of the city. Characteristics of soil and Gradient are used to calculate runoff coefficient of the soil.

Table 6 Soil Characteristics

Soil Type	Gradient (%)	Run-off (%)
Coarse Loamy	0 – 5	30 – 35
Coarse / Fine Loamy	0 – 10	30 – 40
Rocky Surface	0 – 15	35 – 60
Rocky Surface	15 – 50	85

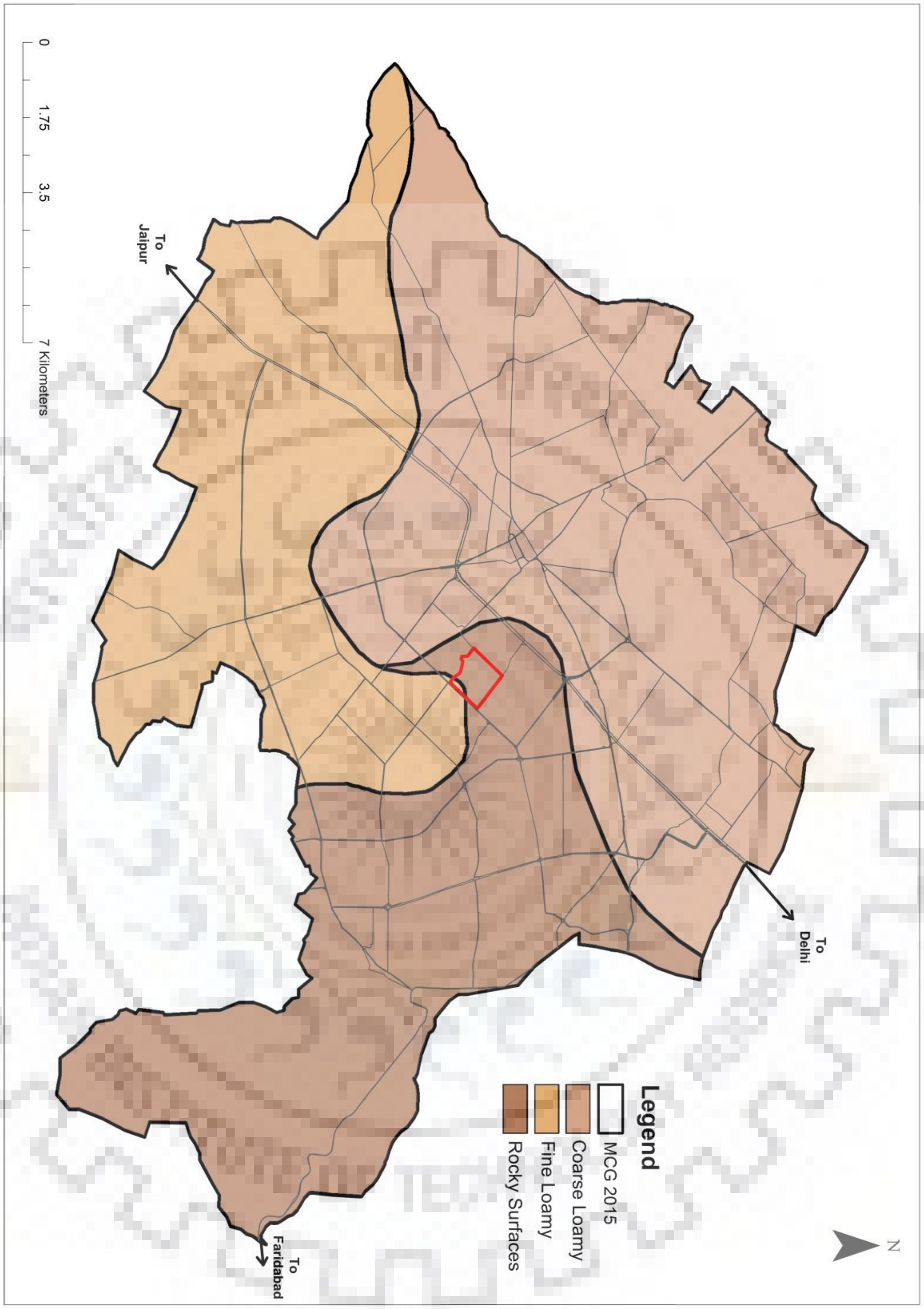


Figure 11 Type of Soil

Coarse and Fine loamy soils have low run-off as compared to Rocky areas and that means they have a high porosity and can percolate high volumes of water. Further, the runoff is dependent upon the Slope of that particular area as given in Figure 12. The intensity of percolation can be identified using infiltration mapping obtained from CGWB district report as provided in Figure 13. The combination of these three maps can help us identify the runoff and water percolation calculations for the specific area as used for our study area.

