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Identification and Selection of Suitable Rainwater Harvesting Sites using LiDAR Technology

A DISSERTATION

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OF

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IN

CIVIL ENGINEERING

(With Specialization in Geoinformatics Engineering)

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I, **Gopal Mohan**, roll No. **2K0/GEO/501** of M.Tech Geoinformatics, hereby declare that the project dissertation titled "**Identification and Selection of Suitable Rainwater Harvesting Sites using LiDAR Technology"** which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associate ship, Fellowship, or other similar title or recognition.

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CERTIFICATE

I hereby declare that the Project Dissertation titled **Identification and Selection of Suitable Rainwater Harvesting Sites using LiDAR Technology"** which is submitted by **Gopal Mohan, roll no. 2K20/GEO/501** [Civil Engineering] Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master in Technology, is a record of the project work carried by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

Place: Delhi

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ABSTRACT

Chandigarh was the first planned city in India, after independence intended as city structure on principles of rationality, orderliness, and social improvement planned by Le Corbusier. Designed initially for 5 lakh population, the city has exploded, crossing 18 lakhs population that lives in Tricity. The fact that explosive population growth that was intended and what has reached now, along with "Indianized" modifications adapted by the city calls for re-envisioning. The amenities that were designed for a small chunk are now struggling to suffice the needs of public, waning off its public intend.

The aim of this academic thesis is outlined to relook into the possibility of rainwater harvesting in Corbusier's Chandigarh plan and ramification of its urban form, to make the city self-sufficient and resilient for all kinds of amenities and facilities. The study of geo-physical layers, current and proposed facilities, and potential of rainwater harvesting (surface and rooftop) in developing water resilience in the city. The study has been based on the usage of LIDAR technology for understanding the layers for better accuracy and fastest route.

The study concludes unravelling innovative pit designs, materials and technology usage in identifying best location of RWH pits in a city.

Key Words: Chandigarh, Rainwater Harvesting, Mobile Lidar, Aerial Lidar, GIS, water resilience

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GOPAL MOHAN

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LIST OF ABBREVIATIONS

DEM	Digital elevation model
DSM	Digital surface model
CPCB	Central pollution control board
CGWB	Central ground water board
GPS	Global positioning system
RWH	Rainwater harvesting
RRWH	Rooftop rainwater harvesting
SRWH	Surface rainwater harvesting
ECD	Earthen check dam
CCT	Continuous contour trenches
LIDAR	Light detection and ranging
GW	Ground water
MGD	Million gallons per day
MLD	Million litres per day
MCM	Million cubic metre
DDA	Delhi development authority
DJB	Delhi Jal Board
STP	Sewage Treatment Plant
HKB	Hathnikund barrage
NGT	National green tribunal
GIS	Geoinformatics software
MTA	Multiple time around
SMU	Sensor management unit
ISO	Integrated sensor orientation
DG	Direct georeferencing
GVHL	Global Vectra Helicorp Limited
MLS	Mobile lidar system
MOUD	Ministry of urban development
Sqm	Square metres
Cum	Cubic metres
Mm-	Millimetres

CHAPTER 1: INTRODUCTION

1.1 MOTIVATION

Water scarcity in India is an ongoing crisis that impacts hundreds of millions of individuals annually. Not only does it affect both rural and urban populations on a large scale, but it also has far-reaching consequences for the environment and agriculture. Despite having a population of over 1.4 billion people, India possesses only 4% of the world's freshwater resources. The scarcity of water in India is exacerbated by the drying up of rivers and reservoirs during the summer months, just before the arrival of the monsoon season. This issue has been further aggravated in recent years due to climate change, causing delayed monsoons and the depletion of reservoirs in various regions. Additionally, inadequate infrastructure, government oversight, and unchecked water pollution contribute to the water shortage in India.

To address the acute water shortage for daily needs, both governmental and non-governmental organizations have implemented stringent measures. The Indian government has introduced several schemes and programs, including the establishment of the 'Jal Shakti' Ministry dedicated to addressing this problem. Emphasizing techniques such as rainwater harvesting, water conservation, and improved irrigation methods, the government aims to combat the issue. It is worth noting that agriculture alone accounts for 80% of the country's water usage. (Board D. j., 2022)

In the context of technological advancements and rapid globalization, it is now possible to expedite the time-consuming analysis of geophysical layers to determine optimal locations and strategies for recharging water. This thesis focuses on harnessing such technologies to identify the most suitable areas for replenishment, ensuring high yields while respecting the natural course of water flow.

1.2 PROBLEM STATEMENT

Rainwater harvesting (RWH) can be highly advantageous in multiple ways, especially given the urgent need to address the existing water crisis. It offers the opportunity to collect rainwater for drinking purposes, but precautions must be taken to prevent water contamination. RWH effectively enhances water supply, reduces water expenses, and promotes eco-friendliness. Additionally, it helps mitigate flooding and waterlogging issues while improving the availability and quality of groundwater. RWH also reduces reliance on regular water supplies, prevents soil erosion, and revitalizes inactive wells and boreholes through groundwater recharge. While there are generally no significant drawbacks associated with RWH, it can pose risks if not implemented according to prescribed designs. These risks include water contamination due to unclean rooftops, inadequate groundwater recharge leading to waterlogging, and roof flooding if filters are not properly designed and regularly cleaned. (Board D. j., 2022)

Improper utilization of rainwater can result in stagnant water on the ground surface. Furthermore, improper installation may cause water seepage into underground drains or nearby toilet pits, as well as the contamination of groundwater by industrial waste. Various methods of RWH have gained popularity and are being practiced worldwide. While some methods have been widely adopted in urban areas, others are implemented individually in buildings, airports, hotels, and other locations.

Rainwater harvesting (RWH) is a proven and widely recognized solution to combat water scarcity. This approach effectively prevents the entry of sewage and stormwater into drainage systems, thereby reducing the risk of flooding. It is a crucial environmentally sustainable practice that helps maintain the groundwater table and replenish aquifers. The structures required for rainwater harvesting should be simple, cost-effective and environment friendly.

1.3 LITERATURE REVIEW

1.3.1 RAINWATER HARVESTING AT INTERNATIONAL LEVEL

Rainwater harvesting has a rich historical background dating back to biblical times. Around 4,000 years ago, Palestine and Greece had sophisticated rainwater harvesting systems in place. In ancient Rome, residential buildings were constructed with individual cisterns and paved courtyards to collect rainwater, which was then used to supplement the city's aqueducts. As early as the third millennium BC, farming communities in Baluchistan and Kutch stored rainwater in dams for irrigation purposes (Tamil Nadu Water harvesting)

In the Hawaiian islands of the United States, the National Volcano Park utilizes rainwater harvesting structures, including rooftop catchment areas, ground catchments, storage tanks, and redwood water tanks. These systems provide water for approximately 1,000 workers, park residents, and 10,000 daily visitors. Smaller buildings within the park also have their own rainwater harvesting setups. The collected water undergoes treatment at a water treatment and pumping plant to ensure good quality water. In China, particularly in the dry province of Gansu, the Gansu Provincial Government supports farmers through the Rainwater Catchment Project, which includes rainwater collection fields and water storage tanks. This initiative supplies water for cash crops and household drinking water needs.

In Tanzania, rainwater is collected from corrugated iron sheet rooftops and directed to foul tanks and underground storage tanks. The water is then pumped into a distribution tank connected to the house's plumbing system. In Botswana, town and district councils under the Ministry of Local Government have embraced rainwater harvesting by implementing roof catchments and constructing tank systems in schools, health clinics, and government houses. Bermuda regulates rainwater harvesting systems through the Public Health Act, which recommends coating

catchments with non-metallic, white latex paint to prevent metal leaching. The collected rainwater is stored in tanks for distribution. (Board C. G.)
In Uganda and Sri Lanka, traditional methods involve collecting rainwater from trees using banana leaves or stems as temporary gutters. A large tree can yield up to 200 liters of water in a single storm. This method allows rainwater to be harvested close to where it reaches the earth's surface. Similarly, Jalkund, a micro-harvesting technology used by rural hill farmers, has proven to be highly beneficial. Jalkunds are constructed at high ridges of crop catchments and store water for crop production, livestock, and fish farming.

1.3.2 RAINWATER HARVESTING IN INDIA

The practice of rainwater harvesting has a long history in India, with civilizations throughout the country employing traditional methods to collect and utilize water. Since prehistoric times, water has been harvested using various techniques. Ancient civilizations, including the Harappan civilization around 6,000 years ago, collected rainwater directly in open wells. The designs of traditional structures varied across states and regions, adapting to local monsoon patterns. Archaeological and historical records indicate that Indians possessed advanced knowledge in constructing dams, lakes, and irrigation systems during the reign of Chandra Gupta Maurya (392-297 BC). In the 11th century AD, King Bhoja of Bhopal built the largest artificial lake in India, covering an area of over 65,000 hectares and fed by 365 streams and springs. Indigenous techniques were developed to divert river water into artificial channels for agricultural purposes using simple engineering structures. The KRS dam in Mysore stands as a notable example of such a structure.

Bangalore, lacking nearby river sources, heavily relied on lakes and tanks for water supply. Even in the 1860s, Bangalore had already developed an intricate rainwater harvesting system. The Commissioner of Bangalore at the time, Sir Lewing Bentham Bowring, implemented stormwater drains in 1866 to divert rainwater to outlying tanks, minimizing wastage in the process. This demonstrates the long-standing presence of water harvesting practices in Indian civilization. (Biome Trust)

Rainwater harvesting is a straightforward process of collecting and storing rainwater for regular use. In the past, it involved collecting rainwater from rooftops and storing it in large tanks, which could be used for various purposes except drinking. However, with appropriate treatment, the harvested rainwater can also be made suitable for drinking.

1.3.3 RAINWATER HARVESTING TECHNIQUES

RWH is the collection of rainwater from building roofs or the surface of the ground and storing it in tanks for use or groundwater recharge. This is a way to help solve the problem of water scarcity. This action prevents sewage or storm water from entering the drain and reduces flooding. It is an important environment/sustainable approach – that benefit in both keeping the groundwater table undisturbed and charging the aquifer. The structures required for harvesting the rainwater should be simple, economical, and eco-friendly.

1.3.3.1 MERITS OF RAINWATER HARVESTING: WHY

i. Increasing Water Needs/Demands:

a. An exponential growth of the human population has made it crucial to maximise the utilisation of freshwater resources.
b. Urban water supply networks face immense challenges in satisfying the demands of the growing population industries and extensive construction projects.
c. The escalating water requirements contribute to the declining groundwater levels and depleted reservoirs leading to the failure of numerous piped water supply systems.
d. Consumption of polluted water is beset with health hazards.
e. Lying rainwater presence of a beneficial alternative solution.

ii. Variations in Water Availability:

a. Hey the accessibility of water from various sources like lakes rivers and shallow groundwater can experience significant fluctuations.
b. Unregulated run-off of rainwater is contributing to soil erosion.
c. And storage of rainwater can service reliable water source for the mystic use during periods of water scarcity.
d. Rainwater can also offer a viable solution when quality of water from rivers and other surface sources is poor and inconsistent, particularly during the rainy season.
e. It aids in mitigating the flooding of roads and roundabouts.

iii. Responsibilities towards Protecting Nature

a. In increasing the utilisation of rainwater contributes to the conservation and enhancement of groundwater storage.
b. It assists in preventing floods and the accumulation of stagnant water in the urban areas.

iv. **Advantage of collection and Storage near the Place of Use**

a. A traditional water sources are often located in considerable distance from communities. By collecting and storing water near households accessibility and convenience of water supplies are improved leading to positive health impacts
b. The cost of collecting rainwater is lower compare to exploiting groundwater sources.
c. Rainwater collection is the only way to recharge water sources and revise dry open wells and hand pumps.
d. Additionally rainwater harvesting and foster a sense of ownership and community cohesion. It provides an opportunity for communities to collaborate and work together enabling the centralised control and community management of water sources.

v. **Quality of Water Supplies**

a. Water supplies can be contaminated as a result of the intensified use of fertilisers and pesticides.
b. Rainwater represents the purest form of freshwater.
c. Rainwater generally possesses a satisfactory quality.

1.3.3.2 TIMINGS FOR RAINWATER HARVESTING: WHEN

i. Water harvesting measures are crucial in situations where the groundwater is brackish or contains high-level of iron or fluoride.
ii. Initiating rainwater harvesting measures should commence 4 months prior to the expected onset of the monsoon season.

1.3.3.3 RAINWATER HARVESTING METHODS: HOW

i. **Surface Runoff Rainwater Harvesting Method (SRWH):**

This method involves the collection of rain water that flows along the ground during rainfall and storing it in an underground tank for various purposes, including irrigation. When storing rainwater, essential to employ efficient water conservation techniques to minimise evaporation. The adoption of this technology is relatively state straightforward and can be highly advantageous if implemented correctly the primary goal of surface run-off rainwater harvesting is to address the growing water demand, reduce water pollution, prevent soil erosion and mitigate road flooding (Figure 1.1).

ii. **Roof Top Rainwater Harvesting Method (RRWH):**

This is a technique for gathering rainwater at its source. Rainwater is collected and stored in the tanks by the roof catchments of residential or commercial buildings. To suit the demands of households and businesses, harvested rainwater is either kept in tanks or diverted to artificial recharge systems. This approach is straightforward, cost-effective, and genuinely efficient. RRWH includes rerouting and replenishing (or) storing rainwater that accumulates on a building's roof. The major goals are to improve the quality of ground water, make water available for future use, etc. Different types of collection systems can be used for each type of catchment system. The types of rainwater collection systems are shown in Figure 1.1 as follows:

a. Storage: Collected rainwater can be kept in reservoirs or lakes and used for immediate use.

b. Storage and groundwater recharge: In this process, excess precipitation is transported to recharge groundwater after being first stored in tanks or other systems. Hand pumps or tube wells can be utilised in the future to use recharged groundwater for drinking.

c. Groundwater recharge only: Using this technique, collected rainfall is sent straight to the earth, with no storage facilities. Examples include recharging groundwater through storm drains or transferring water from road runoff to recharge pits.

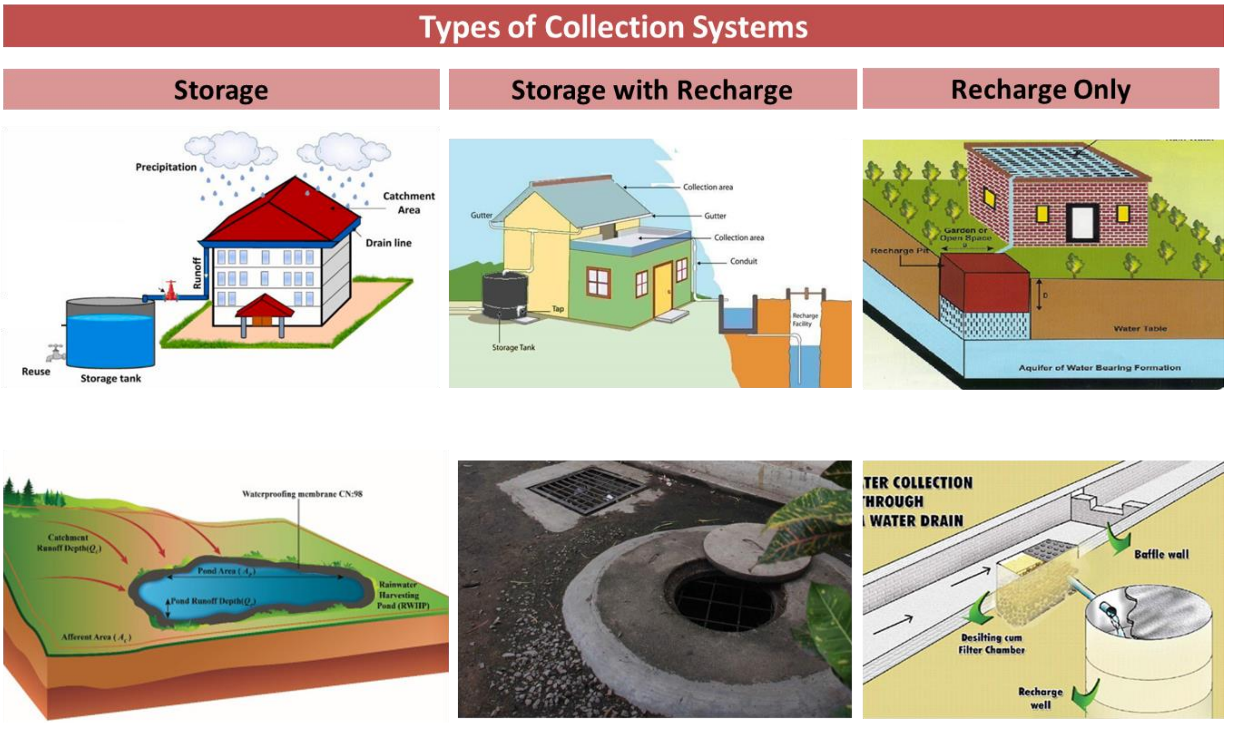


Figure 1: Types of rainwater Harvesting: Types of rainwater Harvesting

1.3.4 TECHNOLOGY: SUITIABILITY OF RAINWATER HARVESTING SITES

The identification or detection of locations suited for this practise is related to the effectiveness of rainwater systems (Grant et al., 2018). Finding suitable sites and developing them technically are crucial for the success of RWH systems. The examination of hydro-geomorphological traits that assist the capture, transport, and storage of rainwater as well as socio-economic factors that increase their utilisation benefit serve as the basis for detection criteria. The most crucial factors in choosing good sites for RWH are slope, land use/cover, soil type, rainfall, distance from populated areas and water sources, and price. (al., 2016)

Digital topographic data that is made available to the public has insufficient spatial resolution to map geomorphic features. Derivatives of the Light Detection and Ranging (LiDAR) technology may offer better vertical accuracy and horizontal resolution. In Holmes's 2017 LiDAR sensors installed on aircraft measure groundcover properties by calculating the time it takes for laser pulses to travel from an object on the ground to the airborne sensor and back again, reproducing the on-surface topographic features as point clouds. LiDAR is ideally suited for the delineation of terrain features that aid in the improved identification of potential places for RWH structures thanks to the current generation of high-resolution Digital Elevation Models (DEM) and Digital Surface Models (DSM). Figure 1.14 shows a sample of data from a LiDAR point cloud.