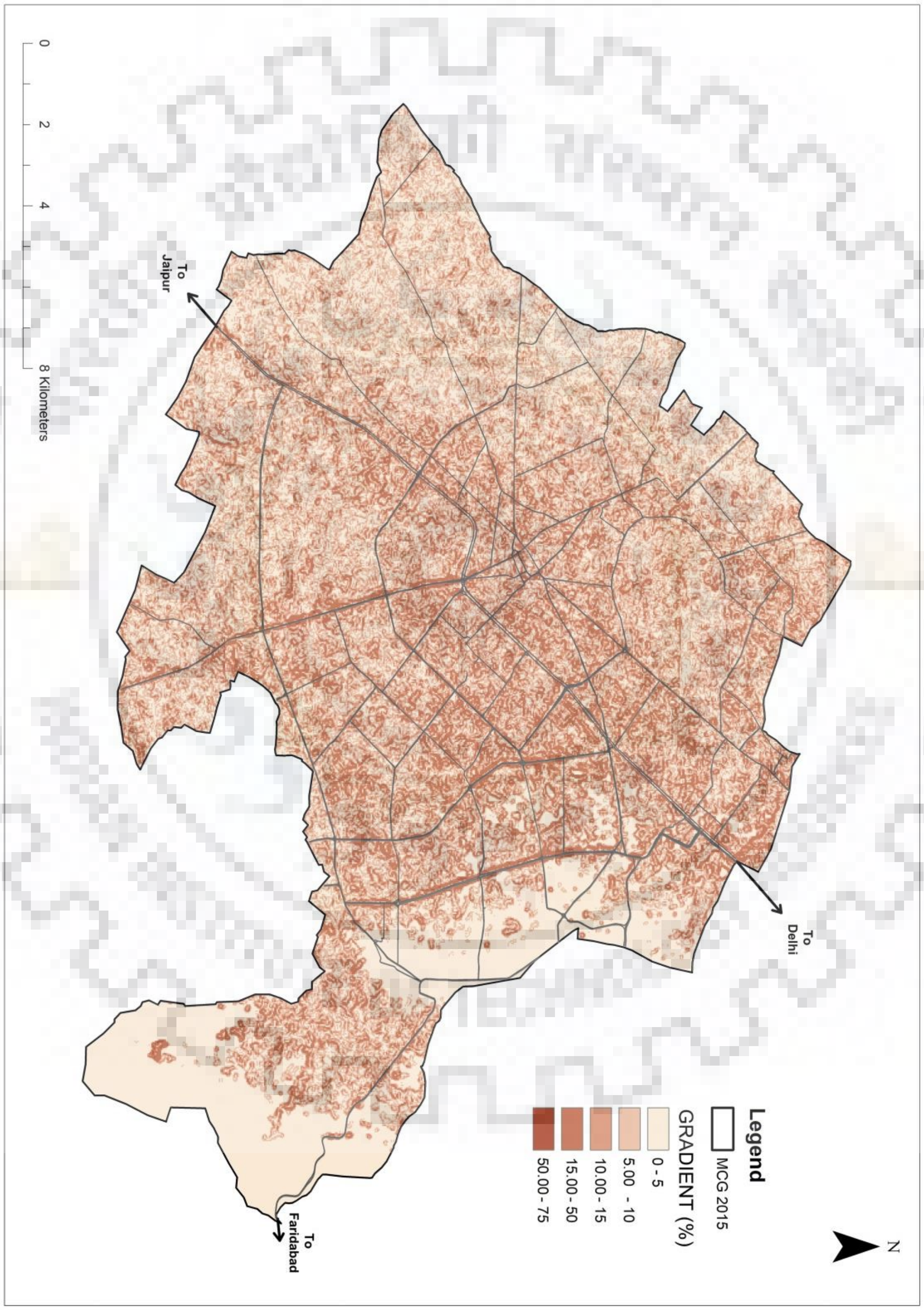


Figure 12 Slope

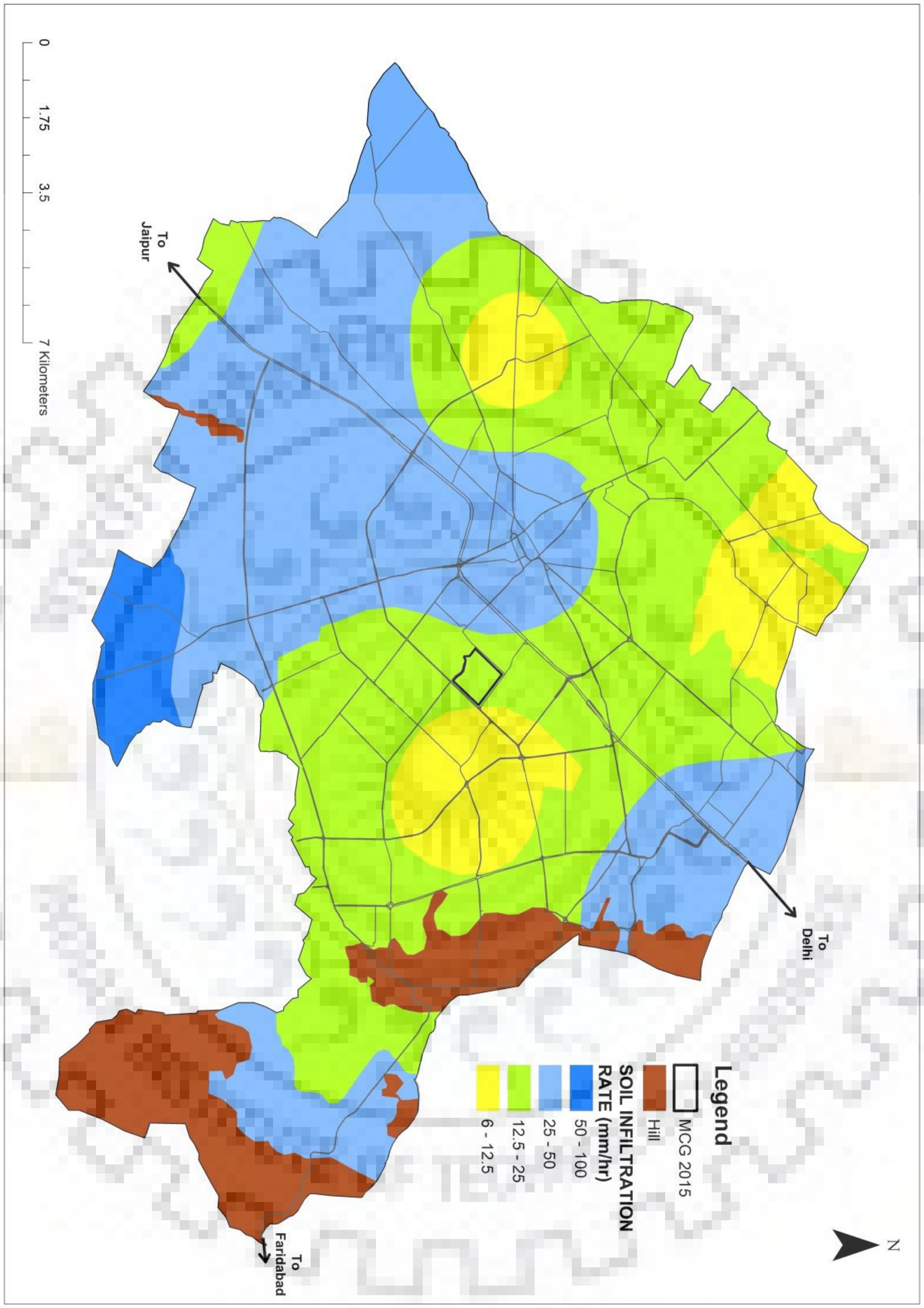


Figure 13 Soil Infilration rate Mapping (CGWB)

ELEVATION

The Digital Elevation model has been developed using GIS with Terrain Model from USGS. The area has a rocky layer at one side due to the presence of Aravalli ranges. The average gradient for the whole city is approx. 0.8 – 1%

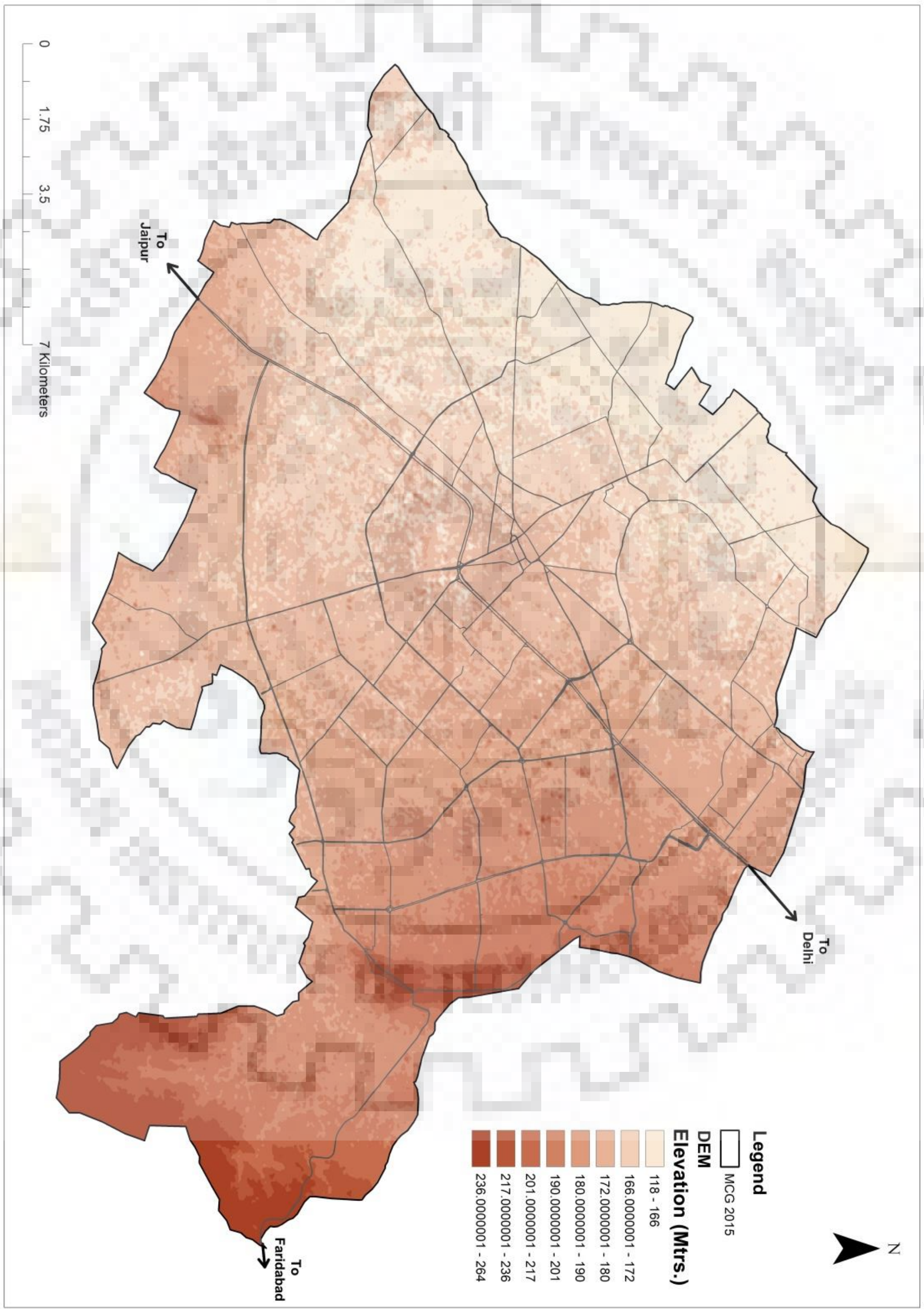


Figure 14 Digital Elevation Model

Analysis

The Analysis has been done at two levels, one city level considering indicators for the whole city, to determine the probable issues. These include slope, Rainfall, Soil characteristics, population density, city has been analyzed based on several indicators related to Urban flooding.

Effect of Built Form on Ground Water Table

Ground Water data has been collected from Central Ground water Board and has been spatially interpolated through ArcGIS to get a mapping of the areas. Due to data lack, results for some part of Gurugram are not displayed.

The data has been analyzed from 2001 to 2019. Initially the maps of existing built forms of 2001, 2011 and 2019 have been prepared using ArcGIS by superimposing Layers of NDBI (Normalized Differential Built-up Index) calculation and Google earth imagery. The achieved results for each year have been displayed separately for the decadal changes.

For the analysis, the area is divided into grids of 2.5 Km x 2.5 Km, then randomly six grids are selected as shown in the map and analyzed for change in built up against the change in ground water table.

Due to lack in ground water data for previous decades, even after interpolation, part of the area of the city could be seen as blank in ground water maps, these could not be studied due to lack of data available. So the grids have been chosen where data is available for all three decades.

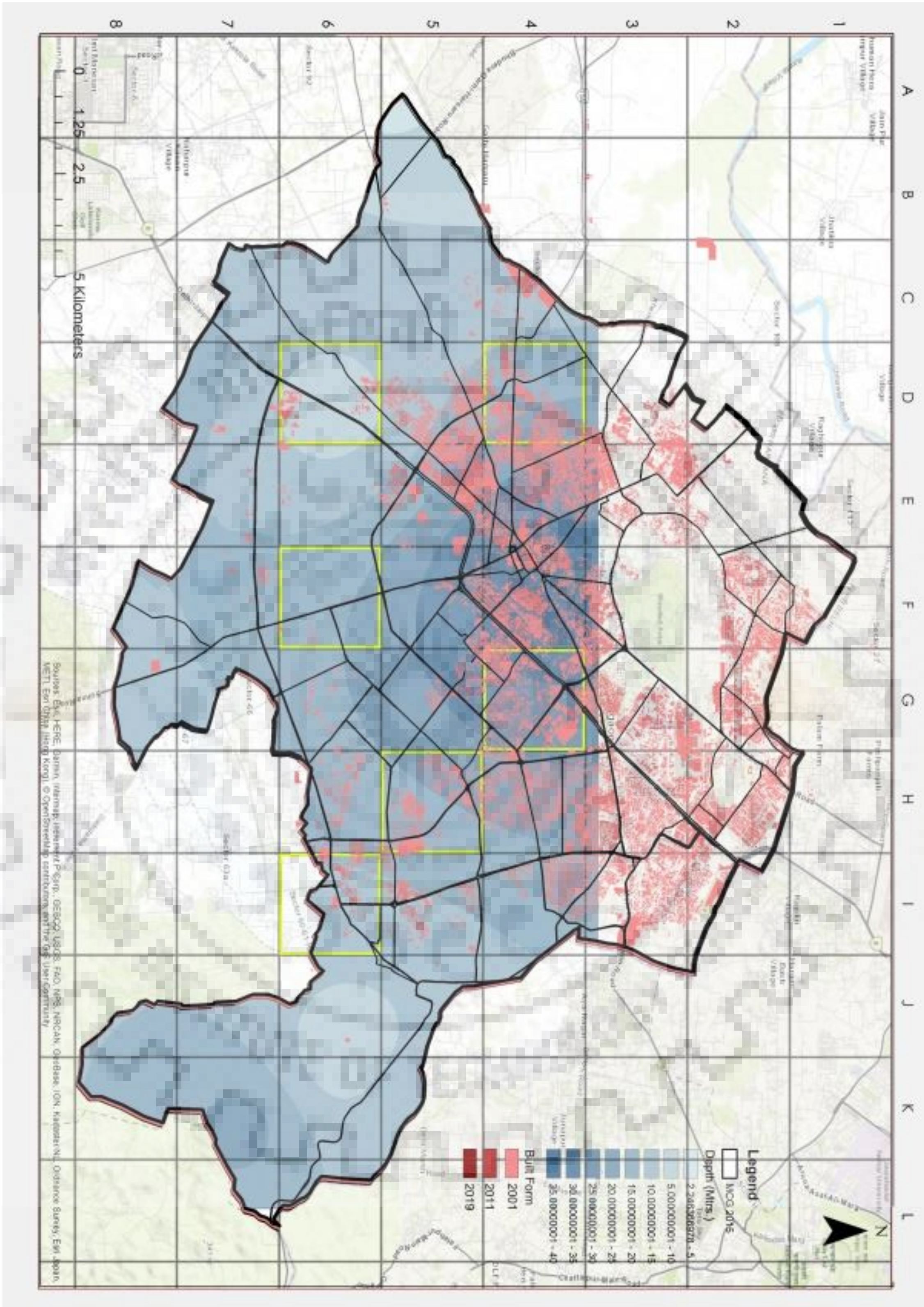


Figure 15 Ground Water - Built Form Spatial map 2001

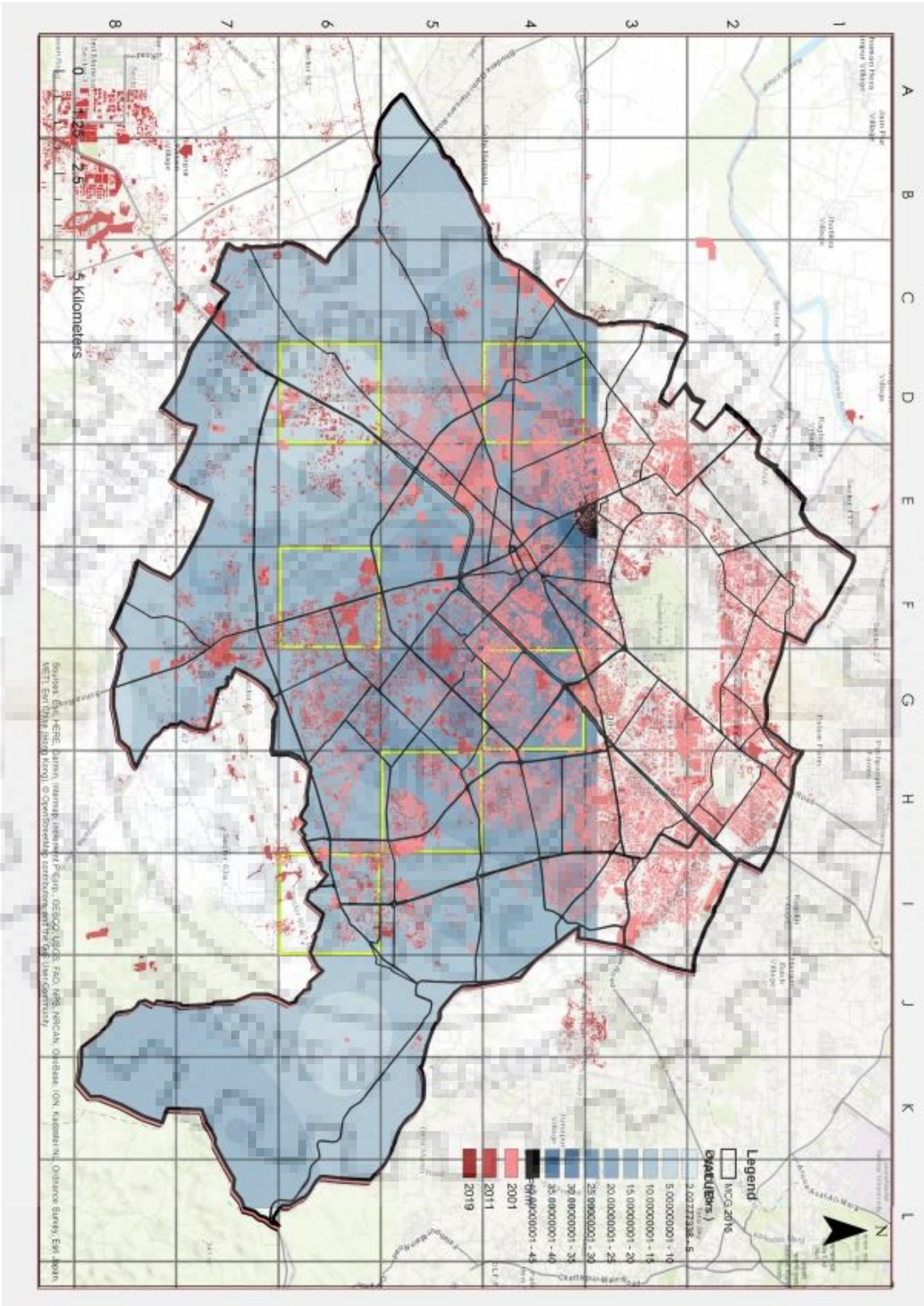


Figure 16 Ground Water - Built Form Spatial map 2011

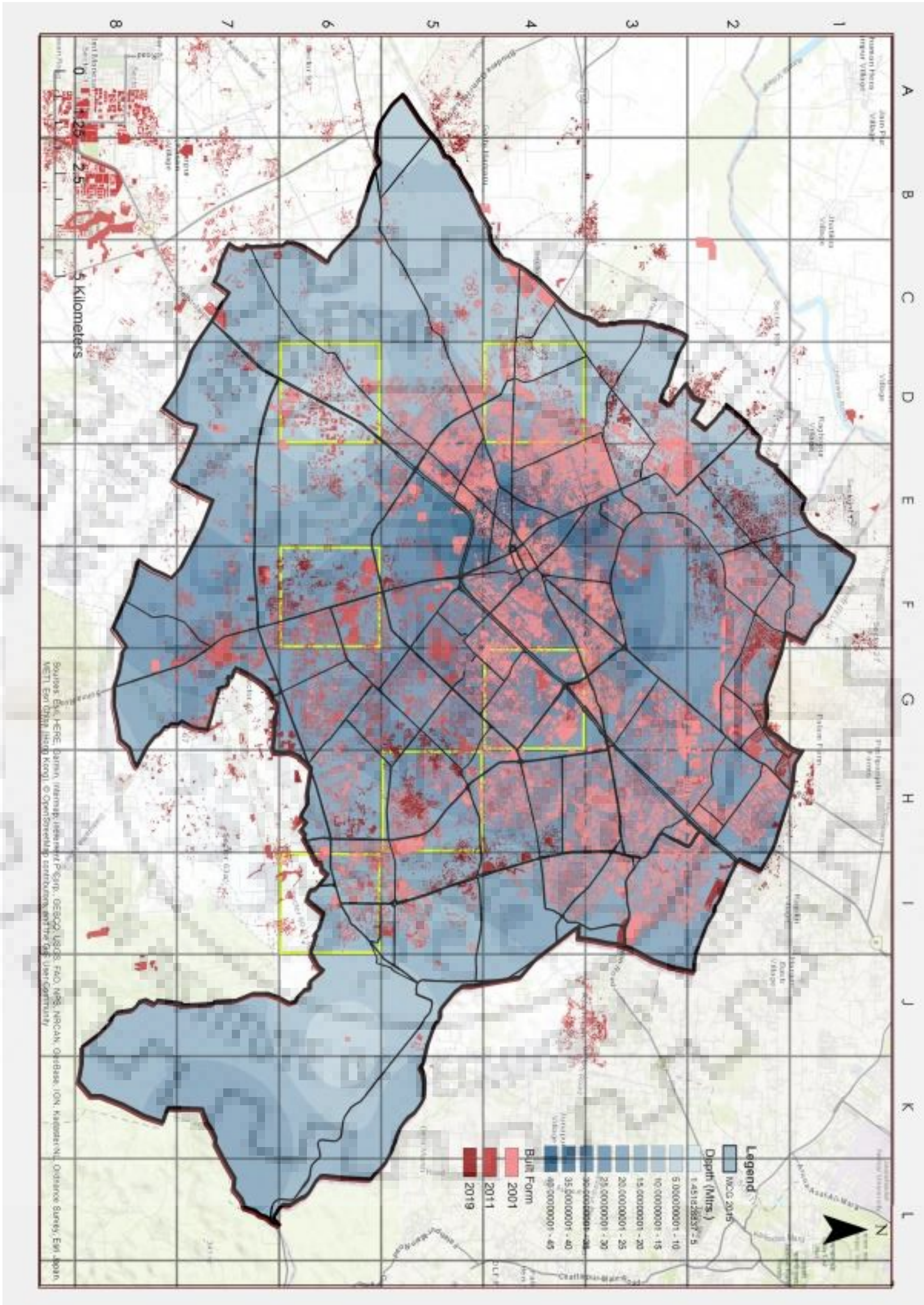


Figure 17 Ground Water - Built Form Spatial map 2019

As per the above maps, the built up during each decade from 2001-2019 has been calculated and the areas of built and average ground water depth present in each grid has been mention across the grid number in Table 7.

Table 7 Table showing decadal values of change in Built Form and Ground water table

		Built (ha)			Ground Water (Mtrs.)		
Grid	Total Area (Ha)	2001	2011	2019	2001	2011	2019
D4	625	171.6	228.1	231.0	18.5	23.0	24.0
D6	625	31.8	97.0	100.1	7.5	9.5	10.0