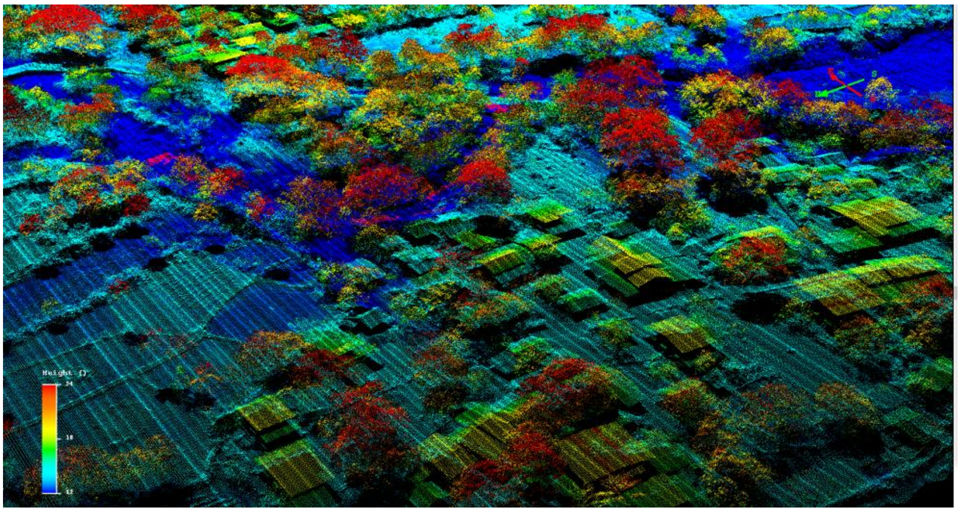


Figure 2: Lidar Point Cloud

LiDAR is a cutting-edge technology for acquiring three-dimensional (3D) coordinates with high precision and density, which integrates laser distance measurement, computer, GPS (Global Positioning System), and INS (Inertial Measurement System). This a significant breakthrough in the acquisition of 3D space information in real time as well as a new method of acquiring high space-time resolution geo spatial information (Figure 1.15).

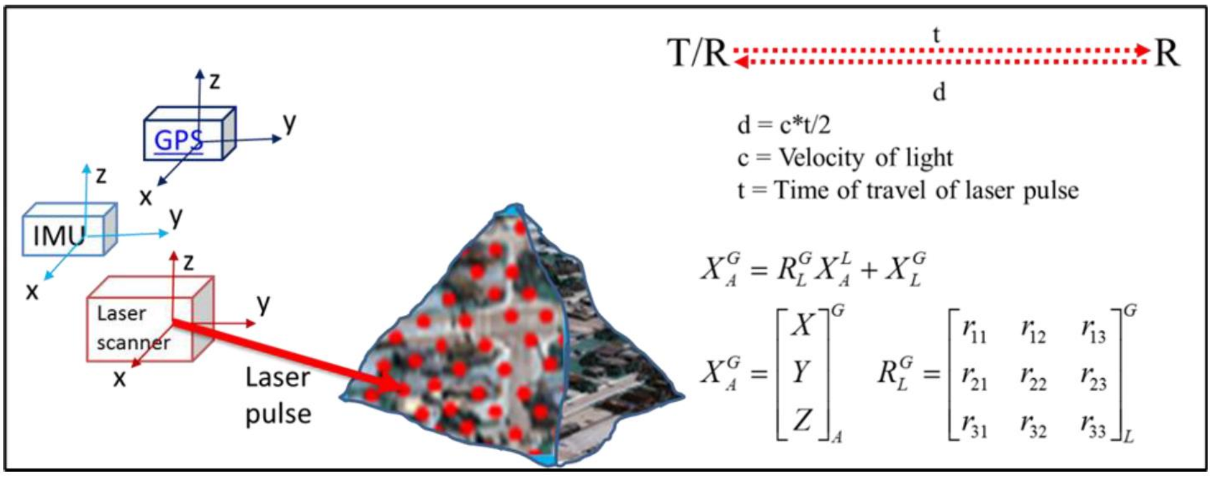


Figure 3: Lidar technology

1.3.4.1 **Aerial LiDAR**

By flying above a location and scanning it with lasers from side to side, a survey is completed. The laser pulses' target reflection value is detected by the receiver, which also keeps track of the time between emission and reception. The distance between the plane and the ground can be determined by dividing this time by two and multiplying it by the speed of light. The aircraft's rotations are picked up by the inertial system along three axes: the flight path (pitch), the wingtips (roll), and the crab (yaw). The GPS tracks the actual location of the aircraft in space. A "point cloud"—a dense, intricate collection of elevation points—is produced when laser ranges are combined with orientation and location data from the Inertial Measurement Unit system and Integrated GPS, respectively, as well as scan angles and calibration data. Each point in the point cloud corresponds to a specific location on the object's or earth's surface from which a laser pulse was reflected and has three-dimensional spatial coordinates (latitude, longitude, and height). In order to create or extract various geospatial products, such as digital elevation models, digital surface models, contours, and GIS layers of land use, buildings, utilities, etc., the point clouds are compared to high resolution aerial images taken concurrently with LiDAR. (2018) Wai Yeung YanThese are the crucial layers for pinpointing RWH locations. Here is an illustration of LiDAR derivatives. (Figure 1.16& 1.17):

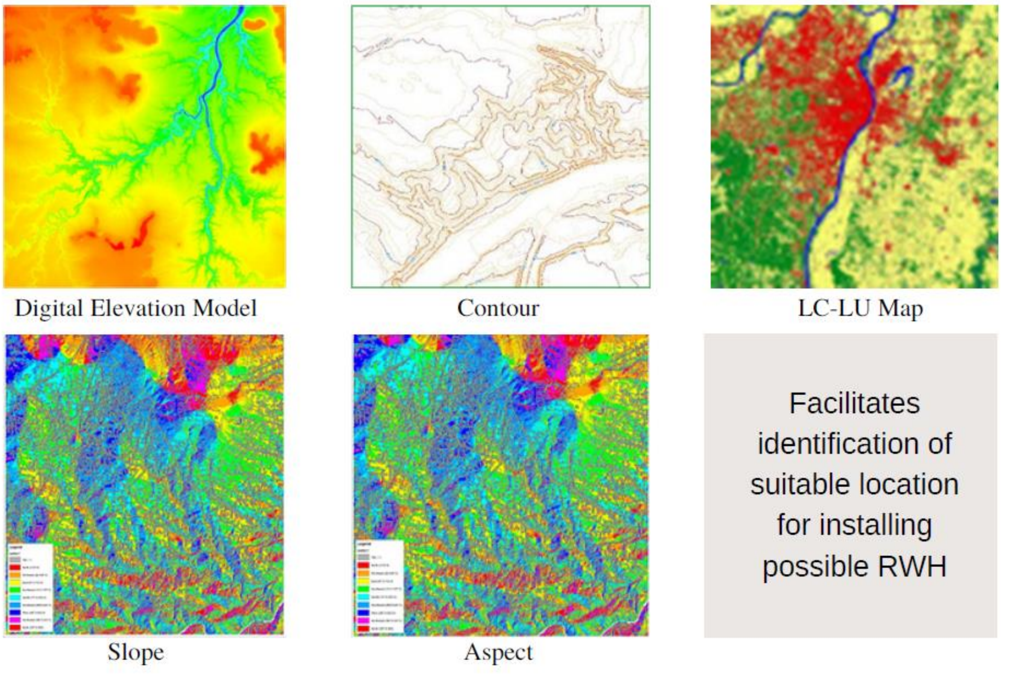


Figure 4: Lidar Derivatives

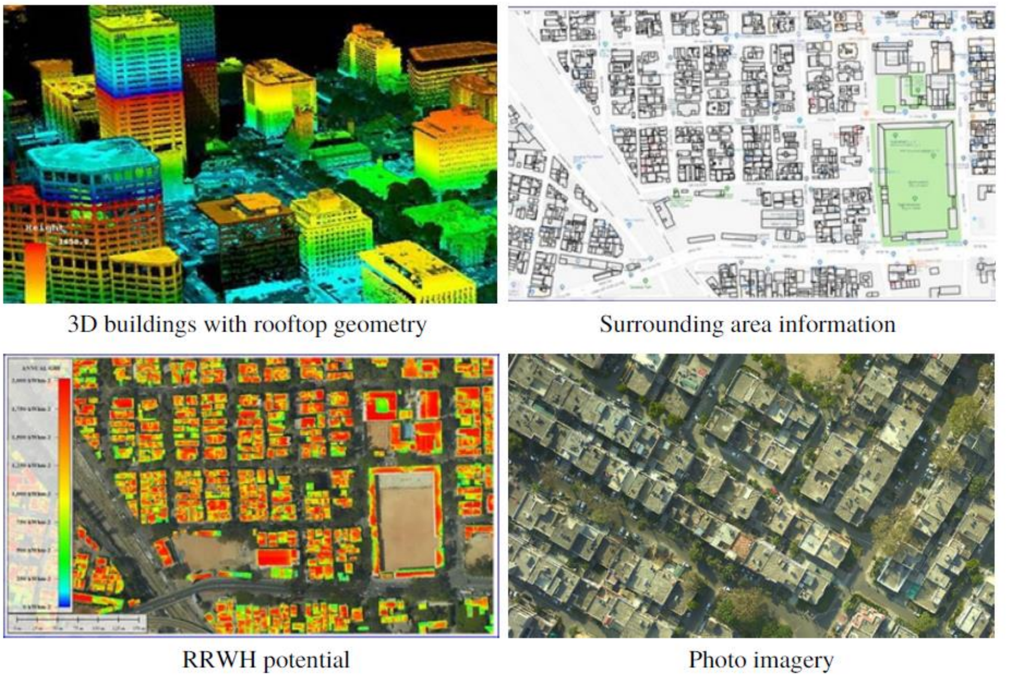


Figure 5: 3D building information for RRWH Potential

1.3.5 METHODOLOGY FOR LiDAR TECHNOLOGY

As the first step, preliminary site assessment and existing inventory of installed SRWH and RRWH system will be studied that could lead to the adoption of suitable methodology for this project. The general workflow/guidelines of the project method are proposed as follows:

1. Preliminary data collection:

   a. Data on existing installed SRWH and RRWH structures.

   b. Data on major catchment/minor catchment areas

c. Existing study reports

d. Historical Rainfall data of the project area

e. Existing data of natural/man-made ponds/lakes or waterbodies etc.

f. Existing data on underground utilities

g. Existing Sewage/Storm water drainage plans

h. Ground water level table data

i. Master Plan Data for future 30 years

2. Bathymetry survey of existing water bodies – River, Lake, Dam and reservoir
3. Establishment of ground control points which will be connected to SOI's CORS network for aerial data acquisition
4. Aerial flying for the acquisition of LiDAR data & aerial images
5. Creation of 3D model of the terrain & buildings.
6. Building GIS Decision support system for identifying potential locations for SRWH
7. RRWH potential mapping to detect suitable buildings for harvesting rainwater
8. DPR and cost estimation for the final location structures for SRWH.

All input data must be checked for accuracy after data collection. LiDAR survey data will be used to create mapping products after a thorough report on data collecting is created. Based on measured intensities and three-dimensional coordinates, LiDAR processing software is used to categorise all the point-cloud data into distinct classes, such as the ground, vegetation, and structures. In order to create ortho-photos, the aerial photographs are concurrently taken using a specialised camera. With the aid of processing tools, contouring and DTM/DEM creation are made possible. Ortho-photos are combined and fixed with the aid of the appropriate software. The initial, raw LiDAR data is processed using an automated artefact removal technique, followed by a manual inspection of the data, to remove the effects of artefacts left in the DTM bare - earth. Error points can be brought on by clouds, birds, pollution, or noise in the data. The first return of the LiDAR data is used to create the Digital Surface Model (DSM). (W.G.M., 1998) (Wai Yeung Yan, 2018) (Lemmens)

1.3.6 METHODS AND TOOLS FOR SUITABLE SITES FOR SRWH

After being transformed into understandable form, the acquired data must be further analysed to clearly identify sites that are suited for RWH. The determination of the most appropriate locations is based on a number of factors, including the surface area and volume of storage, as well as the environment, hydrology, socioeconomics, and geography. These factors include elevation, slope, aspect, precipitation, temperature, proximity to rivers, curve number (CN), landuse/cover, geology, soil type, population density, proximity to roads, proximity to settlements, and proximity to lakes. A popular type of analysis that incorporates data from many criteria is called multi criteria analysis (MCA). An MCA method known as the Analytical Hierarchy Process (AHP) has been used extensively to find possible RWH sites when combined with GIS. The GIS technique combines socio-economic indicators such as landowner, distance to settlements, distance to streams, and distance to highways with biophysical criteria such as slope, vegetation cover, soil texture, and soil depth. (Gottfried Mandlburger, 2019) (Brown)

Based on the competence and understanding of the field, the superiority of one criterion over another will be evaluated. Fourth, the suitability maps for each RWH technique will be determined using the weighted overlay process in GIS. The number of suitable sites will be reduced after the suitability maps are overlay with cadastral maps to apply RWH criteria, and the final suitability map will be combined with socio-economic characteristics and discussions with farmers and locals. A team will then travel to the locations to verify the findings in the field by comparing them to the suitability maps. The following key steps make up the technique for developing the GIS Decision Support System for SRWH siting in this project:

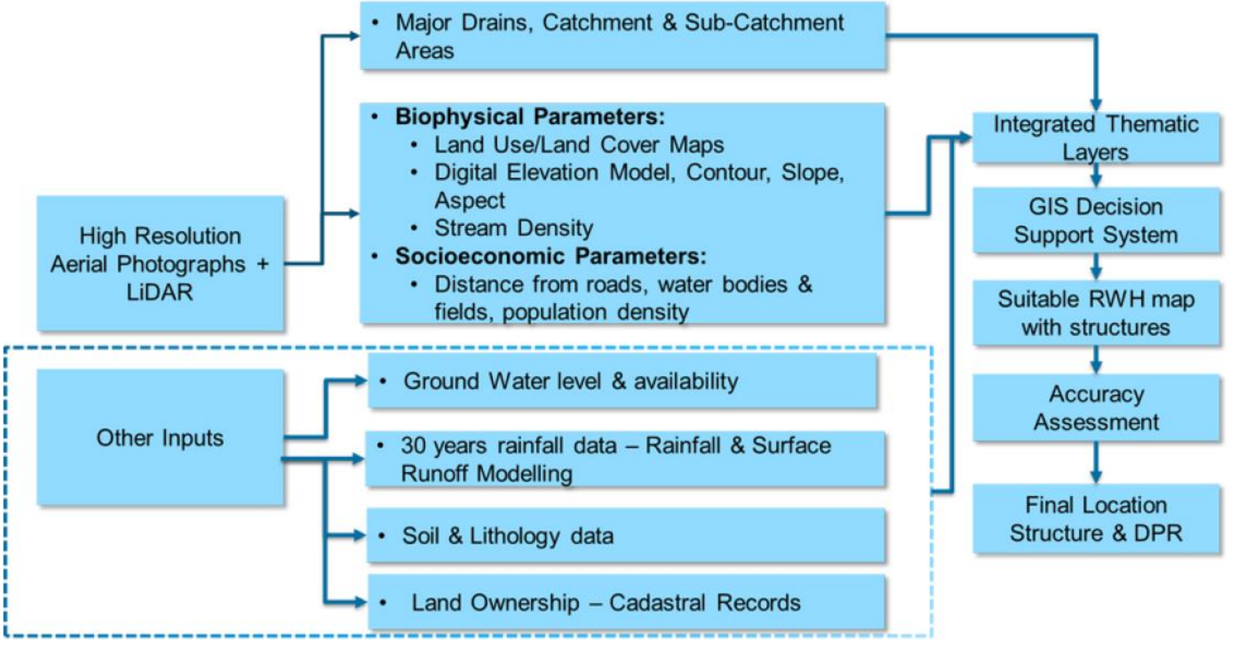


Figure 6: Lidar Data and GIS DSS for SRWH

1.3.7 METHODS AND TOOLS FOR SUITABLE SITES FOR RRWH

The evaluation of RRWH quality and applicability requires thorough and trustworthy data on roofs. The quality of rainwater collected depends on the roof's area, volume, size, and geometry. The size, slope, and length of the roof as well as other architectural elements have an impact on the quality of roof runoff. The size, slope, and material of the roof's catchment area will determine how much rainwater can be collected for harvested rainwater systems. Similar environmental factors, such as a roof's closeness to a highway or an industrial region, might degrade the quality of rainwater that has been collected. Roof runoff pollution is significantly influenced by rainfall levels and timing. LiDAR data and high resolution ortho photos will be used to extract the rooftops in the project area. Ortho-photos are utilised in conjunction with DEM and DSM to identify potential sites. DSM is a 3D model produced by LiDAR, which produces a sizable point cloud with a wide range of elevation values. These elevation values are derived from the tops of structures, the canopy of trees, power lines, and various other elements. The extraction of rooftop area, size, and volume shall be made possible by a high resolution orthomosaic image and 3D DSM model. To verify the rooftop area, the roof catchment area will be manually vectored. The possible buildings for RRWH will be plotted taking into account all parameters like land use/land cover surrounding the buildings, rooftop space, geometry, and rainfall. (W.G.M., 1998) (Gottfried Mandlburger, 2019)This mapping analysis will focus not only on the rooftop's appropriateness but also on the need for nearby free space where the GW recharge pits can be built. As a result, the mapping will include the following categories of probable RRWH:

1. Potential roofs for RRWH (> 100 sqm.)
2. Potential Roofs where adjoining land is available for GW recharge pits.

RRWH potential will be calculated as function of roof area, rainfall, and catchment coefficient.