F6	625	3.3	129.8	170.9	15.5	23.0	27.0
G4	625	230.1	306.1	308.3	28.0	30.5	31.0
H5	625	105.0	203.5	237.0	16.0	22.0	25.5
I6	380	35.9	83.1	84.4	11.0	16.5	18.0

The figures calculated in Table 7 have been analyses by means of percentage change in built against percentage change in ground water and been presented in Table 8 for year 2001-11.

Table 8 Grid wise percentage change in Built Form and Ground Water 2001-2011

Change % 2001 - 11		
Grid	Built	Ground Water Depletion
D4	32.94	24.32
D6	205.32	26.67
F6	3833.34	48.39
G4	33.03	8.93

H5	93.83	37.50
I6	131.09	50.00

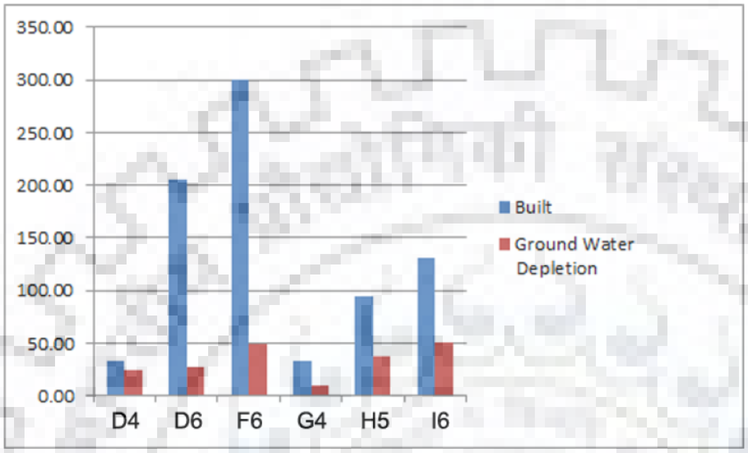


Figure 18 Graph for Change in Built form and Ground water 2001-2011

The figures calculated in Table 7 have been analyses by means of percentage change in built against percentage change in ground water and been presented in Table 9 for year 2011-19.

Table 9 Grid wise percentage change in Built Form and Ground Water 2011-2011

Change % 2011 - 19		
Grid	Built	Ground Water Depletion
D4	1.28	4.35
D6	3.23	5.26
F6	31.70	17.39
G4	0.71	1.64
H5	16.47	15.91