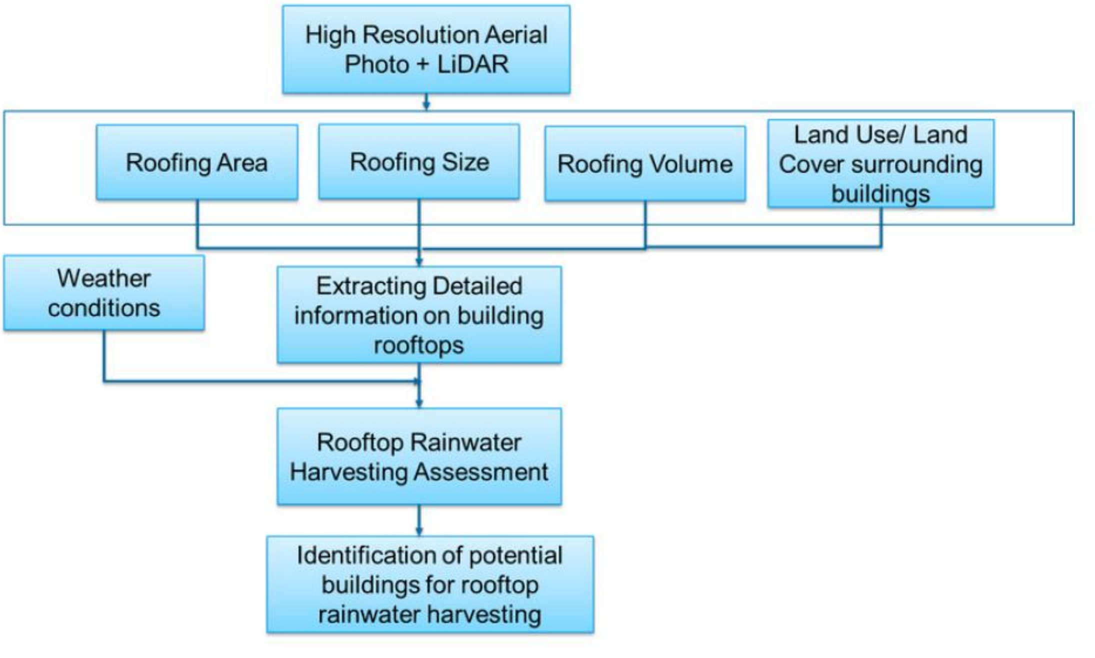


Figure 7: Workflow for RRWH Potential Sites

1.4 RESEARCH GAP

From the extensive data available on rainwater harvesting, new technologies and multiple studies, the main gaps identified are as follows:

- Comparative analyses between methods for selecting suitable sites
- Determination of collection efficiency in variety of pit designs

- High cost of rooftop rainwater harvesting implementation (unit cost per cubic metre of water stored) – Financial analysis including indirect benefits and LCA.
- Poor quality of water stored for long periods in rooftop rainwater harvesting systems (months)
- Social/political barrier to a widespread implementation of RWH (especially in developing countries) and role of research in expediting the process.
- Interdisciplinary aspects in Rain Water Harvesting Research
- Climatic effect of Rain Water Harvesting

……………………………… **END OF CHAPTER 1** ……………………………….

CHAPTER 2: CASE STUDY

2.1 DELHI’S RAINWATER HARVESTING POTENTIAL

Potentially valuable sources of water for human use are water resources. For many different things, including agriculture, industry, homes, recreation, and the environment, water is necessary. Each and every one of these human efforts requires freshwater. With a population of around 20 million, Delhi, the capital of India, has a difficult time keeping up with the demand for services and infrastructure. Since many families either receive little water through municipal pipelines or have no access to piped networks at all, water shortage is a serious problem. Data currently available shows a 323 million gallons per day (MGD) shortage, which is equal to almost 25% of the daily water demand, or 1,260 MGD. Notably, 17% of houses lack a piped water supply, and 13% of unofficial settlements lack access to piped networks. Large swaths of Delhi's population suffer from the negative impacts of inadequate water access, which affects things like sanitation, regular home chores, building, irrigation, and industrial processes. (Board C. G.) (Board C. G., 2022)

The use of rainwater harvesting (RWH) is a widely accepted solution for the problem of water scarcity. This procedure successfully stops sewage or stormwater from entering drainage systems, which reduces flooding. It is a crucial environmentally responsible and sustainable strategy that offers the combined benefits of preserving the stability of groundwater levels and recharging aquifers. The infrastructure required for rainwater collection should be simple, economical, and environmentally responsible.

Scientists assess the potential of rooftop rainwater harvesting (RWH) by comparing Delhi's annual water needs with the amount of water collected by rooftop RWH systems on individual home rooftops in the city. According to data from the Central Ground Water Board's (CGWB) Aquifer Mapping and Groundwater Management study, Delhi will likely receive a recharge of 13 million cubic metres (MCM), or about enough water to last for four days. (Rainwater Harvesting Systems)

This result can be attributable to a number of things, such as:

- Altered topography due to rapid urbanization, which has modified water and drainage patterns.
- Shifts in rainfall patterns over the past decade, characterized by sudden and intense downpours rather than prolonged periods of continuous rainfall
- Changes in land use, particularly the decrease in unpaved areas leading to increased surface runoff.

- Underground recharge of contaminated water, resulting from the use of chemicals, pesticides and the flow of untreated water into recharge pits.

It is vital to develop large-scale recharge pits that can hold the water needed to meet Delhi's water demand in order to maximise the efficiency of rainwater harvesting. However, in the context of Delhi, the idea of building artificial pits on such a large scale is unfeasible. The most practical method, therefore, is to design recharge pits within naturally existing recharge basins.

According to data from the Central Ground Water Board (CGWB), Delhi's annual groundwater pumping topped 100% in 2017. The depth of the water in various parts of the city in January 2019 ranged from 0.80 to 65 metres below ground level (m bgl). The maximum depth increased by three metres over a three-year period, going from 62 m bgl in May 2015 to 65 m bgl in January 2019. (UNEP publications) (Delhi-cityoflakes, 2022)

In the months of July, August, and September, the rainy season accounts for about 81% of Delhi's yearly precipitation. The remaining precipitation occurs during the winter or during infrequent thunderstorms all year long. The patterns of precipitation are highly variable and are characterised by flashes of heavy rain. There are sporadic dry spells lasting a few days without rain throughout the monsoon season. Notably, large excess or deficit variations from the average precipitation level as well as evaporation losses are also seen.

According to the data, Delhi receives about 800 mm of precipitation on a yearly average. However, the city only received 544 mm of rain in 2018, which was 31% less than the average, and 680 mm in 2019, which is an 11% shortfall. The city's expected annual capacity for rainwater harvesting (RWH) is 900 billion litres, which is equal to 2,500 million litres per day or 550 million gallons per day. A further estimate places the daily capacity of rooftop rainwater gathering at 27 million litres (or 6 million gallons). Unfortunately, a sizable amount of rainwater is lost due to insufficient RWH installations in many urban locations.

Managing the capital city's water supply and demand effectively presents a number of difficulties for the Delhi government. Water shortage and the steady depletion of groundwater supplies are the main problems. Encouragement of the use of rainwater harvesting (RWH) techniques is one way to address these problems.

The government of Delhi has launched initiatives to encourage the use of rooftop rainwater harvesting systems (RRWH). These programmes provide cash support of up to Rs 50,000 and a 10% water bill decrease. A financial incentive equal to 50% of the total cost of the RRWH structure is offered for rooftops with an area between 100 square metres and 199.99 square metres. A complete list of installed RWH systems, their operation, and the amount of captured rainwater are currently unavailable for both public and private properties, as well as government and private properties. To effectively utilise the advantages of RWH, it is essential to fill in these informational gaps.

In order to address this, the government would benefit greatly from the implementation of a Geographic Information System (GIS) database that identifies potential buildings suitable for RRWH systems. This would allow the government to better monitor the allocation of subsidies, cut costs associated with field verification, and identify potential properties and open/public spaces suitable for RWH system installation.

The Aravalli Biodiversity Park project near Delhi is a noteworthy example of rainwater harvesting. The Aravalli Biodiversity Park in South Delhi is a reclaimed wasteland that has been turned into a lush area with a diverse range of plants. As part of this project, the Delhi Development Authority (DDA) put rainwater collection systems in place.

Rooftop rainwater collection structures and recharge wells are installed as part of the Aravalli Biodiversity Park's rainwater harvesting systems. Rainwater that has been collected on rooftops is directed into recharge wells where it can seep into the soil and replenish groundwater aquifers. (UNEP publications) (Jonathan D Paul, 2020)

This project's numerous goals include groundwater recharging, ecological restoration, and water conservation. The rainwater harvesting systems assist the growth of vegetation in the park, which boosts groundwater levels, biodiversity, and general ecological balance.

The Aravalli Biodiversity Park's rainwater gathering systems' effectiveness serves as an example of the potential of such efforts to address Delhi's water shortage and advance sustainable water management. It serves as an illustration of how rainwater collection can be used into urban green areas to accomplish a variety of environmental objectives.

2.2 PILOT STUDY BY DELHI GOVERNMENT

2.2.1 PAPPANKALAN RECHARGE BASIN

A pilot programme was started in 2021 as a result of feedback from public representatives regarding water logging in the Dwarka Sector 16 area. Additionally, it was based on recommendations from the Master Drainage Plan report that IIT Delhi produced and submitted to the Delhi government in 2018. Delhi Jal Board has the authority to carry out the project. The 10 square km research area is made up of the urban environment surrounding Dwarka Sector 16. There are many different types of buildings in the region, mostly made of concrete, and there is a lot of open space. Due to high water levels in the Najafgarh Drain that cause backflow in the Pappankalan 20 MGD STP outfall and local storm water drain, the problem of water logging becomes more noticeable during the monsoon season. Storm water was diverted, and STPs were discharged into recharge lakes that were spread out across an area of 11 acres each inside Pappankalan STP, 5 acres inside Najafgarh STP, and 5 acres inside Dwarka WTP. Pipelines and bridges connect each of the recharge lakes. Table 1 lists the holding capacity of various recharge lakes.

S.No	**Location**	**Area**	**Depth**	**Volume (m3)**	**Holding Capacity in Million Gallon**
1	Pappankalan STP	11 Acres	6 m	2,67,036	~ 60
2	Najafgarh STP	5 Acres	6 m	1,21,380	~ 27
3	Dwarka WTP	5 Acres	6 m	1,21,380	~ 27
Total		21 Acres		5,09,796	~114 Million

Table 1: Holding Capacity of Recharge Lakes

The average percolation rate in saturated strata was determined to be 1 meter/day based on the Double Ring Percolation Test. To monitor the rise in ground water level, several piezometers have been positioned at various distances along the lake's perimeter. To recharge lake overflow into the ground water, several recharge pits have been built around the lake. These recharge trenches increase the amount of water that can be handled. Over a year has passed since the project began. After one monsoon season, Pappankalan Lake's piezometer measured an increase of almost 4 metres, as well as 2.5 metres around Najafgarh Lake and Dwarka. Ground water levels have increased to 6 metres and roughly 3 metres around Pappankalan Lake as a result of the utilisation of post-monsoon lakes for recharging water from treated effluent from STP. Delhi-cityoflakes, government, 2022

The STP's initial topography survey was carried out using drone mapping. Lake levels were chosen based on the contour maps that were created. To transport water to the lakes, many inputs from the closest storm drain were made. To prevent pollution from sewage and undesired organic material deposited during the non-monsoon season, pipe connections were made above the lean flow of the drain.

Conclusion: Increase in 6 metres ground water level reducing depth of GW from 20 metres to 14 metres in 1.25 years.

Figure 8: Images of Flash Rain Flooding in Dwarka Area

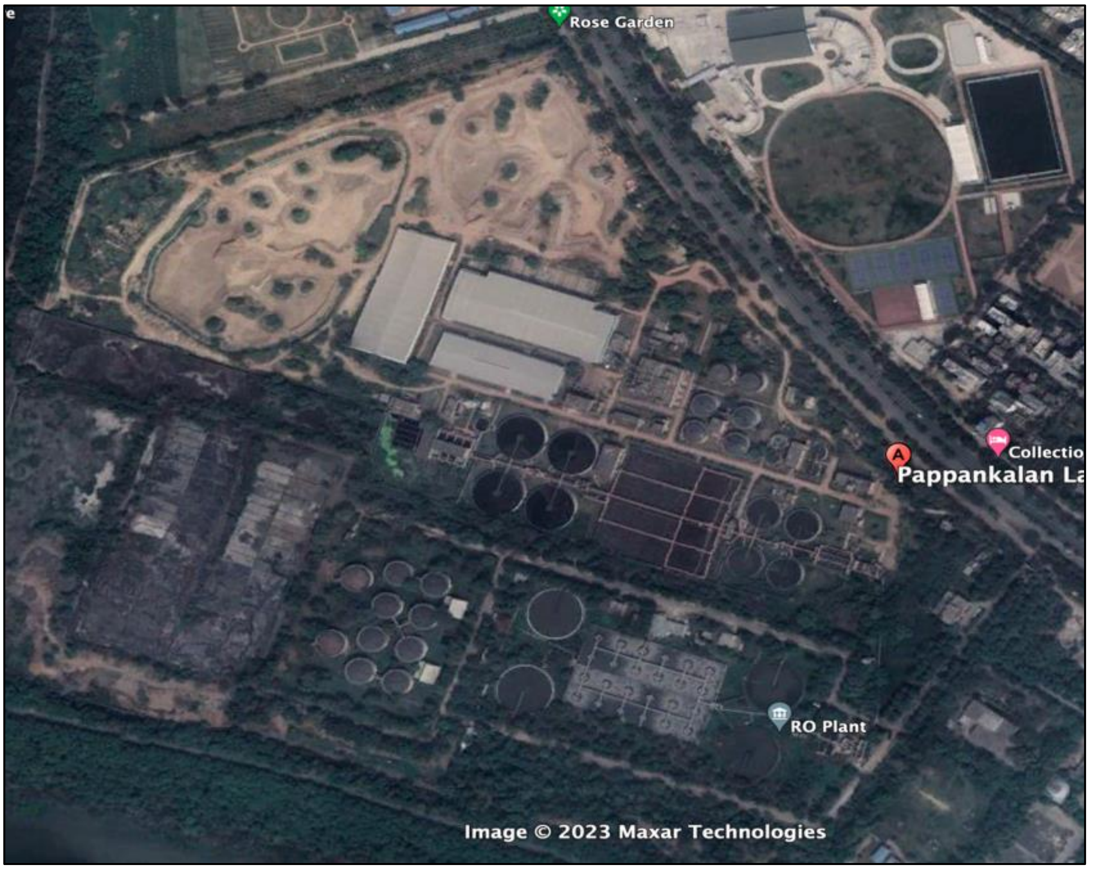


Figure 9: Drone Image of Excavation of Recharge Lakes

Figure 10: Drone Image after Filling of Lake

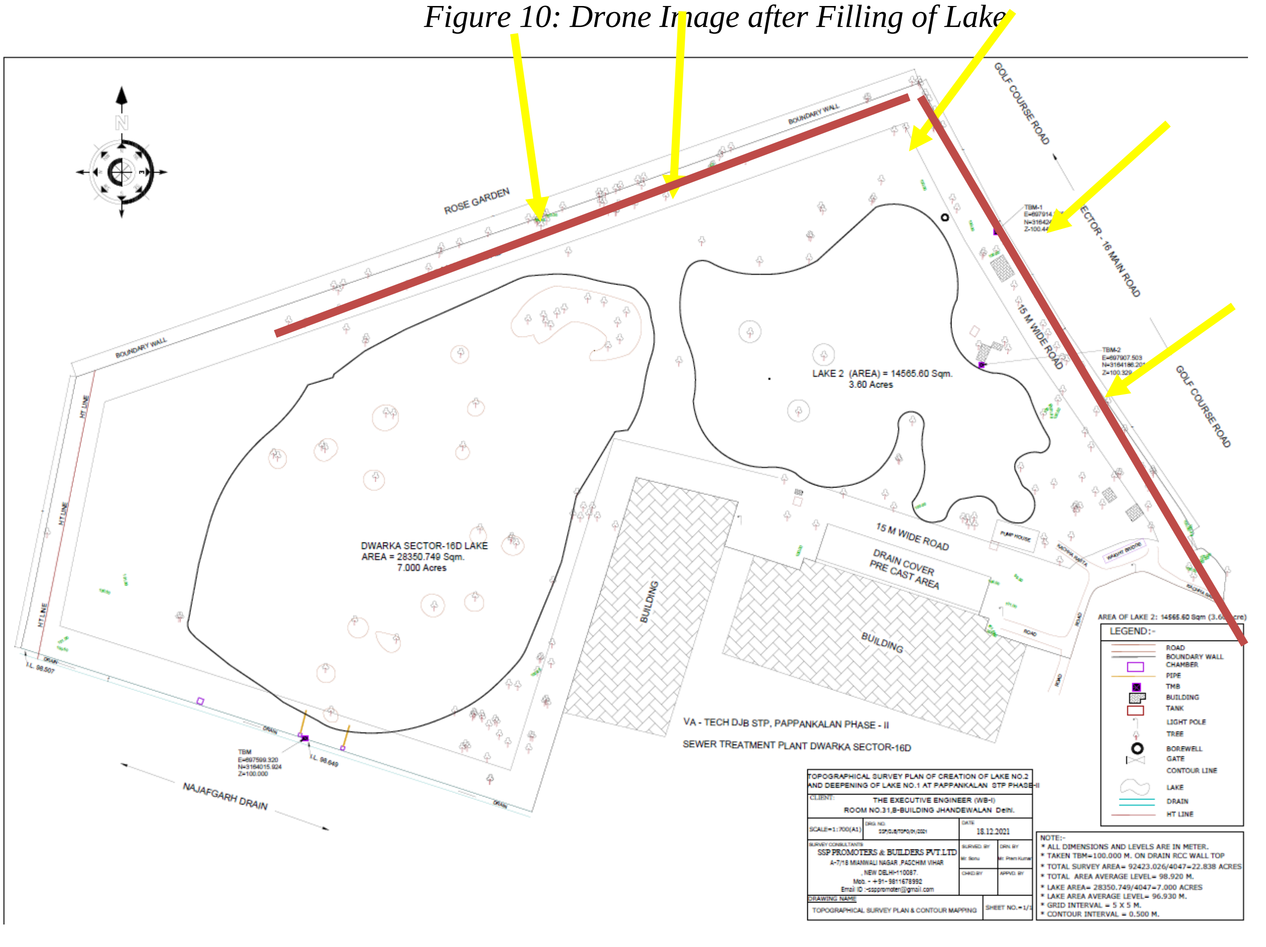


Figure 11: Identified Location for Creating Recharge Basin (lake) at Pappankalan

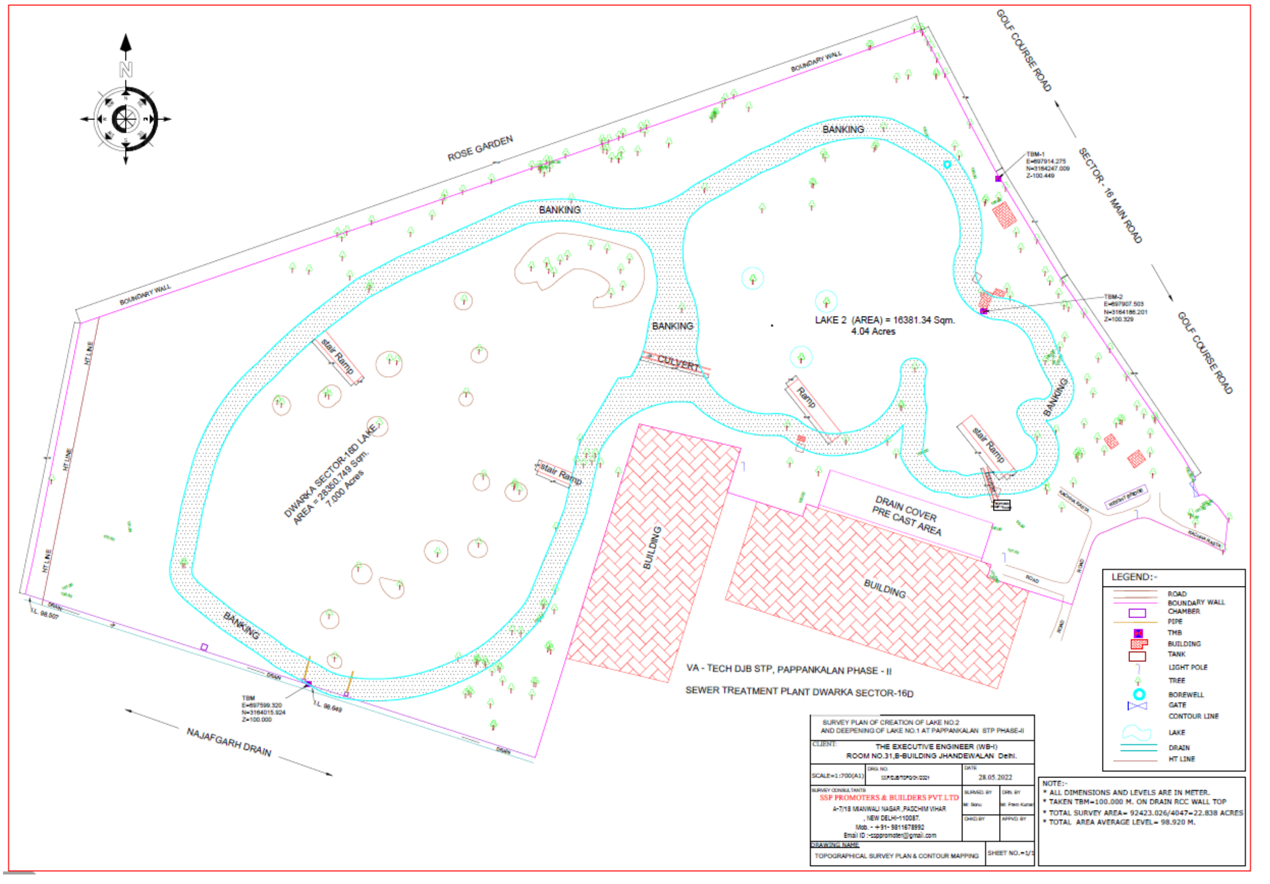


Figure 12: Excavated Lakes at Pappankalan

2.2.2 PALLA RECHARGE BASIN

By holding onto extra water during the monsoon season for ground water recharge, the Irrigation and Flood Control Department (I&FC) of NCT Delhi is working on the creation of reservoirs/water bodies in the flood plain of the river Yamuna from Palla to Wazirabad. While the highest demand for water is approximately 1120 MGD, DJB typically supplies roughly 940 MGD. Therefore, in times of a water shortage, it is always necessary to consider alternative water sources. The Delhi Government suggested a pilot project—the first of its type in the nation—to build small reservoirs along the Yamuna Floodplains that would be topped off by diverting extra water from the River Channel and letting it percolate.

Up to 227.5 MGD of water can only be released into the Yamuna River downstream of the Hathnikund Barrage during non-monsoon months. Between Hathnikund Barrage (HKB) and Wazirabad, the river regains some of its water due to ground water accumulation and contribution through the Somb River and Pathrala River, which are tributaries to the river Yamuna. Every year, the Yamuna River floods during the monsoon season due to healthy flows from the upstream catchment in the steep area. The project's goal is to collect this extra floodwater and store it on the Yamuna floodplains from Palla to Wazirabad.

(Government, 2019)

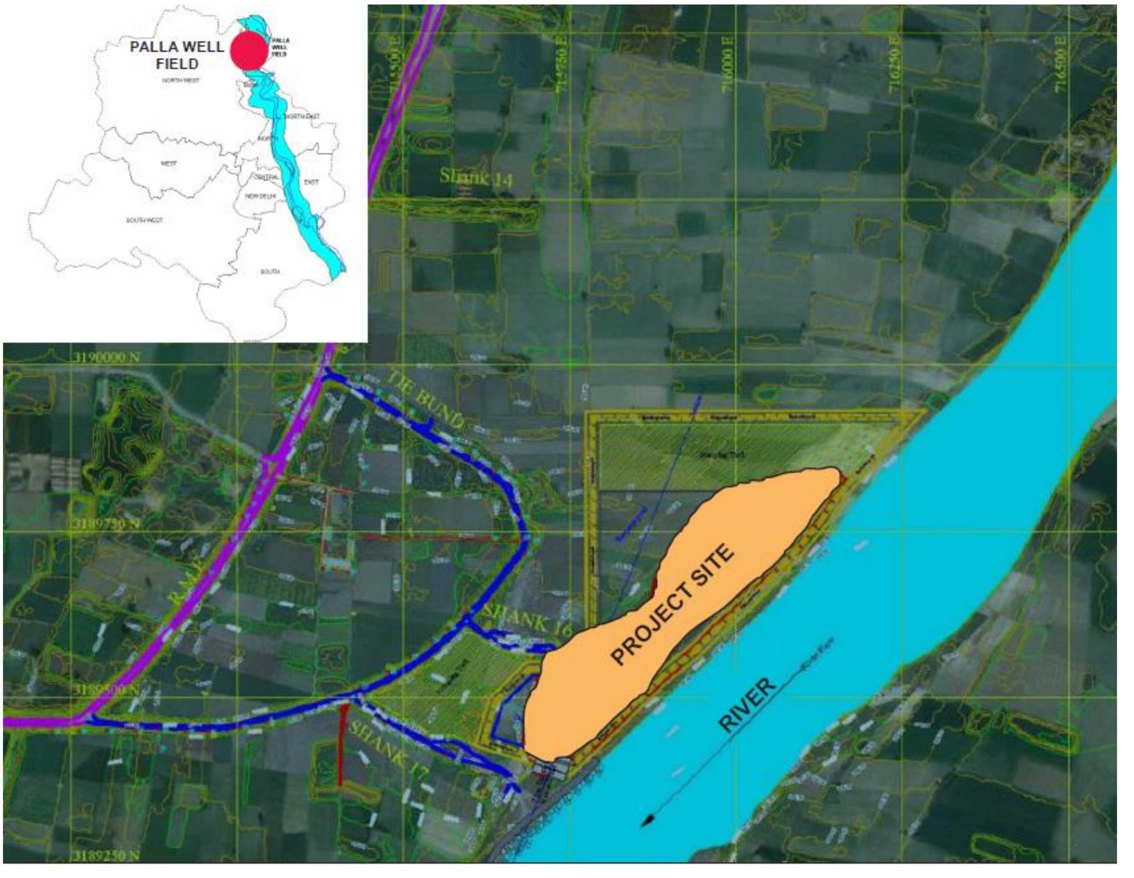


Figure 13: Palla Project Site

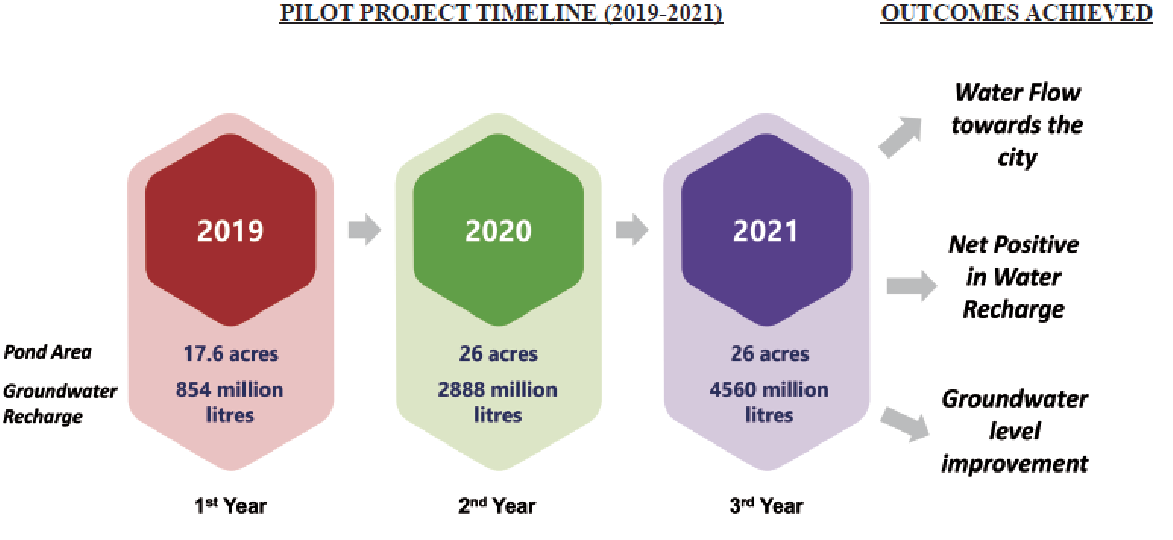


Figure: TOP-Location of Recharge Pond at Flood Plain of Yamuna River (Shank 14-17)
BOTTOM- Project Timeline and achieved outcome summary, Source: Delhi Jal Board

Figure 14: Pilot Project Timeline

Process and Techniques

i. Land Availability and Pond Excavation

The government of the NCT of Delhi's revenue department and I&FC department had several meetings to discuss the negotiations with the landowners and cultivators. Finally, Sungarpur had 43 acres of land available. On this piece of land, this trial project was carried out. (Jonathan D Paul, 2020) When the pond started receiving too much floodwater on August 9 and continued until August 19, 2019, excavation of the pond or water body was only possible during that brief period. Approximately 17.6 acres of pond were excavated in the pilot project's first year (2019), with an average excavation depth of 1.5 metres. From June 22 through July 15, 2020, 26 acres were excavated. We kept the 26 acres of pond land in 2021 because the pilot study's desired outcomes were attained.

According to this graphic, 17 acres of the pond were dug in the first year of the pilot project (2019), 26 acres in 2020, and 26 acres in 2021.

ii. **Slope Protection Work**

On the project site, the excavated dirt was appropriately stacked, and bamboo chicks and bellies were used to decorate the borders of the pond by anchoring them to the earth. This slope protection strategy was implemented in accordance with the committee's recommendations.

Boundary slopes are susceptible to collapse because high pore pressure can develop quickly. Flood water with great momentum and speed can pour down the slope and topple the bund built around the pond to contain the water. By introducing the loose soil and lowering the pond's capacity, this could harm the pond. Slope protection was advocated as something that should be done. Erosion will be decreased with the aid of this slope protection.

There are various slope protection measures, which can be implemented, such as:

- Surface protection such as vegetation
- Rigid covers like masonry, plaster, or shotcrete

Accordingly, in conformity with the NGT order, the bamboo mesh was made and this mesh was placed at the toe of the slope at the inner wall of the pond. The configuration of the mesh is shown in Figure 2.8 below. The structural and physical characteristics of the stems of certain bamboo species turn them into a highly effective construction material for complementary soil bioengineering support structures.

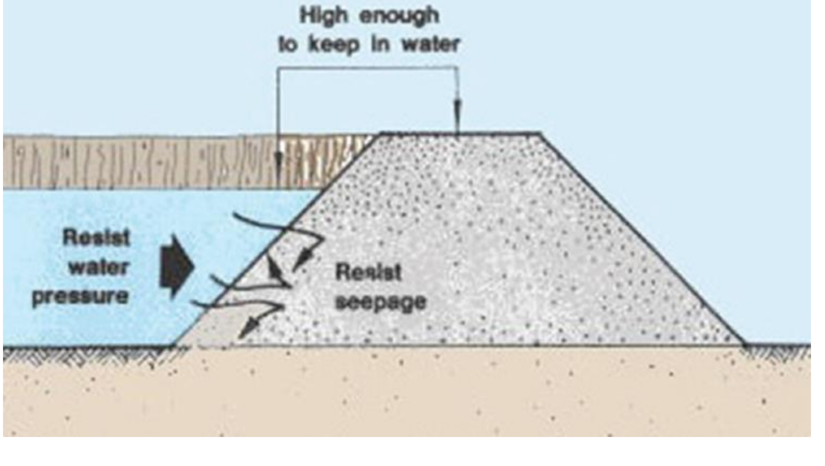


Figure 15: Top-Slope protection technique (Example: Concrete), Bottom- Bamboo sticks for slope protection, Bamboo Diameter was approximately 80mm, and number of mesh used were 405 nos. Source: Development of Waterbodies/ Reservoirs in Yamuna Flood Plain Final Report for Pilot Project

iii. Peizometer

A network of 10 piezometers was installed near the pond area and 3 piezometers in non-pond area. It was recommended to install piezometers at suitable locations in addition to the existing network at a distance of 1 km. It was recommended by the Joint Committee to enhance the network of piezometers in the Yamuna floodplain area with a spacing of about 1 Km to monitor and study the groundwater regime in the area. To adhere to this recommendation, a network of 20 piezometers was established through approval by the CGWB in 2020. The total piezometers installed in final year 2021 was 33. (Board D. j., 2022)