I6	1.66	9.09

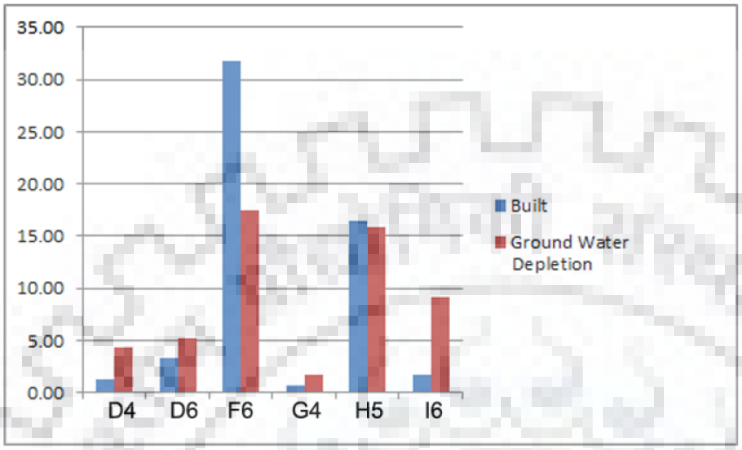


Figure 19 Graph for Change in Built form and Ground water 2011-2019

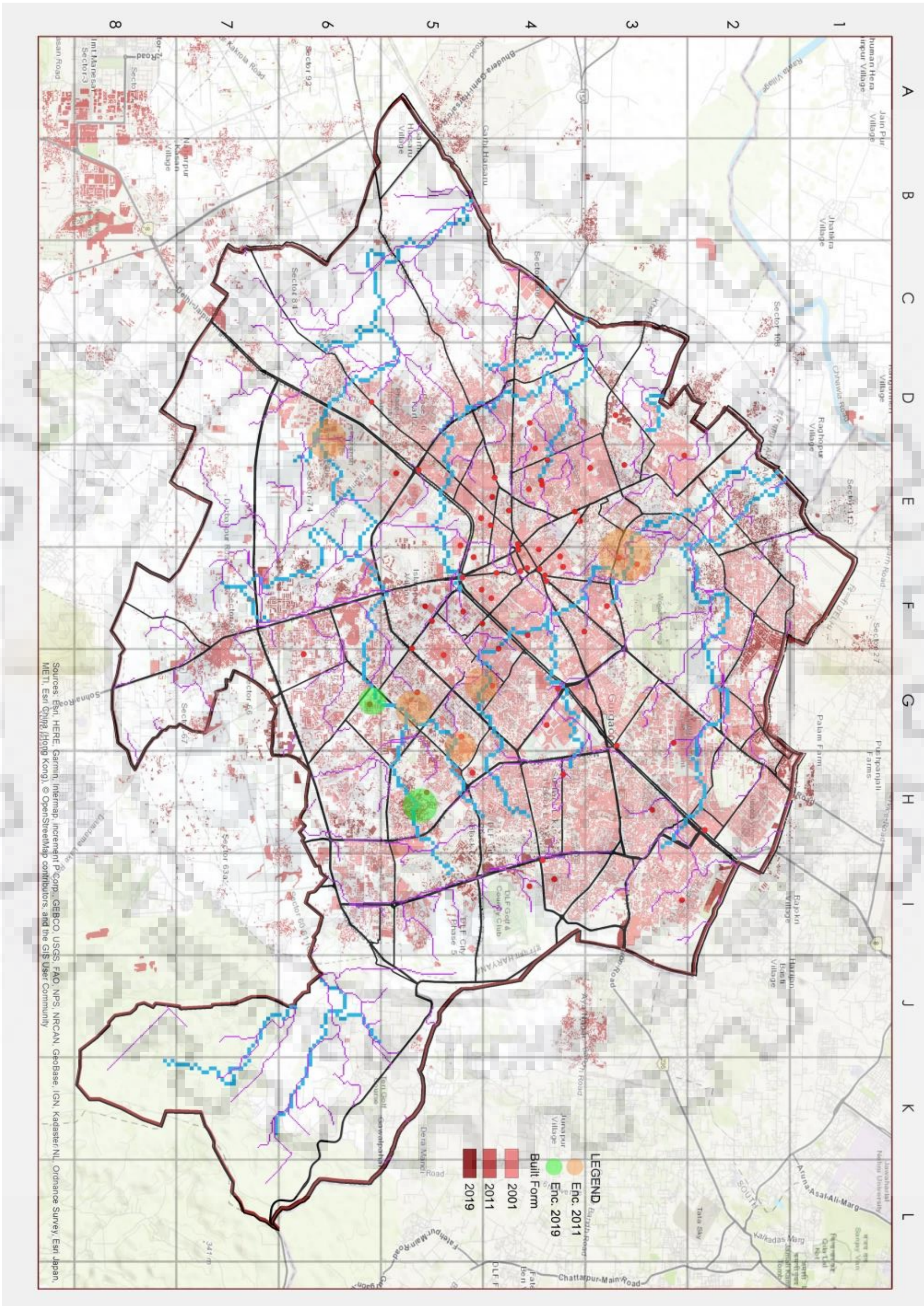
The above graphs shows that in the duration 2001-2011, there is a pattern reflected in most cases where there is a direct effect of depletion in Ground water Table with increase in Built form.

While analyzing the other graph for 2011-2021, in some cases, the level of depletion was higher than the rate of change of built form. The reason when analyzed, resulted that due to increase in population, extraction of ground water has increased over years and in last few years, the total annual rainfall has been very less ranging from 350-450 mm. These may be the reason for increase in level of ground water depletion in these cases.

Effect of Encroachments on Flooding

City level analysis of Gurugram has been done by mapping natural drainage streams for the year 2000 and year 2011 as per data availability. It has been found that there has been a major change in natural streams due to intense development. Also most of the Floods have recurred in the locations along the natural stream path that has been hindered since past.

The map below shows the natural streams as extracted from terrain model of the year 2001 and 2011 along with locations where flooding occurs and changes in built form.



The above map has been analyzed by identifying the locations of flooding and the stream flow direction and it has been found that there is a direct correlation between built form and streams causing floods. Wherever the natural flow of streams has been disrupted by new developments, there has been flooding occurences.

Badshahpur Drain

The major concern is concretization of natural drains in the city. And Badshahpur being the oldest and carrier of Maximum storm water, experiences maximum suffering. This results in reduction of pervious layer and due to this, there is high reduction in ground water levels.

The National Green Tribunal (NGT) heard a plea over the encroachment and filling up of a natural stormwater drain — the Badshahpur Nallah — in Gurgaon. Residents alleged that the encroachment is a blatant violation of the provisions of the Water (Prevention and Control of Pollution) Act, 1974 and Environment (Protection) Act, 1986.

A petition was filed against Badshahpur Drain construction. The petitioners alleged that due to the illegal encroachment of the Badshahpur Nallah, the city witnesses waterlogging during the monsoon and the ground water table is also depleting every year.The petition stated, "The encroachments, construction and granting of licence and change in landuse by town and country planning department, including construction on the Badshahpur Nallah, is illegal and in violation of the provisions of the Water (Prevention and Control of Pollution) Act, 1974 and directions of NGT as well as the 2010 Guidelines on Urban Flooding prepared by the National Institute for Disaster Management."

"The Haryana town and country planning department has not speci□ed the minimum distance that should be left from a water body and its □oodplain, with regard to approving construction work in its vicinity," she said.

Encroachment on Green Belt

As per the NCR Regional Plan 2001, the demarcated areas of Nathupur and Dhundahera Villages were demarcated for Green Belt, but in 1996, the government changed the use 260 acres of green belt to special use and it was handed to a private enterprise for development due to estimated increase in population.

As per Ravi S. Singh, The Tribune (5/12/1998), The Haryana government published a Draft Development Plan for Gurgaon for inviting public objections and suggestions, under Section 4 and Section 5 of the Punjab and Scheduled Roads and Controlled Areas Restriction of Unregulated Development Act, 1963, vide the Haryana Government Gazette Notification No. 10 DP-82/6528 dated April 29, 1982, to accommodate an anticipated population of 10 lakhs by the year 2001. Later on, when the NCRPB formulated the Regional Plan, the provisions of the Draft Development Plan for Gurgaon were incorporated to the extent related to the regional policies with regard to population, employment, density pattern, traffic and transportation aspects and environmental and ecological aspects. The National Capital Region Plan-2001 (Regional Plan)as approved by the NCRPB on November 3,1988, also has an overriding effect. The Haryana Government, in the year 1996, notified the Final Development Plan for Gurgaon (the amended Plan), formulated under Sub-Section 7 of the Section of the Punjab Scheduled Roads and Controlled Areas (Restriction of Unregulated Development) Act, 1963 vide the Haryana government Gazette Notification No. JS-96/250 dated January 8,1996.

The drainage network of most of the areas have been concretized, the concretized network is considered to be a formal development, but as per environmental specialists, the reduces ground water recharge and also speeds us the storm water to the river which ultimately may result into flooding of Yamuna River or Najafgarh Drain.

Effect of Change in Pervious cover

In this section, for determining the effect of change in pervious cover and its relation with Flooding, a site has been selected within the boundary of Gurugram Municipal Corporation and impervious covers on the site have been mapped.

Criteria for Site Selection

The Study area has been selected based on several factors:

1. Increase in Built Form

2. Multiple Instances of Floods

3. Encroached Natural Drainage channel

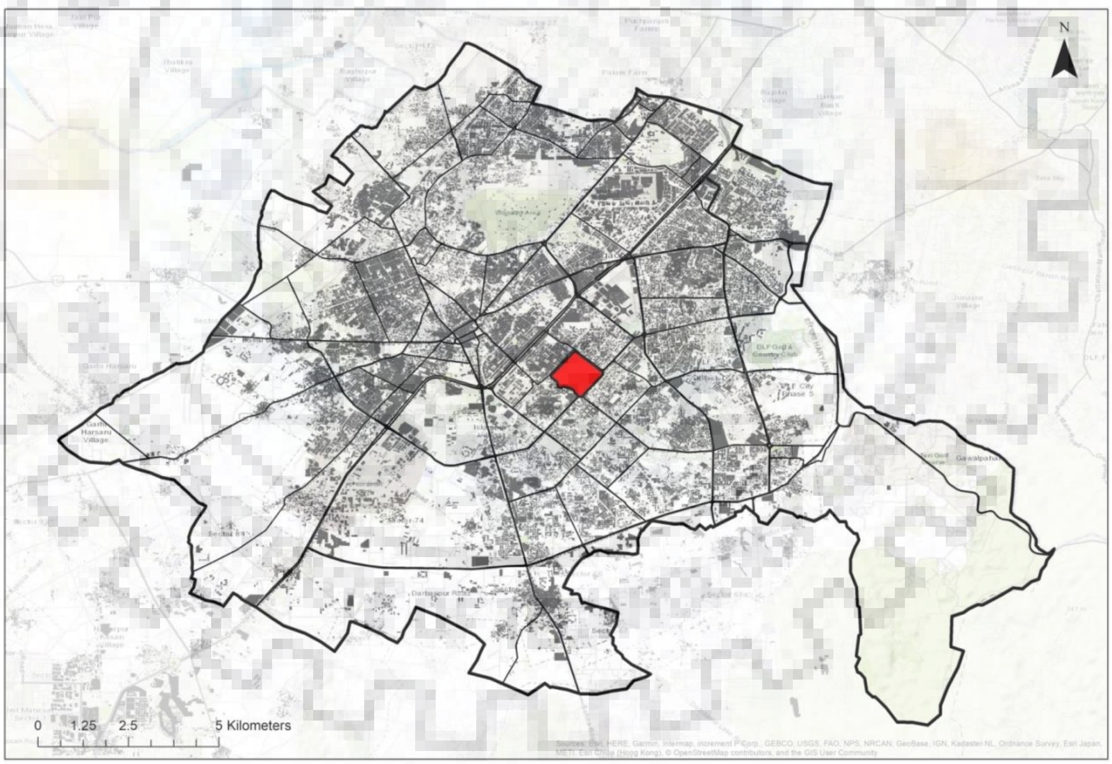


Figure 20 Selected study area within MCG Boundary

The mapping has been done at every 5 years starting from 2004 - 2019. The mapping covers identified Green Cover and Undeveloped land.