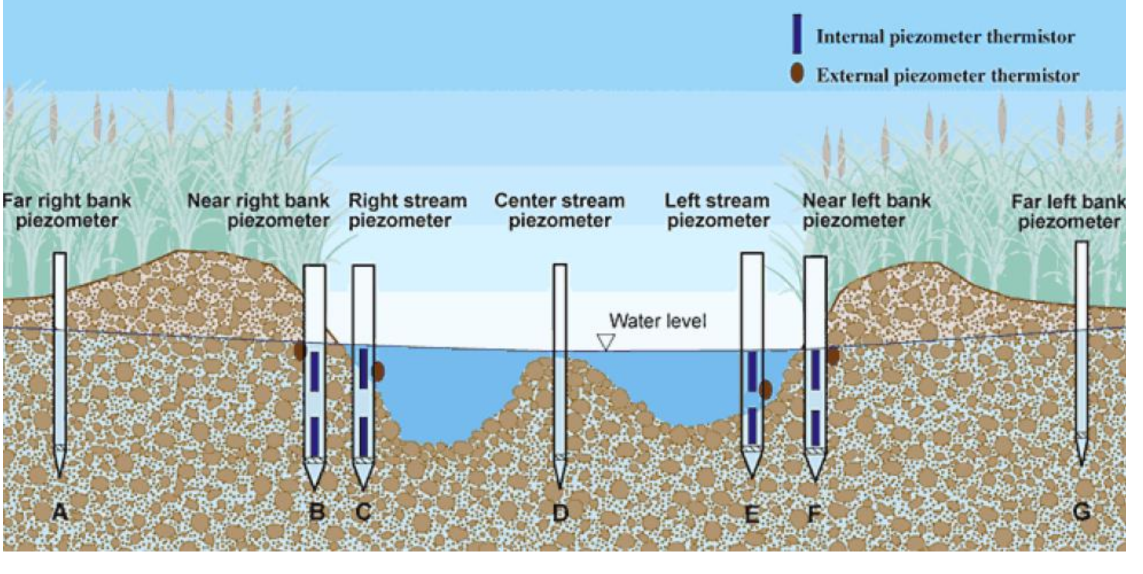


Figure 16: Piezometer installed in the Waterbody, Source: USGS Publications Repository

iv. Percolation

The process through which soil absorbs water is known as percolation. The rate of absorption varies depending on the kind of soil. The makeup of the soil affects how quickly it absorbs water. Water can be temporarily stored in soil with a high percolation rate. A soil with a low percolation rate, on the other hand, will retain water for a longer period of time. The percolation rate aids in choosing the best soil for growing crops. The formula below can be used to determine the percolation rate. Water quantity (ml) divided by percolation time (min) equals percolation rate. (Rainwater Harvesting Systems; K.A., 2008)

Given Delhi's mixed, sandy and loamy soil type, which allows for efficient percolation of water, the notion of the reservoir seems viable. n.d. (Vedantu) The formation of floodplains beside a water body is caused by the rivers' monsoon-induced transport of fine sand from the mountains, and these areas are very fruitful. The Yamuna floodplains have an extremely porous and permeable aquifer soil layer, with an average depth of roughly 40 metres. The top layer of sand can, according to laboratory tests, contain up to 50% of its capacity in water. As a result, the floodplains have a huge capacity to store water reserves and raise water table levels. (CSE)

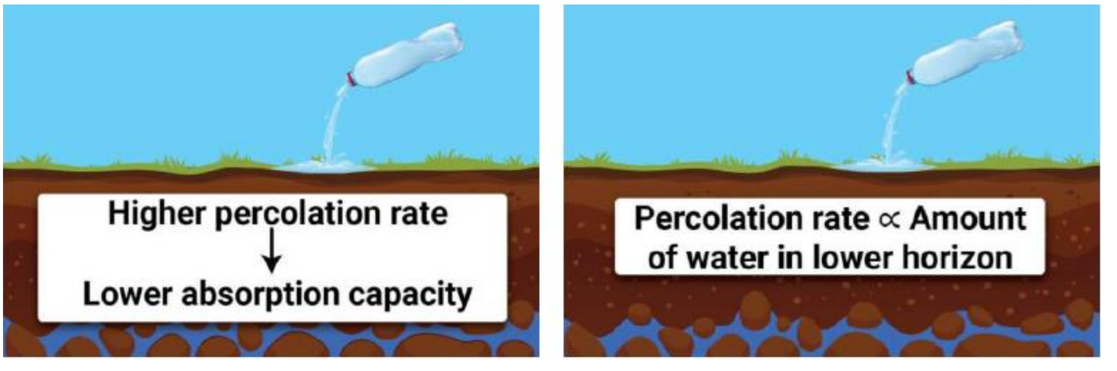


Figure 17: Measurement of Water level in percolation Pit on Site in Palla

Figure 18: Pit 1,2,3 Percolation Rates for 2020

2019: The percolation rate during saturated condition at the time of flood season: a) Point-1: 25 mm in 18.5 min (= 81 mm /hr) in 2019. The percolation rate during saturated condition at the time of flood season: a) Point-1: 25 mm in 18.5 min (= 81 mm /hr)

2020: High percolation rates are favourable for ground water recharge. The percolation rate observed in the area is about 500-1000mm/hrs per the following details. Values of Percolation test of all 3 locations are given below: Pit No. 1: - 800 mm/hr and Pit No. 2: - 720 mm/hr • Pit No. 3:- 384 mm/hr.

v. Pond Submergence

The pond was submerged for 14 days in 2019, 19 days in 2020, followed by 30 days in 2021. The maximum flood discharge from Hathnikund in 2019 was 445606 MGD, 19674 MGD in 2020, and 85976 MGD in 2021.

Year	Near pilot project region	Away from pilot project region
2019	1- 1.3 m	0.2-1 m
2020	0.5- 2.5 m	0.2- 1.5m
2021	0.5- 2.5 m	0.2- 1.5m

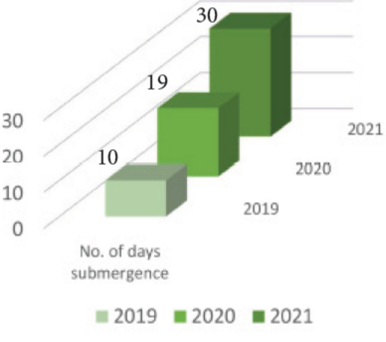


Table: (Left) Average Water Table rise in meters
Figure: (Right) No. of Days of Submergence of Pond

Table 2 Average water table rise in meters

vi. Ground Water Recharge

The amount of ground water recharged in pilot study area and surrounding areas was 854.5 million litres in 2019, followed by 2858 million litres in 2020 and 4517 million litres in 2021 monsoon season as shown in Figure below.

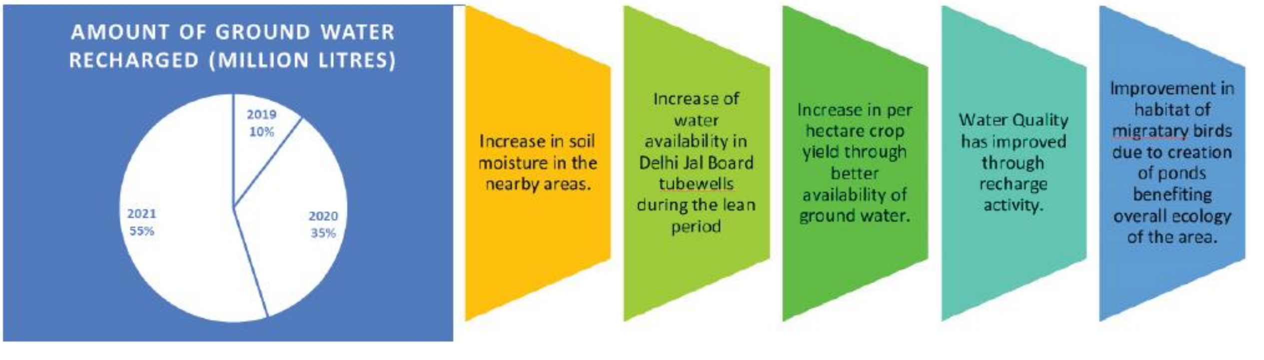


Figure 19: (LEFT) Amount of Water Recharged in Million litres. (RIGHT) The Advantages of Ground Water Recharge

The potential for groundwater recharge through floodplains to act as an underground reservoir with the capacity to serve as a buffer water source and ease summertime water shortages is enormous. The River Yamuna Channel is overflowing with water for four months during the monsoon season. Palla Yamuna Floodplain area has exceptionally high levels of ground water percolation. It is crucial to make sure that floodplains are conserved as a water sanctuary and that all attempts are made to stop the illegal dumping of waste and sewage as well as the practise of farming there. (Roshankar 2020)

The summary of the conclusions are as follows:

- Ground Water Movement is from River towards the City side.
- Ground Water Level improvement in pond area compared to non-pond area. The ground water levels in pond area from 100m to 2000 m from pond area are higher compared to ground water levels in non-pond area.
- Ground Water Recharge estimated as compared to ground water withdrawal is estimated in section.

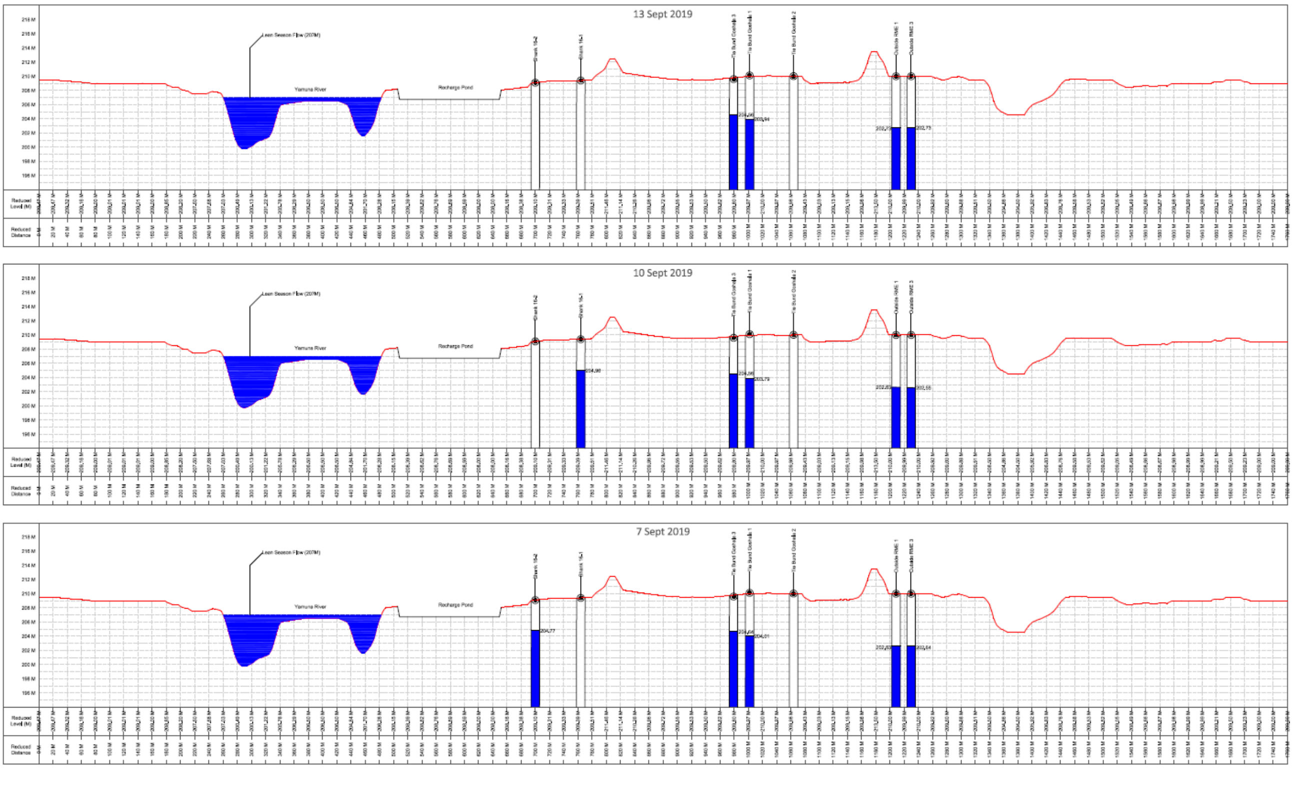
vii. Estimated Withdrawal and Recharge in Project Area

After the execution of the pilot project, it is possible to estimate the withdrawal and corresponding recharge comparison in the pilot project area and thereafter infer if the project is net positive in water recharge.

As per Data Collected, 102 Tube wells (0.2 MGD discharge per tube well) and 10 Ranney wells (2 MGD) of Delhi Jal Board wells are existing in the project are from Palla to Wazirabad. Total 40 MGD as per data shared by DJB. (board, 2023)

The pilot project area is 25 times smaller than total project area. Estimated withdrawal in study area is 90/25 MCM = 3.6 MCM. The Average Annual recharge due to the pond recharge per year as per the estimation done is, in the year 2020 and 2021 is 3.75 MCM which is more than the withdrawal done from the pilot project area. Therefore, the pilot project is net positive in water recharge.

(Board D. j., 2022)



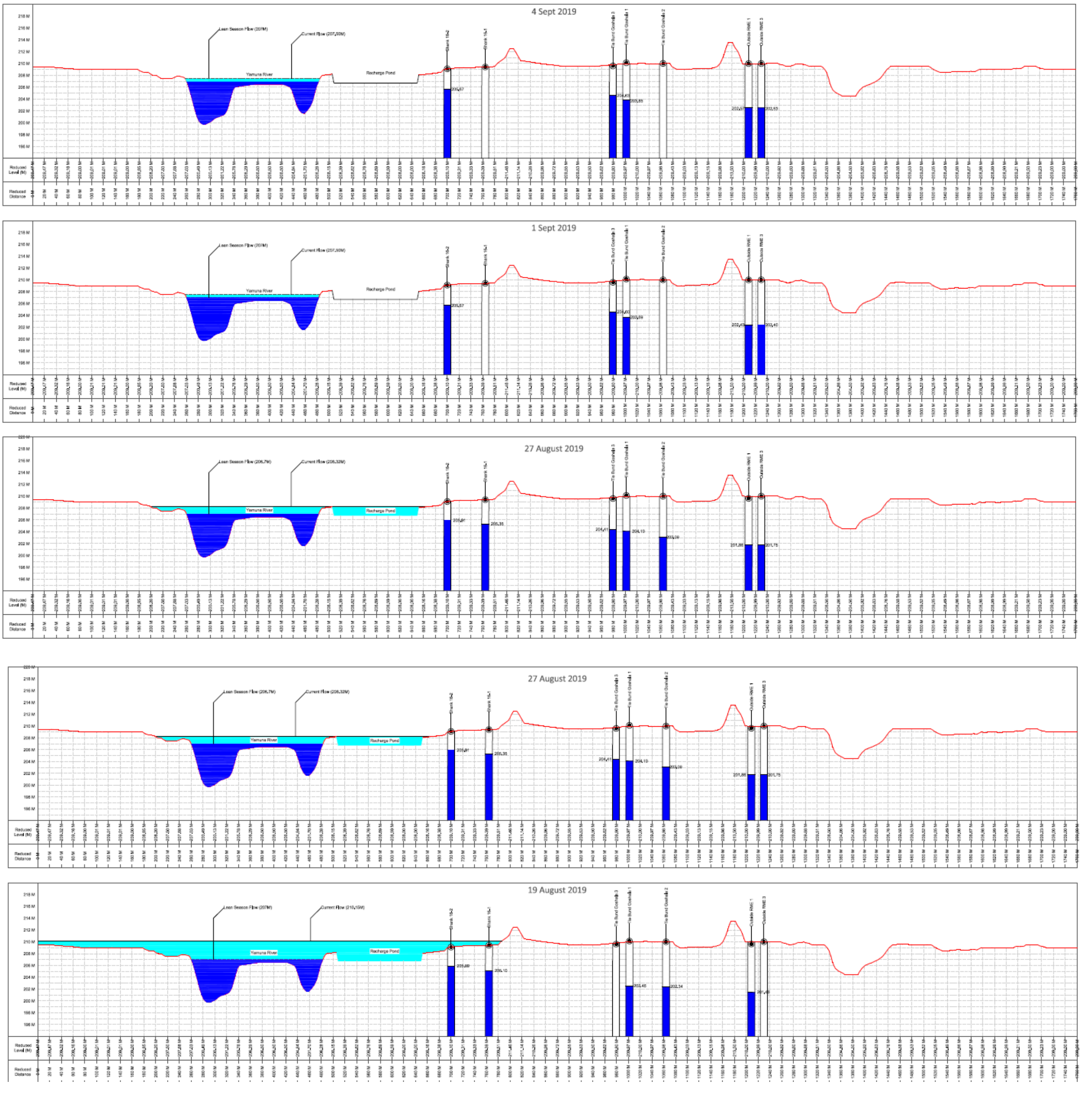


Figure 20: Sectional View of Palla Basin with Piezometers

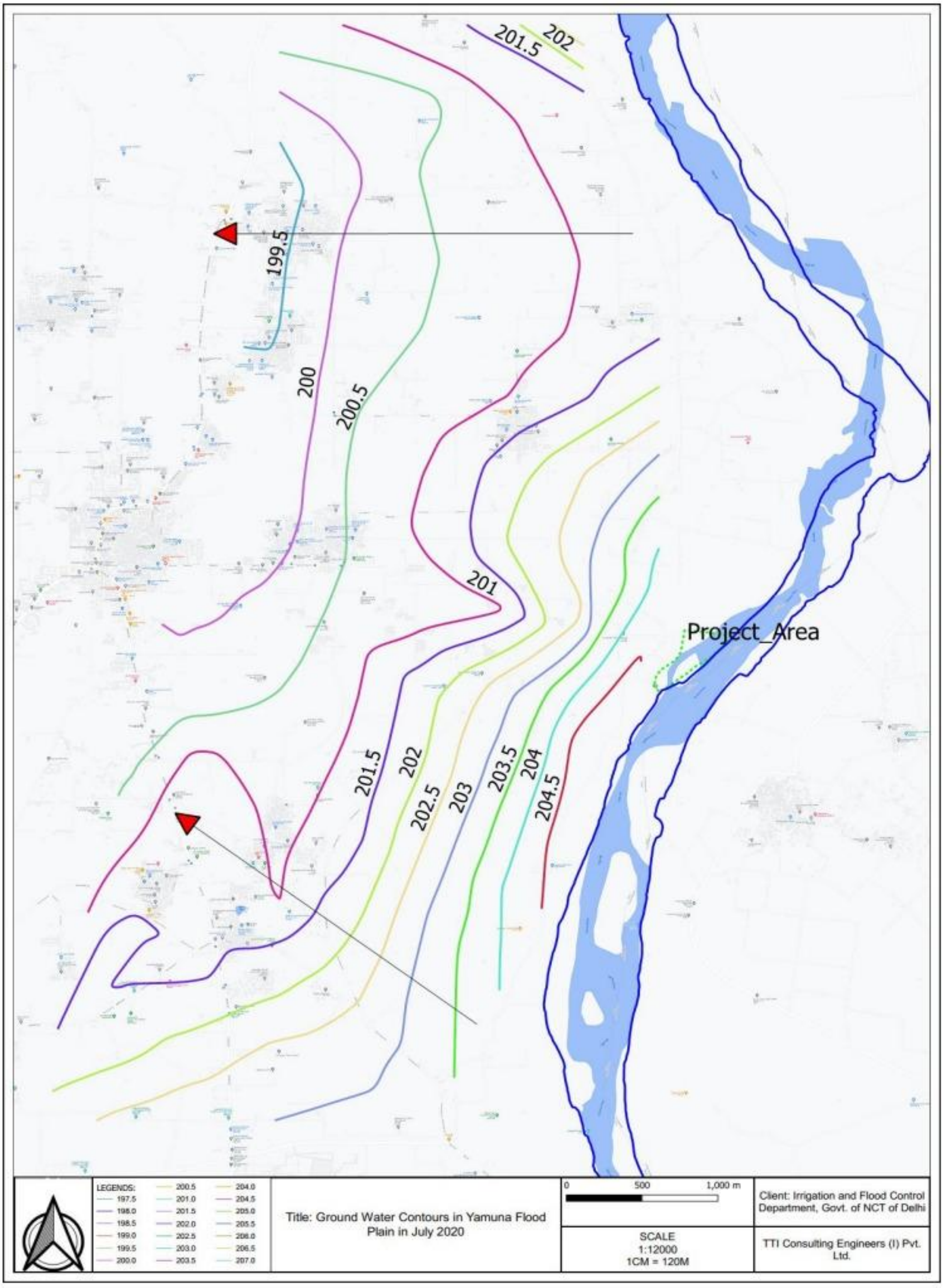


Figure 21: Groundwater Contours for July 2020

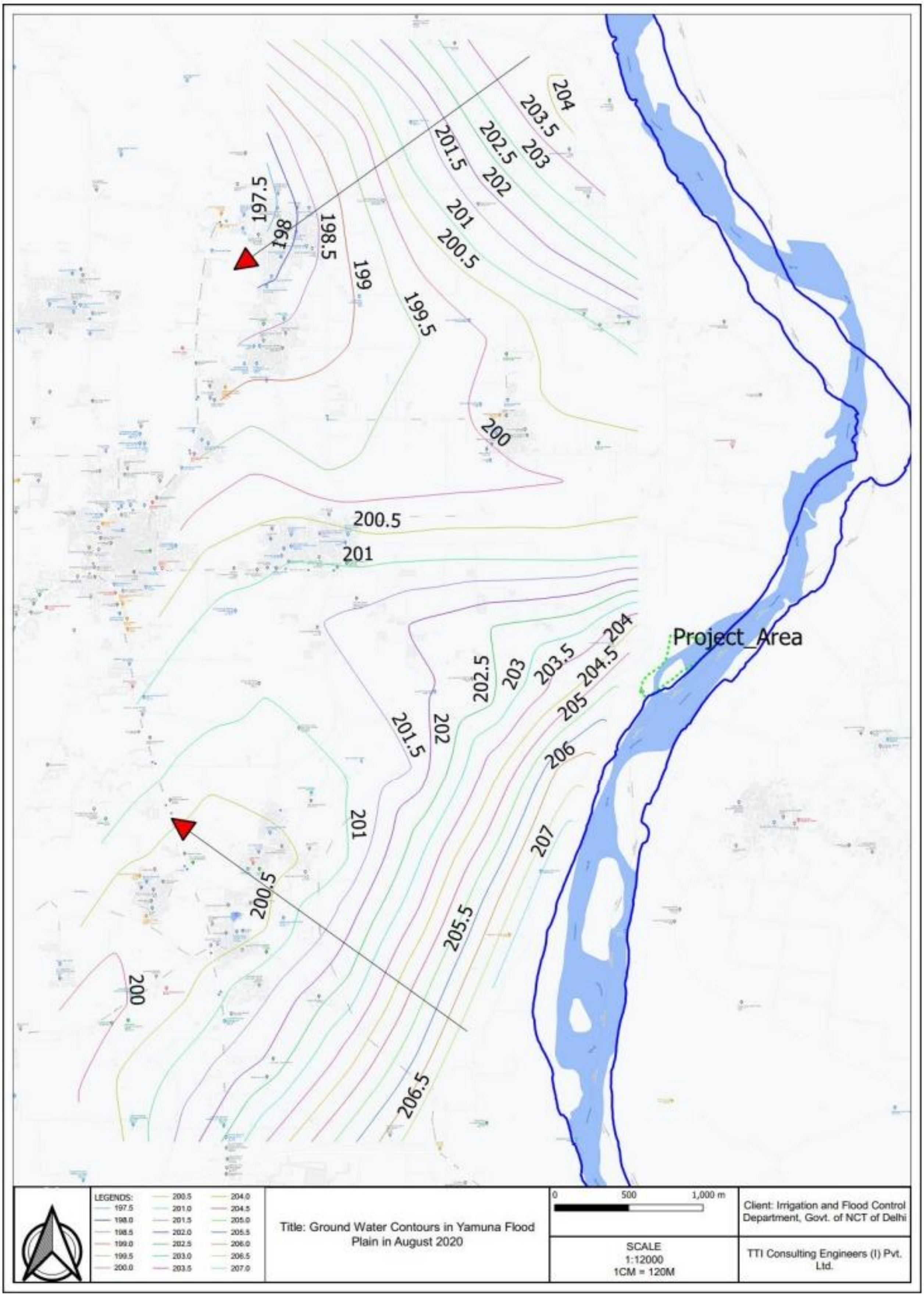


Figure 22: Groundwater Contours for August 2020

2.3 Discussion

Rooftop rainwater collecting was determined not to be a practical solution after examining the aquifer management practises used in Delhi. Researchers compare Delhi's annual water consumption to the amount of water Rooftop RWH collects from specific home roof catchments in Delhi to determine the potential of Rooftop RWH. According to the CGWB's assessment on Delhi's aquifer mapping and groundwater management, 13MCM of water, or roughly 4 days' worth of the city's water consumption, is being recharged. However, by capturing surface runoff, the city will benefit from a much larger aquifer. Only PWD is responsible for the roughly 15000 km of roads in Delhi. MCD roads are a supplement. Surface runoff from these must be captured in order to increase water recharge by at least five times. Therefore, it was agreed that the project would primarily focus on surface rainwater gathering.

……………………………… **END OF CHAPTER 2** ………………………………..

CHAPTER 3: STUDY AREA: CHANDIGARH

3.1 INTRODUCTION

The first planned city in independent India was Chandigarh. The city was intended to serve as a representation of the goals of the young republic. It was largely built to address the state of Punjab's demand for a new capital after independence. The city of Chandigarh is expanding quickly. The provisional census from 2011 indicates that there are 10.54 lakh people living there. The Chandigarh administration predicted that by 2021, there will be 19.5 lakh people living in Chandigarh. This will almost be four times what the city was intended for. In this case, the city requires a reliable water supply. The city receives water from the Bhakra Main Canal (27.5 kilometres away from Chandigarh), as there is no in-situ supply, and the water augmentation procedure is delayed because of events outside Chandigarh Administration's control. To close the water supply-demand mismatch, deep restricted aquifers' groundwater is used. Due to the lack of a methodical recharging option, some aquifers are already in decline. The aquifers must be recharged if the city is to have a long-lasting source of water. Groundwater information pamphlet for Chandigarh. (board, 2023) (Board C. G., 2011) (Biome Trust)

The initial estimate of 500,000 residents for the future city was dismissed as being overly ambitious because nobody wanted to live in a barren area constructed on uninhabited ground. However, the population of the city has already surpassed 11,000, bringing the total number of residents in the Chandigarh metropolitan area to 18, 000 by 2015. Unprecedented population growth in a city with a tight layout has led to issues with housing, slums, street vending, squatters, public utilities, infrastructure, traffic, etc. The city has lately extended its boundaries to Zirakpur, Dera Bassi, New Chandigarh, and Baddi in an effort to ease strain on its immediate perimeter satellite cities of Mohali and Panchkula. (K.A., 2008)

Chandigarh has the distinct advantage of having a network of storm water drains that is well-planned and maintained. More than 70% of the city's total rainfall falls on the network. In order to increase the city's water supplies, it will be effective to use the storm-water drains for deep aquifer recharge.

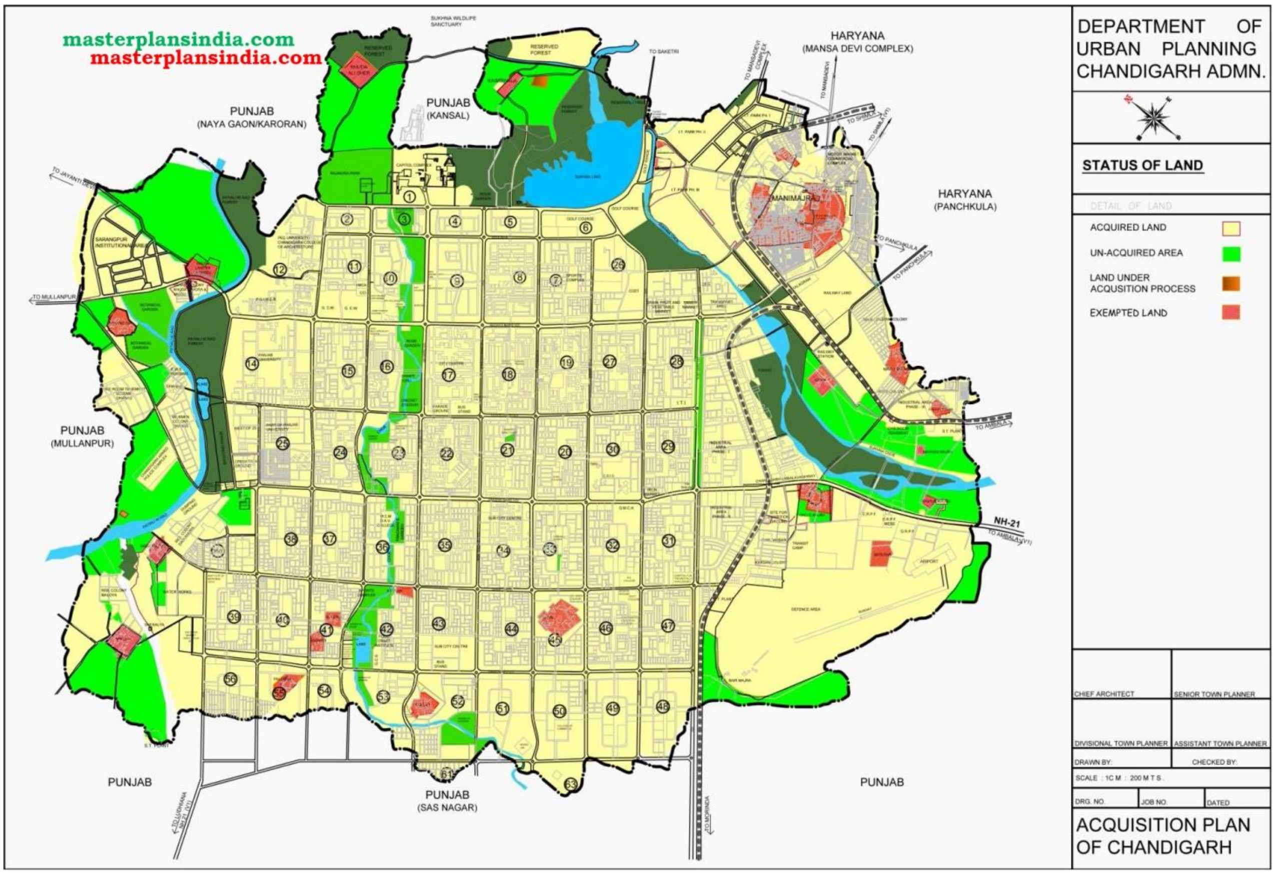


Figure 23: Base Map of Chandigarh as per Masterplan 2021 released by Chandigarh Administration

3.2 TOPOGRAPHY

The climate in Chandigarh is monsoonal and continental. Its climate features a brisk winter, a lovely rainy season, and a somewhat hot summer. In northwest India, Chandigarh is situated close to the Shiwalik range of the Himalayas. It spanned a region of around 140 km2.Its borders are shared by Punjab and the states of Haryana. Chandigarh's precise coordinates on a map are 30.74°N 76.79°E. Its typical elevation is 321 metres (1053 feet). A fertile and level area is present in the city located in the northern plains. There are Bhabar-like regions in the northeast and Terai-like regions elsewhere. Mohali, Patiala, Zirakpur, and Roopnagar in Punjab, and Punchkula and Ambala in Haryana, are the nearby cities. (Board C. G., 2011)

3.3 CLIMATIC CONDITIONS

Chandigarh has a subtropical monsoon and a chilly, dry winter, which places it in Koeppen's CWG category. There were four seasons in the region: Mid-March to Mid-June is considered the summer or hot season. Late-June to Mid-September is considered the rainy season. Mid-September to Mid-November is considered the post-monsoon autumn/transition season. Mid-November to Mid-March is considered the winter. Summer's dry spell lasts for a long time, but there are sporadic downpours

or thunderstorms. The hottest months of the year were May and June, with mean daily maximum and lowest temperatures of roughly 37°C and 25°C, respectively. Up to 44°C in maximum temperatures is possible. LiDAR sensor data collection is not affected by solar inclination, nighttime conditions, or slightly inclement weather; however, other integrated sensors, such as photogrammetric sensors, need clear skies and an appropriate sun angle to prevent shadow effects. For the mobile LiDAR data collection to produce high-quality images, a clear climate was necessary. (Board C. G., Groundwater information booklet for Chandigarh, 2011)
(Refer Figure 3.2)

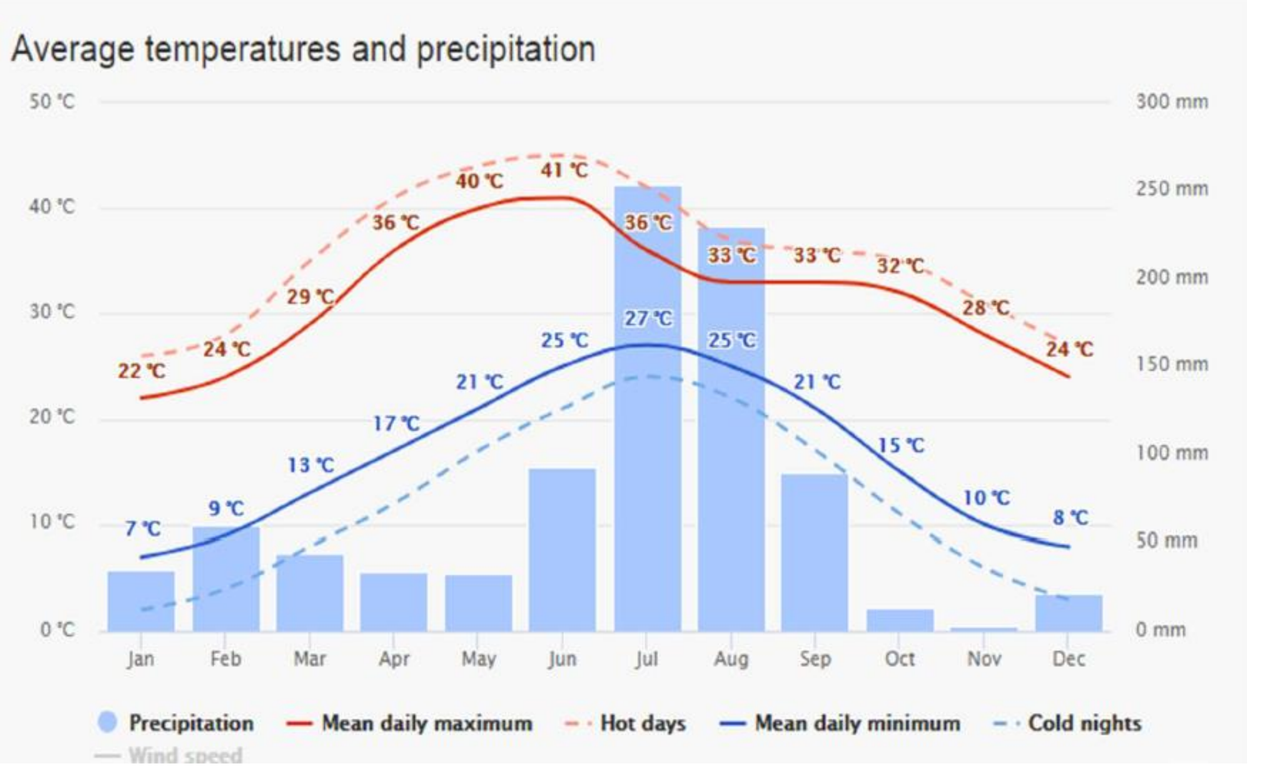


Figure 24: Temperature and precipitation for Chandigarh

3.4 RAINFALL

In late June, the southwest monsoon season with its intense showers starts. It was a steamy and warm time of year. The annual rainfall varies significantly from year to year, ranging from 700 mm to 1200 mm. Chandigarh saw 1100.7 mm of rainfall on average over the past 20 years. With mean maximum and lowest temperatures of about 23 and 36°C, respectively, January was the coldest month. Rainy days made it difficult to collect data using mobile or aerial LiDAR. For climate data, see Figure 3.3.