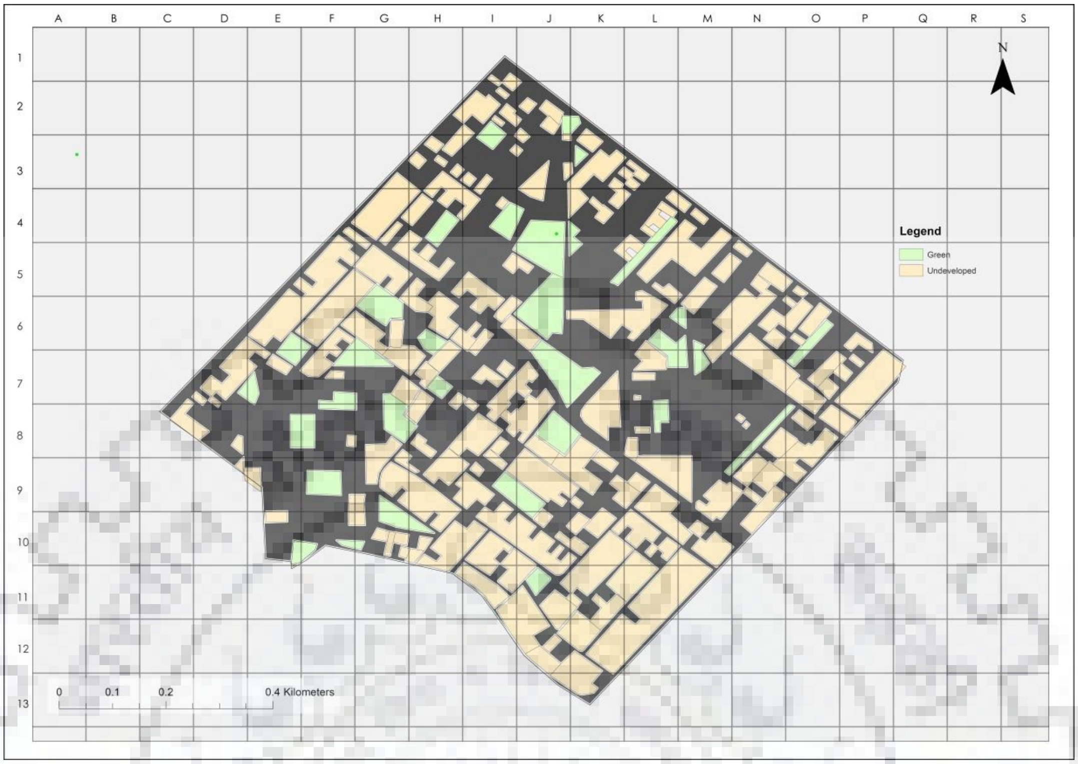


Figure 21 Unbuilt area in Site Year 2004

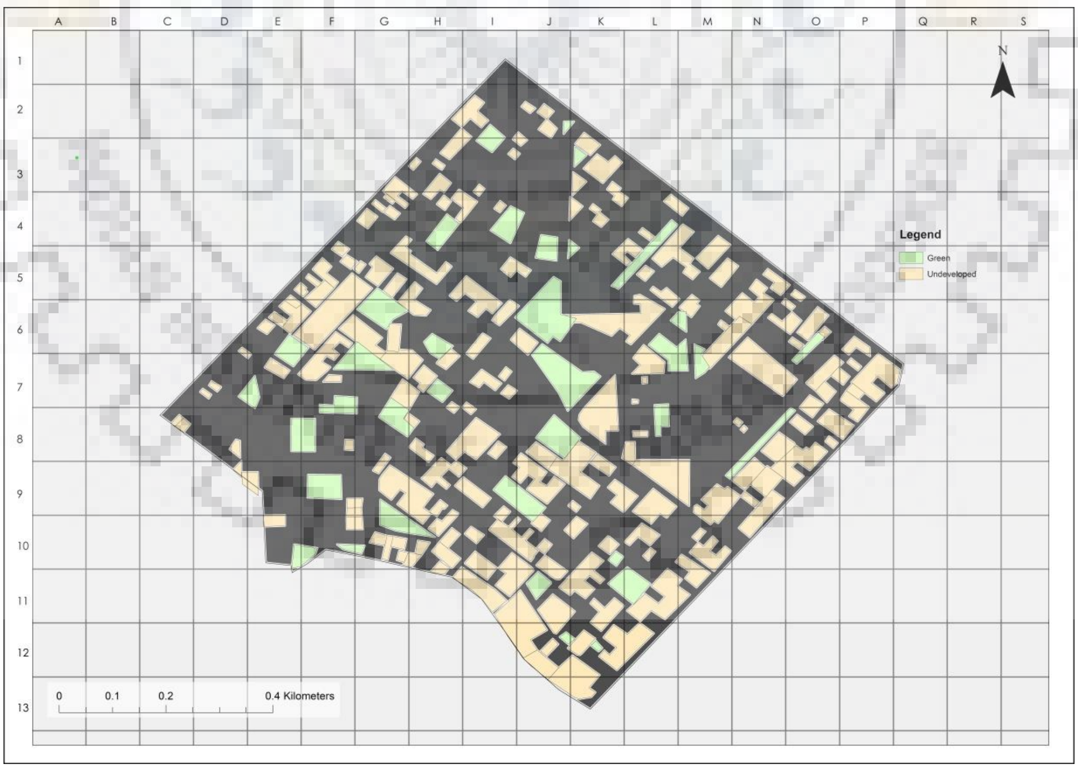


Figure 22 Unbuilt area in Site Year 2009

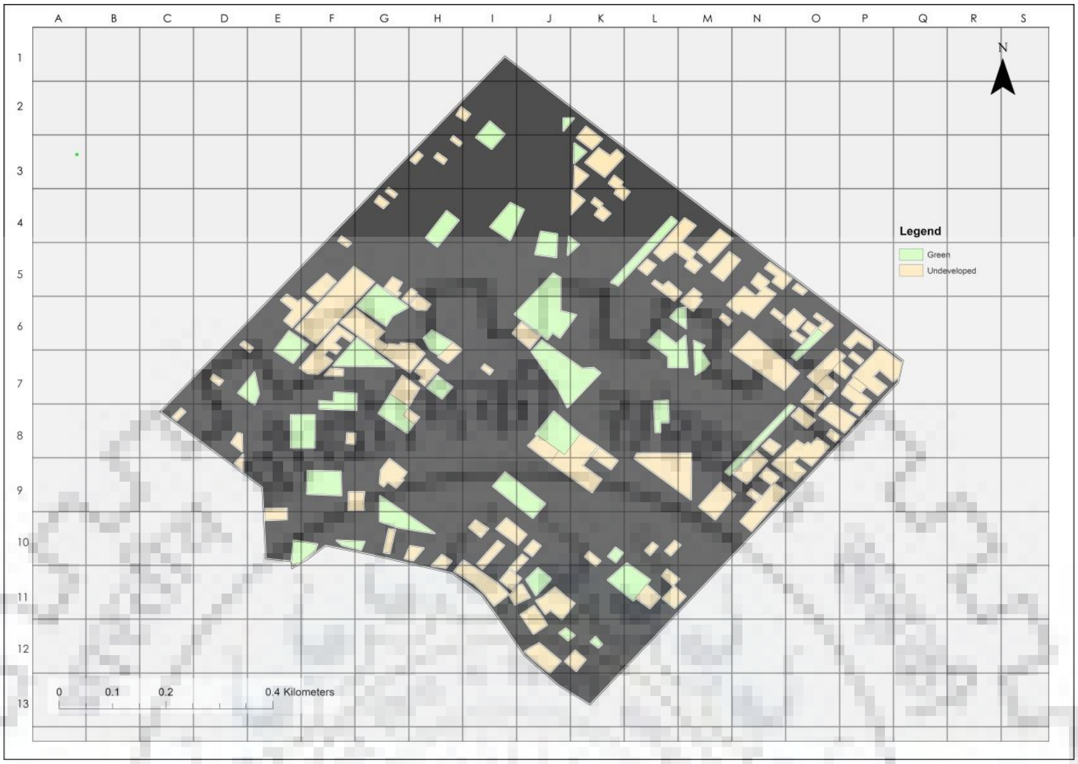


Figure 23 Unbuilt area in Site Year 2014

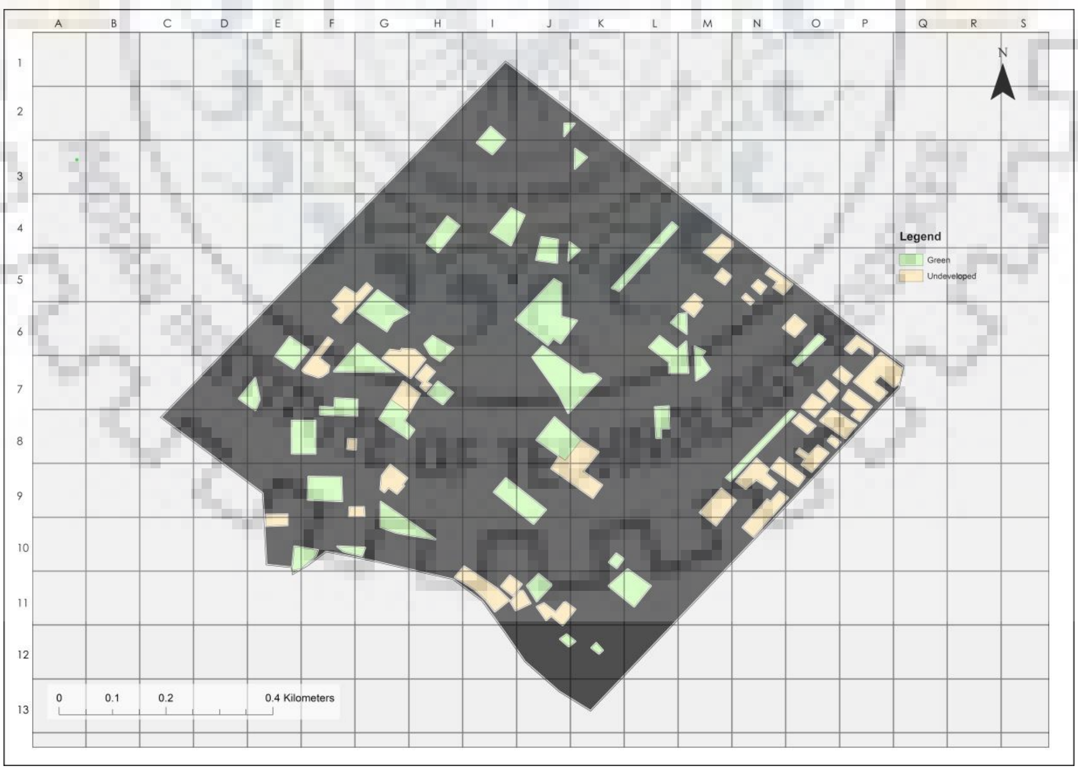


Figure 24 Unbuilt area in Site Year 2019

The mapping has been done for selected study area based on Satellite Imagery and there has been a drastic decline in Unbuilt cover in last 19 years.

The areas have been calculated and computed for total run off and discharge

Table 10 Built Unbuilt Cover on Site

Year	Site Area (M2)	Green (M2)	Undeveloped (M2)	Unpaved (M2)	Paved (M2)
	A	B	C	D = B + C	E = A - (B + C)
2004	980000	82526	342352	424878	555122
2009	980000	77526	259821	337347	642653
2014	980000	77526	128670	206196	773804
2019	980000	77526	54475	132001	847999
2024	980000	77526	0	77526	902474

Table 11 Run off Calculation

Runoff (M2) (Unpaved)	Runoff (M2) (Paved)	Volume of Runoff (CuM) per day			Vol of Runoff (CuM) per Hr	
0.35	0.95	R/f : 80 mm	R/f : 120 mm	R/f : 160 mm	R/f : 20 mm	R/f : 40 mm
148707.3	527365.9	54085.856	81128.784	108171.712	13521.464	27042.928
118071.5	610520.	58287.34	87431.016	116574.68	14571.836	29143.672

	4	4		8		
72168.6	735113.8	64582.592	96873.888	129165.184	16145.648	32291.296
46200.4	805599.1	68143.952	102215.928	136287.904	17035.988	34071.976
27134.1	857350.3	70758.752	106138.128	141517.504	17689.688	35379.376

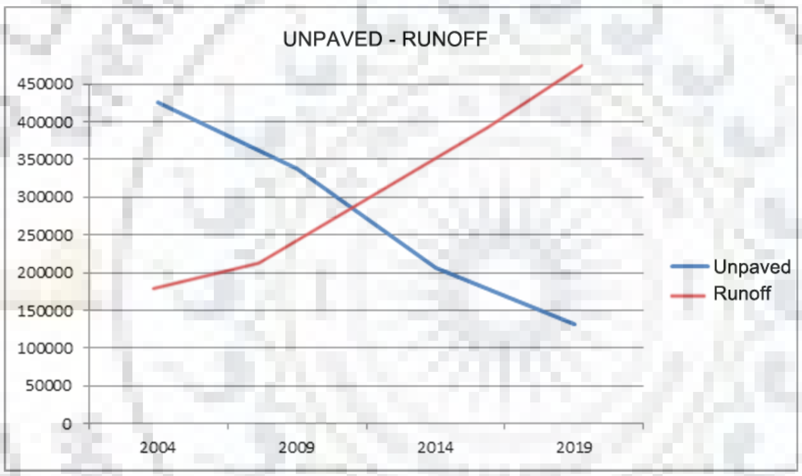


Figure 25 Graph Unpaved - Runoff Volume

The discharges have been calculated separately for infiltration in soil and drainage discharge by using Manning Formula.

$$Q = \frac{K\, A\, R^{2/3} S^{1/2}}{n}$$

Q = flow rate
A = cross-sectional area of flow
R = hydraulic radius (cross-section area divided by wetted perimeter)
S = slope of the channel at the point of measurement
n = surface roughness (based upon channel material and condition)
K = constant dependent upon units