Climate data for Chandigarh													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	27.7 (81.9)	32.8 (91)	37.8 (100)	42.7 (108.9)	44.6 (112.3)	45.3 (113.5)	42.0 (107.6)	39.0 (102.2)	37.5 (99.5)	37.0 (98.6)	34.0 (93.2)	28.5 (83.3)	45.6 (114.1)
Average high °C (°F)	20.4 (68.7)	23.1 (73.6)	28.4 (83.1)	34.5 (94.1)	38.3 (100.9)	38.6 (101.5)	34.0 (93.2)	32.7 (90.9)	33.1 (91.6)	31.8 (89.2)	27.3 (81.1)	22.1 (71.8)	30.4 (86.7)
Average low °C (°F)	6.1 (43)	8.3 (46.9)	13.4 (56.1)	18.9 (66)	23.1 (73.6)	25.4 (77.7)	23.9 (75)	23.3 (73.9)	21.8 (71.2)	17.0 (62.6)	10.5 (50.9)	6.7 (44.1)	16.5 (61.7)
Record low °C (°F)	0.0 (32)	0.0 (32)	4.2 (39.6)	7.8 (46)	13.4 (56.1)	14.8 (58.6)	14.2 (57.6)	17.2 (63)	14.3 (57.7)	9.4 (48.9)	3.7 (38.7)	0.0 (32)	0.0 (32)
Average rainfall mm (inches)	33.1 (1.303)	38.9 (1.531)	30.4 (1.197)	8.5 (0.335)	28.4 (1.118)	145.2 (5.717)	280.4 (11.039)	307.5 (12.106)	133.0 (5.236)	21.9 (0.862)	9.4 (0.37)	21.9 (0.862)	1,059.3 (41.705)
Average rainy days	2.6	2.8	2.6	1.1	2.1	6.3	12.3	11.4	5.0	1.4	0.8	1.4	49.8
Source: India Meteorological Department (record high and low up to 2010)													

Figure 25: Rainfall data for Chandigarh

3.5 ROAD NETWORK

In late June, the southwest monsoon season with its intense showers starts. It was a steamy and warm time of year. The annual rainfall varies significantly from year to year, ranging from 700 mm to 1200 mm. Chandigarh saw 1100.7 mm of rainfall on average over the past 20 years. With mean maximum and lowest temperatures of about 23 and 36°C, respectively, January was the coldest month. Rainy days made it difficult to collect data using mobile or aerial LiDAR. For climate data, see Figure 3.3.

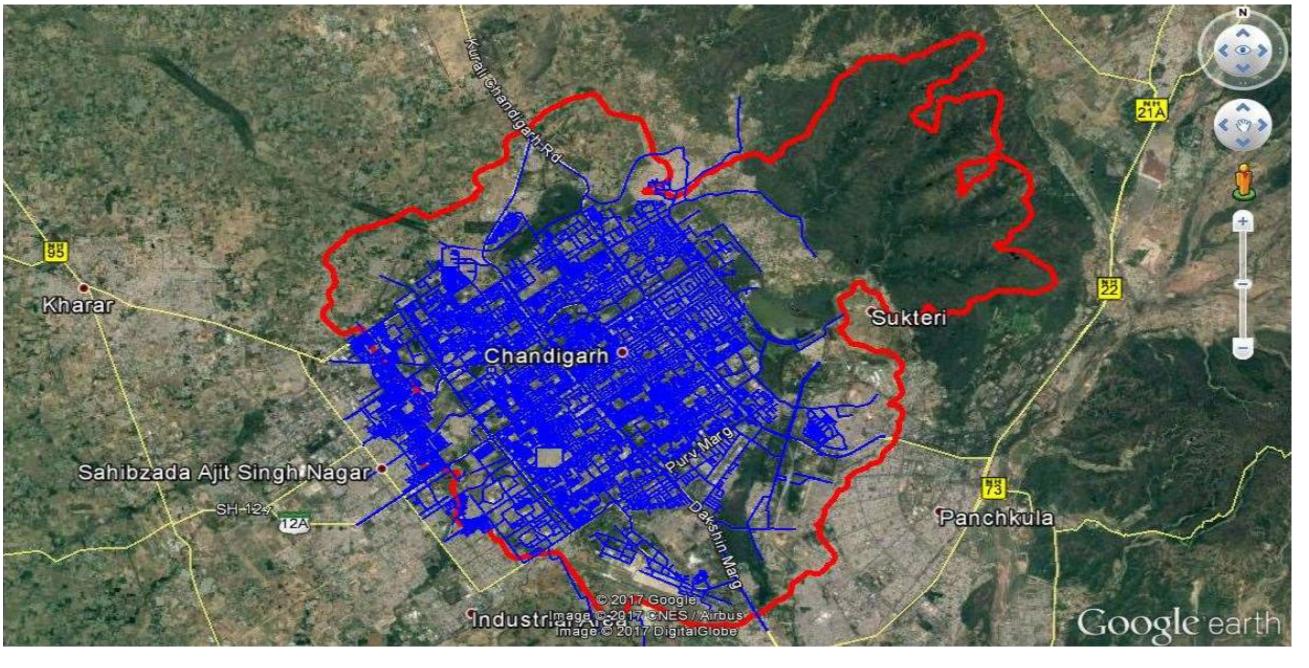
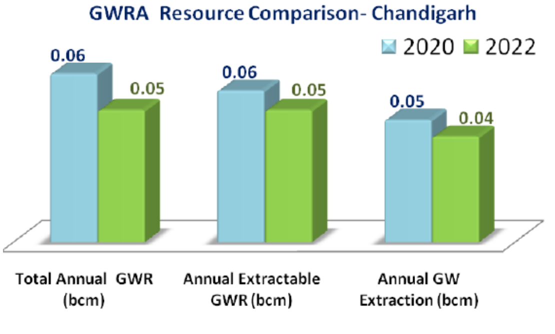


Figure 26: Road network of Chandigarh

3.6 GEOPHYSICAL LAYERS

Layers of fine sand and clay make up the foundation of Chandigarh, which is underlain by Quaternary alluvial deposits. While considerably finer sediments underlay the region between these two streams, coarser sediments are found between the Sukhna Choe and Patialiki Rao. Most of Chandigarh has fair to good aquifer horizons, which are composed of medium to coarse sand up to a depth of 180 m bgl before becoming finer. In this region, both confined and semi-confined conditions exist for ground water. Ground water is present in Manimajra in an unrestricted state down to a depth of roughly 80 metres. Below 20 to 30 metres, semi-confined situations are prevalent in other locations. The studied depth of the deeper aquifer system spans from 40 to 450 m bgl, whereas the depth of the shallow aquifer system is less than 30 m bgl. The deeper aquifer system's transmissivity values range from 74 to 590 m2/day. Between 70 and 466 m2/day of transmissivity can be found in shallow aquifers up to a depth of 100 m. Fresh groundwater that is good for irrigation and drinking has been discovered. (Board C. G., 2022)

The entire UT of Chandigarh was used as an assessment unit despite having a very tiny area. The annual extractable ground water resources are estimated to be 0.046 bcm and the total annual ground water recharge to be 0.05 bcm. The stage of ground water extraction in Chandigarh's UT, which has been designated as "Semi Critical," is 80.99%. Total yearly recharge has dropped from 0.063 bcm to 0.05 bcm in compared to the 2020 assessment. Additionally, the present extraction of groundwater dropped from 0.046 bcm to 0.037 bcm. Chandigarh's groundwater extraction is entirely regulated by the government, and only the government draws groundwater for the city's water supply.



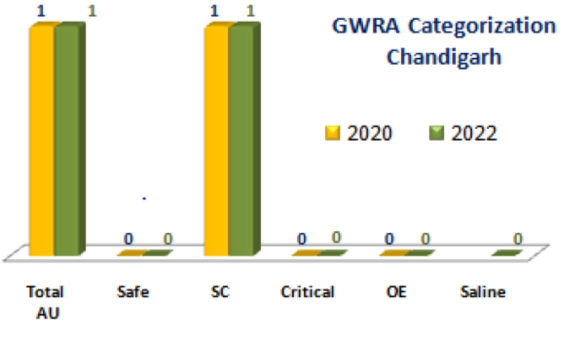


Figure 27: Groundwater extraction comparison

A national compilation on Dynamic ground water resources by Central ground water board released in 2022 describes state wise extraction and recharge potential. The graph below tells that Chandigarh has 70% extraction for domestic purposes.

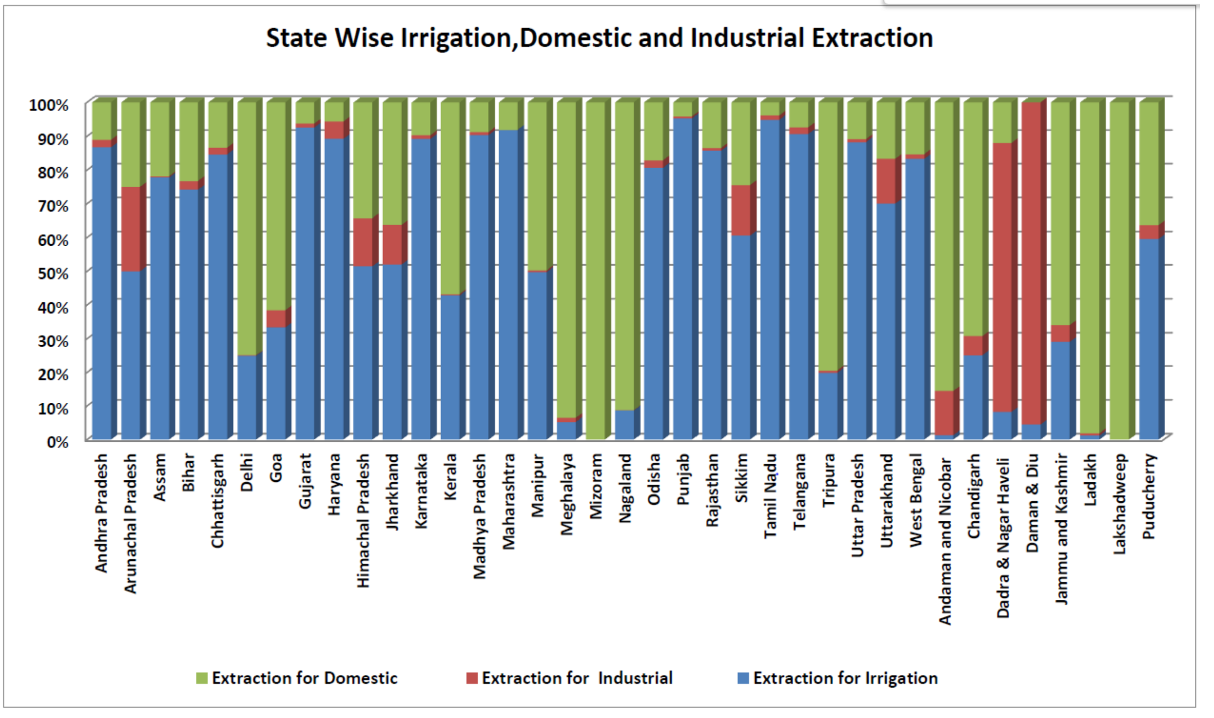


Fig-6.4: State wise Irrigation Draft *Vs* Domestic & Industrial

Figure 28: Source: CGWB report, 2022

The report also extensively mentions ground water recharge potential, the critical, semi-critical and over-exploited assessment zones in the City.

DYNAMIC GROUND WATER RESOURCES OF INDIA, 2022															
CHANDIGARH															
S. No.	Name of District	Ground Water Recharge					Total Natural Discharges	Annual Extractable Ground Water Resource	Current Annual Ground Water Extraction				Annual GW Allocation for Domestic Use as on 2025	Net Ground Water Availability for future use	Stage of Ground Water Extraction (%)
		Monsoon Season		Non-monsoon Season		Total Annual Ground Water Recharge									
		Recharge from rainfall	Recharge from other sources	Recharge from rainfall	Recharge from other sources				Irrigation	Industrial	Domestic	Total			
1	2	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
1	Chandigarh	772.06	1424.78	313.00	2695.13	5204.97	520.50	4684.47	950.70	217.35	2625.71	3793.76	2625.72	890.72	80.99
	Total(Ham)	772.06	1424.78	313.00	2695.13	5204.97	520.50	4684.47	950.70	217.35	2625.71	3793.76	2625.72	890.72	80.99
	Total (Bcm)	0.01	0.01	0.00	0.03	0.05	0.01	0.05	0.01	0.00	0.03	0.04	0.03	0.01	80.99

DYNAMIC GROUND WATER RESOURCES OF INDIA, 2022												
CHANDIGARH												
S.No	Name of District	Total No. of Assessed Units	Safe		Semi-Critical		Critical		Over-Exploited		Saline	
			No.	%	No.	%	No.	%	No.	%	No.	%
1	Chandigarh	1			1	100.00						
	Total	1			1	100.00						

DYNAMIC GROUND WATER RESOURCES OF INDIA, 2022											
CHANDIGARH											
S.No	Name of District	Total Annual Extractable Resource of Assessed Units (in Mcm)	Safe		Semi-Critical		Critical		Over-Exploited	
			Annual Extractable Resource (in Mcm)	%	Annual Extractable Resource (in Mcm)	%	Annual Extractable Resource (in Mcm)	%	Annual Extractable Resource (in Mcm)	%
1	Chandigarh	46.84	-	-	46.84	100.00				
	Total	46.84	-	-	46.84	100.00				

Table 3: Water Assessment Zones in Chandigarh by CGWB, Source: CGWB report, 2022

3.6.1 Geomorphology and Soil Types

The Siwalik range, which forms Chandigarh's north-eastern boundary and is exposed in a small section on the north-eastern side, is one of the city's four physiographic units. Alluvial fans are formed when hill torrents deposit loose talus debris on the southwest slopes of the foothills. The piedmont Kandi formation, which runs along to the hill ranges, is formed when these alluvial fans come together. The cobble, pebble, and boulder deposits found in the piedmont are mixed with sand, silt, and clay. In the south and southwest, the Kandi formations converge with the Sirowal formations. In the south and southwest, the Sirowal combines with the main Alluvial plain. The layers of fine sand and clay in the alluvial deposits are Quaternary in age. The area between the Sukhna Choe and Patiali ki Rao is underlain by relatively finer sediments, which restrict the aquifer's lateral disposition. Coarser sediments are found along these two streams. Since the source formations are fine-grained, the typical Kandi formations of boulders, gravel, and coarse sand are not common in the region. Loamy sand makes up the surface soil in UT Chandigarh, and calcareous sandy loam makes up the underlying layers. At depths ranging from 20 to 30 metres, the hard clay crystallises into pan. The soil is sandy to sandy loam in the northern regions, while it is loamy to silt loam in the southern regions. Chandigarh's soils range in colour from light yellowish brown to pale brown. The majority of calcareous soils include kankar. Almost all soils lack sufficient amounts of phosphorus, nitrogen, and potash. (Board C. G., 2022)

3.6.2 Hydrogeology

In this geographical area, groundwater is present under the water table, mostly in limited and partially confined conditions. Based on the pumping test data conducted on the city's aquifers, sectors 10, 33, 38, and 47 exhibit well-confined aquifers, while sector 28 has leaky confined aquifers. The analysis of the water table's depth reveals that the flow of groundwater predominantly occurs in a north-south and south-south direction. The water table is situated at elevations ranging from 330 m amsl to 310 m amsl, with a 20 m variation between the northern and southwestern parts. This hydraulic gradient explains the movement of groundwater from the north to the southwest. In the western region, groundwater flows parallel to Sukhna Choe and in the direction of Patiala-ki-Rao. The movement of groundwater from the far north to the southwest indicates that the Siwaliks recharge area serves as a source of groundwater replenishment. Long-term statistical data on water level fluctuations in the shallow aquifer system demonstrates an upward trend in the southern sectors of the city, while the northern and central areas experience a decline in water levels. Although there is a localized rise of 0.04 m at Maloya and 2.92 m at sector 52, the general trend shows a decrease in water levels, ranging from -0.43 m at sector 37 to -7.19 m at sector 12.(Board C. G., 2022)

3.6.3 Ground Water Resources

The estimation of groundwater resources in Chandigarh, as of March 31, 2011, considered the following data:

- Chandigarh has a total geographic area of 114 square kilometers, with no areas unsuitable for groundwater recharge.
- The depth to the water table in shallow aquifers varied from 4.48 meters to 8.47 meters during the pre-monsoon period of 2006-2010, and from 4.53 meters to 8.07 meters during the post-monsoon period of the same years.
- For the zone where the water table fluctuates, the specific yield was assumed to be 12%, and the rainfall infiltration factor was taken as 20% according to established norms.
- Based on available information, there was no pumping or withdrawal of groundwater from shallow aquifers.
- A total of 239 tube wells were installed to supply drinking water to the rural and urban population. These tube wells access confined aquifers located below 90 meters from the ground surface, with well depths ranging from 200 to 300 meters (Board C. G., 2011)

Note: All maps related to Geophysical layers of Chandigarh have been attached as annexures (part 2).