Table 12 Soil Infiltration

Infiltration (CuM) (20mm/hr)	**Time Taken (Infiltration) (hrs)**		
D x 0.02	R/f : 80 mm	R/f : 120 mm	R/f : 160 mm
8497.56	6.4	9.5	12.7
6746.94	8.6	13.0	17.3
4123.92	15.7	23.5	31.3
2640.02	25.8	38.7	51.6
1550.52	45.6	68.5	91.3

Table 13 Artificial Drainage Line Discharge

Drainage Discharge Time (hrs) (0.86 CuM/sec)			**Drainage Discharge Time (hrs) (0.86 CuM/sec)**		
R/f : 80 mm	R/f : 120 mm	R/f : 160 mm	R/f : 80 mm	R/f : 120 mm	R/f : 160 mm
17.5	26.2	34.9	15.6	23.5	31.3
18.8	28.2	37.7	16.9	25.3	33.7
20.9	31.3	41.7	18.7	28.0	37.4
22.0	33.0	44.0	19.7	29.6	39.4
22.9	34.3	45.7	20.5	30.7	40.9

On the basis of Contour map of the study area, the areas affected by flooding have been mapped for 20 mm hourly rainfall, 40 mm hourly rainfall and 80 mm rainfall per day.

Figure 26 Flooding areas in 20mm hourly rainfall for year 2019

Figure 27 Flooding areas in 40mm hourly rainfall for year 2019

Figure 28 Flooding areas in 80mm per day rainfall for year 2019

By the above analysis, it has been found that, the change in runoff volumes due to change in surface is approximately 10 percent but the discharge time variation is very high as there is more area for water to percolate quickly in the soil. And many of the areas being flooded have highly intense residential development.

Research Findings

As per the analysis for different scenarios, there have been many issues associated with preplanning of the area. The above study is required to be conducted before formulation of Master Plan of the city so the areas could be identified to be left undeveloped for water percolation, natural streams path.

The high reduction in pervious layer have resulted in flooding along with intense depletion of ground water which is one of the major sources of freshwater supply in the city. So this intensification in built form is not only causing floods but also gives way to another disaster situation of water shortages.

Concretization of Drainage system does not solve the problem, but shifts problem from one location to another with flashier effects. As in our case, most of the drainage is being connected to Najafgarh Drain, approximately 60% of the Gurgaon's runoff would be transferred to Najafgarh drain, ultimately leading to Yamuna river in Delhi. So Natural drains are very important for reducing the speed of water flow to other streams and also helps in Ground water recharge.

At the neighbourhood level, planning could be done to identify areas to be marked as green or any activities involving high pervious cover could be proposed based on the topography. This helps in reduction of loss to built areas due to flooding and increases percolation resulting in ground water recharge for the area. In the study area, site studies have shown that even in the private parking areas or road offsets, most of the areas have been concretized either privately for car parking or by government. For the city level, this is a very small intervention but can help a lot in reduction of Flooding.

So, the conclusion from the whole discussion would be that, water is considered as a free or very less cost resource and not much planning is done considering its importance. In most of the cases, it has been observed that for an area with less change in contours, the planning is done considering it a completely plain area and the topographical and geographical features of the site are ignored. If these could be identified in the pre planning stage, the development could be planned with less harm in the natural water cycle like there could be provision of ponds or other water bodies in low lying areas covering more area under drainage basin. And the natural elements could be conserved as in the initial stage, land is considered against monetary value and water is a free resource. But at a later stage, as in the case of Gurugram, the rate of increase in land is static but the rate of increase is damage due to flooding have been exponentially increasing. So the value of this resource is required to be understood at each level.

Bibliography

Balaji Narasimhan, S. M. B. A. M. S. G. P. M., 2016. *Chennai Floods 2015 - A Rapid Assessment,* s.l.: Interdisciplinary Centre for Water Research.

Emanuel, K., 2005. *Increasing destructiveness of tropical cyclones over the past 30 years,* s.l.: s.n.

Floodsite Projects, n.d. *Flooding in urban areas (urban flooding).* [Online]
Available at:
http://www.floodsite.net/juniorfloodsite/html/en/teacher/thingstoknow/hydrology/urbanfloods.html
[Accessed 24 11 2018].

Geographic, N., 2017. *Floods.* [Online]
Available at: https://www.nationalgeographic.com/environment/natural-disasters/floods/
[Accessed 22 04 2018].

IFRC, n.d. *Hydrological hazards: General floods and flash floods.* [Online]
Available at: http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/definition-of-hazard/floods/
[Accessed 22 04 2018].

King, A. D., 2010. *Emergence of heat extremes attributable to anthropogenic influences,* s.l.: s.n.

Knutson, T. R. &. T. R. E., 2004. *Impact of CO2-induced warming on simulated hurricane intensity and precipitation: Sensitivity to the choice of climate model and convective parameterization,* s.l.: s.n.

Konrad, C. P., 2003. Effects of Urban Development on Floods. *U.S. Geological Survey–Water Resources.*

Leonard F. Konikow, E. K., 2005. Groundwater depletion: A global problem. *Springer-Verlag.*

Lyons, W. B., 2014. Water and urbanization. *Environmental Research Letters.*

Ministry of Urban Development, 2017. *Urban Flooding Standard Operation Procedure,* s.l.: Govt of India.

P.H. Gleick, A. S. a. H. S., 2001. *Threats to World's Freshwater Resources.* s.l.:Pacific Institute for Studies in Development, Environment and Security.

PRAHARAJ, M., 2014. *Drain encroachment main cause of flooding in capital city.* [Online]
Available at: https://www.dailypioneer.com/2014/state-editions/drain-encroachment-main-cause-of-flooding-in-capital-city.html
[Accessed 12 01 2019].

Shastri, H., 2015. Impacts of urbanization on Indian summer monsoon rainfall. *" Journal of Geophysical Research: Atmospheres.*

Swamy, G. a. N. S., 2016. *Study of Urban Heat Island (UHI),* s.l.: s.n.

Tamilarasu S, V., 2017. *Vikaspedia.* [Online]
Available at: http://vikaspedia.in/social-welfare/disaster-management-1/guidelines-on-disaster-management/urban-flood-management/introduction
[Accessed 24 11 2018].

Tingsanchali, T., 2011. Urban flood disaster management. *Procedia Engineering,* Volume 32, pp. 25 - 37.

United Nations World Water Assessment Programme, 2010. Water for sustainable urban human settlements. *UN Water.*

Urbanization and The Natural Drainage System - Impacts, S. a. P., 1991. Derek B. Booth. *The Northwest Environmental Journal.*

Ahmad, S. S., & Simonovic, S. P. (2013). Spatial and temporal analysis of urban flood risk assessment. *Urban Water Journal*, *10*(1), 26–49. https://doi.org/10.1080/1573062X.2012.690437

Barroca, B., Bernardara, P., Mouchel, J. M., & Hubert, G. (2006). Indicators for identification of urban flooding vulnerability. *Natural Hazards and Earth System Sciences*, *6*(4), 553–561. https://doi.org/10.5194/nhess-6-553-2006

Boonya-aroonnet, S., Maksimovi, Č., Prodanovi, D., & Djordjevi, S. (2007). Urban Pluvial Flooding : Development of GIS Based Pathway Model for Surface Flooding and Interface with Surcharged Sewer Model. *Novatech*, 481–488.

Christopher, P. K. (2003). *Effects of Urban Development on Floods*. *U.S. Geological Survey–Water Resources* (Vol. 150).

Debroy, S. (2018). Top Searches :Heavy downpour floods many areas in Bengaluru. *Times of India*, pp. 1–15.

Express News Service. (2018). Overnight rain leaves parts of Kolkata. *The Indian Express Ltd*.

Holman-dodds, J. K., Bradley, A. A., & Potter, K. W. (2003). EVALUATION OF HYDROLOGIC BENEFITS OF INFILTRATION BASED URBAN STORM WATER MANAGEMENT, *53706*, 205–215.

Hua-peng Qin, Zhuo-xi Li, G. F. (2013). The effects of low impact development on urban flooding under different rainfall characteristics. *Journal of Environmental Management Journal*, *129*, 577–585. https://doi.org/10.1016/j.jenvman.2013.08.026

Huong, H. T. L., & Pathirana, A. (2013). Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. *Hydrology and Earth System Sciences*, *17*(1), 379–394. https://doi.org/10.5194/hess-17-379-2013

Ie, L. N. (2004). *Flooding Analysis of Urban Drainage Systems*.

James D. Miller, Hyeonjun Kim , Thomas R. Kjeldsen, John Packman, Stephen Grebby,

R. D. (2014). Assessing the impact of urbanization on storm runoff in a peri-urban catchment using historical change in impervious cover. *Journal of Hydrology*, 59–70. https://doi.org/10.1016/j.jhydrol.2014.04.011

Jung, I. W., Chang, H., & Moradkhani, H. (2011). Quantifying uncertainty in urban flooding analysis considering hydro-climatic projection and urban development effects. *Hydrology and Earth System Sciences*, *15*(2), 617–633. https://doi.org/10.5194/hess-15-617-2011

Kaźmierczak, A., & Cavan, G. (2011). Surface water flooding risk to urban communities: Analysis of vulnerability, hazard and exposure. *Landscape and Urban Planning*, *103*(2), 185–197. https://doi.org/10.1016/j.landurbplan.2011.07.008

Nath, A. (2018). Chennai Floods in 2015 man made, says CAG. *India Today*, pp. 12–15.

Pelling, M. (1998). Participation, social capital and vulnerability to urban flooding in Guyana. *Journal of International Development*, *10*(4), 469–486. https://doi.org/10.1002/(SICI)1099-1328(199806)10:4<469::AID-JID539>3.0.CO;2-4

Press Trust of India. (2018). Evacuation Process On As Water Levels Continue To Rise In Yamuna River, 10–12.

Sharma, A. (2018). As Heavy Rain Pounds Delhi , Roads Flooded , Waterlogging Hits Traffic. *NDTV*.

Staff, F. (2018). Mumbai rains : Four days of torrential downpour derailed city ’ s infrastructure , killed 10 ; BMC says new ood points emerge. *FirstPost*.

Suriya, S., & Mudgal, B. V. (2012). Impact of urbanization on flooding: The Thirusoolam sub watershed - A case study. *Journal of Hydrology*, *412–413*, 210–219. https://doi.org/10.1016/j.jhydrol.2011.05.008

Ten Veldhuis, J. A. E., Clemens, F. H. L. R., & Van Gelder, P. H. A. J. M. (2009). Fault tree analysis for urban flooding. *Water Science and Technology*, *59*(8), 1621–1629. https://doi.org/10.2166/wst.2009.171

Veldhuis, J. A. E. ten. (2010). *Quantitative risk analysis of urban flooding in lowland areas*.

Annexure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