……………………… **END OF CHAPTER 3** ……………………………….

CHAPTER 4: IDENTIFICATION OF POTENTIAL RWH SITES USING LIDAR DATA AND GIS MODELS

4.1 INTRODUCTION

Northwest India's Chandigarh is situated in the Shivalik range of the Himalaya. The city is situated at 30°45′N latitude and 76°47′E longitude in the world. Punjab's Rupnagar and Patiala districts, as well as Haryana's Ambala district, around the city. Kharar, Morinda, Kurali, Mohali (S. A. S. Nagar), Zirakpur, Panchkula, Derra Bassi, and a few smaller satellite towns are located in these districts. In addition to these populous places, a number of villages are located near to the city and the neighbouring satellite towns. The project area essentially encompassed the whole of Chandigarh. This area's aerial extent was about 140 sq. km. The region is divided into 63 gridded Sectors, 22 Villages, and a Manimajra. Aerial LiDAR and aerial pictures were used to capture the entire area, while mobile LiDAR and panoramic images were used to map the roughly 1500 km of highways that run through it. Out of the roughly 1500 km of roadways, 250 km were main roads that made up Chandigarh's primary grid layout. The remaining roads were either outside or within sector roads or village roads. 2019's Gottfried MandlburgerThe survey did not include the Defence area. The linear length of all roads, whether they were single lanes or multilanes, including slip roads, was treated as a single unit in kilometres. State lines from Punjab and Haryana surrounded the area. The city is well connected to other states and New Delhi by road, railroads, and air. The area primarily consists of residential areas, commercial areas, industrial areas, institutional areas, agricultural areas, forest areas, green belts, parks, gardens, and road network. (Jonathan D Paul, 2020) (Lemmens) (Wai Yeung Yan, 2018)

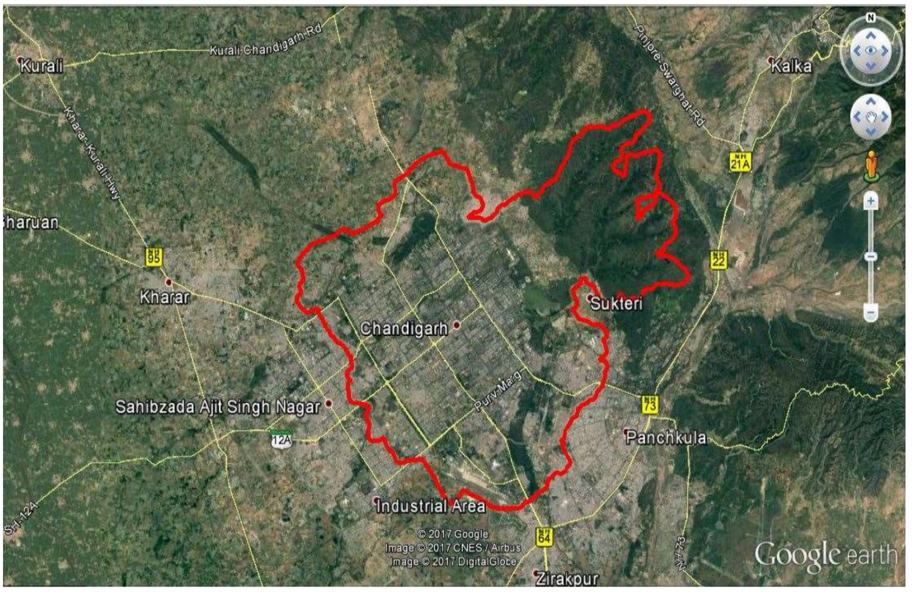


Figure 29: Chandigarh boundary demarcation

4.2 LiDAR DATA STUDY

This chapter explains the LiDAR components and product wise data sheet for the system used for LiDAR survey during the study.

4.2.1 AERIAL LIDAR SPECIFICATIONS

Parameters	RFP Specifications
Data Density	15 Points/m^2
Fundamental spatial Accuracy Requirements	Fundamental Vertical Accuracy (FVA) <= +/- 15 cm. 95% confidence interval Fundamental Horizontal Accuracy (FHA) <= +/- 20 cm. 95% confidence interval
Horizontal Datum	WGS-84
Vertical Datum	**Orthometric:** All Deliverables are in SOI Vertical Datum (MSL) **Ellipsoid:** All Deliverables are in terms of WGS-84
Map projection	Universal Traverse Mercator (UTM)
Geoid Model	EGM 2008

Table 4Aerial lidar specifications

4.2.2. AERIAL PHOTOGRAPH SPECIFICATIONS

S No	Parameters	RFP Specifications
1	GSD	5 cm
2	Band	RGB
3	End Overlap	60% Minimum
4	Side Overlap	30% Minimum
5	Photograph Format	Uncompressed Geotiff
6	Radiometric Resolution	Minimum 8 Bit
7	Horizontal Datum	WGS-84
8	Map Projection	Universal Traverse Mercator (UTM)
9	Vertical Datum	**Orthometric:**
		All Deliverables are in SOI Vertical Datum (MSL)
		Ellipsoid:
		All Deliverables are in terms of WGS-84
13	Geoid Model	EGM-2008
14	Equipment Specification	Camera with Minimum 60 MP resolution and RGB Channels

Table 5Aerial photograph specifications

4.2.3 MOBILE LIDAR SPECIFICATIONS

Parameters	RFP Specifications
Data density	50 Points/m^2
Accuracy Requirements	Relative Co-ordinate accuracy in horizontal and vertical < +/- 3 cm at 95% confidence interval. Absolute Co-ordinate accuracy in horizontal and vertical < +/- 4 cm at 95% confidence interval.
Horizontal Datum	WGS-84
Vertical Datum	**Orthometric:** All Deliverables are in SOI Vertical Datum (MSL) **Ellipsoid:** All Deliverables are in terms of WGS-84
Map Projection	Universal Traverse Mercator (UTM)
Geoid Model	EGM-2008
Equipment Specifications	**LiDAR Sensor specifications** 1. Two number of LiDAR Scanners with 1.1 PRF > 400 KHz 1.2 Scanning Frequency > 200 Hz 1.3 Range 100 m at reflectivity > 20% 1.4Field of view was 360 degrees of 2D scanner 1.5Noise of scanner < 8mm 2. Two LiDAR Scanners at oblique configuration was used for complete coverage **IMU specification** 1. Data rate > 350 kHz 2. Gyro Bias > 0.05 deg/hr 3. Roll Pitch Accuracy better than 0.003 deg 4. Heading Accuracy better than 0.007 deg 5. Velocity Accuracy better than 0.005 m/s 6. Acceleration bias better than 5mm/Sq. s **GNSS**: Dual Frequency GNSS receivers **Digital Panoramic Camera** with 6 cameras, each having a resolution of 5 MP. **DMI:** Optical Distance Unit (Odometer)

Table 6: Mobile lidar specifications

4.2.4 DATA DERIVATIVES

1. Classified Point Cloud Data with 1km x 1km Grid in. LAS Format
2. OrthoPhoto with 5 cm GSD in Geotiff/ECW Format
3. Topographic Map with 1:500 Scale in CAD and Shape file Format
4. Contour Map at 30 cm Interval in CAD and Shape File Format
5. Digital Surface Model (DSM) and Digital Elevation Model (DEM) at 0.5 m Grid.

4.2.5 COMPONENTS OF AERIAL LIDAR SYSTEM

Aerial LiDAR system consists of LiDAR equipment, GNSS unit for position, Inertial Measurement Unit (IMU) for orientation and cameras for recording images which were all mounted on an aircraft.

Figure 30: Aerial lidar components

4.2.6 AERIAL LIDAR SCANNER

The RIEGL LMS-Q780 is an advanced airborne laser scanner that offers the advantage of up to 10 simultaneous pulses in the air, resulting in optimal ground coverage. This eliminates the need for terrain following while maintaining a high pulse rate. By leveraging Digital Signal Processing and the RIEGL software suite, it delivers high-quality LiDAR data. The LEPTON equipment incorporates a state-of-the-art configuration using the RIEGL LMS-Q780 Airborne Laser Scanner, as shown in Figure 6. The innovative RIEGL LMS-Q780 long-range airborne laser scanner utilizes a powerful laser source, multiple-time-around (MTA) processing, echo digitization, and waveform analysis. This unique combination allows for operation at different flight altitudes and is well-suited for aerial surveys of complex terrains.(Jonathan D Paul, 2020) (K.A., 2008) (Lemmens)

Figure 31: Range measurement and scanner performance of RIEGL LMS Q-780

S No	PERFORMANCE	RIEGL LMS-Q780
1	Max Laser Pulse Repetition Rate (PRR)	400 kHz
2	Max Range Target Reflectivity 60%	5800 m
3	Max Range Target Reflectivity 20%	4100 m
4	Minimum Range	50 m
5	Accuracy	20 mm
6	Effective Measurement Rate	Up to 266000 meas./sec
7	Field of View (FOV)	Up to 60º
8	Max. Operating Flight Altitude (AGL)	4700 m / 15,000 ft.
9	Max Laser Pulse Repetition Rate (PRR)	401 kHz
10	Max Range Target Reflectivity 60%	5800 m

Table 7 Aerial LiDAR Scanner Performance

4.2.7 AERO CONTROL

The AERO control system, developed by IGI, is a precise GNSS/IMU solution used to determine the position and altitude of an airborne sensor. It comprises an Inertial Measurement Unit (IMU) based on Fiber-Optic Gyros (FOG) and a Sensor Management Unit (SMU) equipped with a high-end integrated GNSS receiver. When combined with AERO office software, this system offers an optimized workflow for Direct Georeferencing (DG) and Integrated Sensor Orientation (ISO). The accuracy of the positioning depends on the GNSS constellation and the distance from the GPS/GNSS Base/Monitor Station. In post-processing, it is possible to achieve a positioning accuracy better than 0.05m RMS and an altitude accuracy of 0.007º RMS for heading, as well as 0.003º RMS for roll and pitch.

Figure 32:Aero Control specifications

S No	PERFORMANCE	AERO Control-III
1	Position (m)	0.05
2	Velocity (m/s)	0.005
3	Roll/ Pitch (deg)	0.003
4	True Heading (deg)	0.007
5	Available Data Rates	400 Hz

Table 8: Aero Control performance table

4.2.8 GLOBAL POSITIONING SYSTEM (On-board GPS)

Utilising L1 and L2 frequencies is GPS-702-GG. Both antennas can receive GPS and GLONASS signals simultaneously. The same antenna can be used for GPS-only or GPS with a second constellation, increasing flexibility and lowering equipment costs. These two antennas' phase centres remain constant despite variations in the satellites' azimuth and elevation angles. Placement and installation of the antennas are simple because signal reception is unaffected by antenna rotation or satellite height. These antennas are perfect for baselines of any length since the phase centres for the L1 and L2 signals are in the same place and there is little difference in the phase centres between the antennas. (Holmes, 2017)

Figure 33:On-board GPS

Global positioning system datasheet is as follows:

PERFORMANCE

3 dB Pass Band	
L1	1588.5 ± 23.0 MHz (typical)
L2	1236 ± 18.3 MHz (typical)
Out-of-Band Rejection	
L1 ± 100 MHz	30 dBc (typical)
L2 ± 200 MHz	50 dBc (typical)
LNA Gain	29 dB (typical)
Gain Roll-Off (from Zenith to Horizon)	
L1	13 dB
L2	11 dB
Noise Figure	2.0 dB (typical)
VSWR	≤2.0 : 1
L1-L2 Differential Propagation Delay	5 ns (maximum)
Nominal Impedance	50 Ω
Altitude	9,000 m

PHYSICAL AND ELECTRICAL

Dimensions	185 mm diameter[1] × 69 mm
Weight	500 g
Power	
Input Voltage	+4.5 to +18.0 VDC
Power Consumption	35 mA (typical)
Connector	TNC female/N-Type[2]

ENVIRONMENTAL

Temperature	
Operating	-40°C to +85°C
Storage	-55°C to +85°C
Humidity	95% non-condensing
Vibration (operating)	
Random	MIL-STD-202F
Sinusoidal	SAEJ1211, Section 4.7
Shock	IEC 68-2-27 (Ea)
Bump	IEC 68-2-29 (Eb)
Salt Spray	MIL-STD-810F, 509.4
Waterproof	IEC 60529 IPX7
Compliance	FCC, CE
RoHS	EU Directive 2011/65/EU

For the most recent details of this product:
www.novatel.com/products/gnss-antennas/high-performance-gnss-antennas/

novatel.com

sales@novatel.com

1-800-NOVATEL (U.S. and Canada)
or 403-295-4900

China 0086-21-54452990-8011

Europe 44-1993-848-736

SE Asia and Australia 61-400-883-601

Figure 34: Global positioning system datasheet

4.2.9 CAMERA SYSTEM

The structural integrity and skilled engineering required for a real metric calibrated camera. The outstanding functionality, dependable performance, and pin-point accuracy of DIGICAM 100 are guaranteed. These cameras use mechanisms to safely lock its lens to the camera body and, when necessary, to lock lenses at infinity focus. For information on the camera system and camera system data sheet, see Figures 10 and 11.

Figure 35: Camera system for lidar

	iXU-R 1000 iXU 1000	iXU-R 180 iXU 180	iXU-R 160 iXU 160	iXU-R 160 Achromatic iXU 160 Achromatic	iXU 150
Resolution	**100 MP** 11608 x 8708	**80 MP** 10328 x 7760	**60.5 MP** 8984 x 6732	**60 MP** 8964 x 6716	**50 MP** 8280 x 6208
Dynamic range	>84 db	>72 db			>84 db
Aspect ratio	4:3				
Pixel size	4.6 micron	5.2 micron	6.0 micron		5.3 micron
CCD size effective	53.4 x 40.0 mm	53.7 x 40.4 mm	53.9 x 40.4 mm	53.8 x 40.3 mm	43.8 x 32.9 mm
Lens factor	1.0				1.3
Light sensitivity (ISO)	50-6400	35-800	50-800	200-3200	100-6400
Camera type	Medium format camera for aerial photography				
Lens mount	- Phase One R dedicated mount — for iXU-R cameras - Phase One SK dedicated mount — for iXU cameras				
Shutter speed	Leaf shutter: up to 1/1600 second*				
Shutter control	1/3 f-stop increments				
Interfaces	- USB 3.0 - Secured power input (LEMO) - Camera trigger - Mid-exposure pulse - Camera status - iX Link				
Live View/HDMI	iXU 1000 - 1920 x 1080 25p/30p - 1280 x 720 50p/60p				- 1920 x 1080 25p/30p - 1280 x 720 50p/60p
GPS/IMU support	Applanix, NovAtel, IGI, NMEA Devices				
Forward Motion Compensation	N/A	TDI controlled			N/A
Data storage	- 1 TB SSD storage (optional iX Controller) - CompactFlash card Type I/II including UDMA 6 and 7				
Syncronization speed in multiple camera configuration	100 microseconds with factory calibrated (FS) lenses				
Capture rate — full resolution frame	**IXU-R** 0.85 s **IXU** 0.95 s	**IXU-R** 1.25 sec **IXU** 1.6 sec	**IXU-R** 1.1 sec **IXU** 1.45 sec	**IXU-R** 1.1 sec **IXU** 1.45 sec	**IXU** 0.85 sec
RAW File compression	IIQ large: 100 MB IIQ small: 65 MB	IIQ large: 80 MB IIQ small: 54 MB	IIQ large: 60 MB IIQ small: 40 MB		IIQ large: 50 MB IIQ small: 33 MB

Table 9: Camera specifications for lidar

4.3 SURVEY DESIGN

4.3.1 Ground Control Network

Anywhere on Earth with an unhindered line of sight to four or more GPS satellites can receive location and time information from the Global Positioning System (GPS), a space-based satellite navigation system. GPS works in all types of weather. A modification to the GPS called the Differential Global Positioning System (DGPS) offers better location accuracy. For the development of the master control network and secondary control network, high accuracy dual frequency GPS receivers with dual frequency (carrier phase: L1&L2) capabilities were used.

A well-conditioned ground control network has been created, with no internal angle greater than 120 degrees or less than 30 degrees, to accommodate any triangular shapes. For the closure errors, the stations' coordinates were calculated using the DGPS Processing programme, and the network correction was done for the observed coordinates.

4.3.2 Survey Control Monumentation

The control points should be set up in such a way that they are evenly distributed throughout the project area in order to achieve the necessary horizontal and vertical precision. Before the project began, permanent DGNSS observation pillars were installed inside the project area. The positions of the pillars were chosen based on their visibility, constructability, stability, and safety. Additionally, the pillars were built so that subsequent surveys could be conducted using the same coordinate values as the pillars. (Wai Yeung Yan, 2018)

The main work for the monument was the excavation for the base's foundation. We dug up to 40 centimetres for this job, and the monument was ground-anchored for excellent stability. The pit was dug out until it reached the appropriate level. After the pit had been cleaned out, PCC had been laid, and shuttering had been kept on top of it. The concrete is then filled in after the formwork is complete. The built-in pillars underwent curing and were painted with weather-resistant paints. The position of the survey control stations was collaboratively inspected on site.

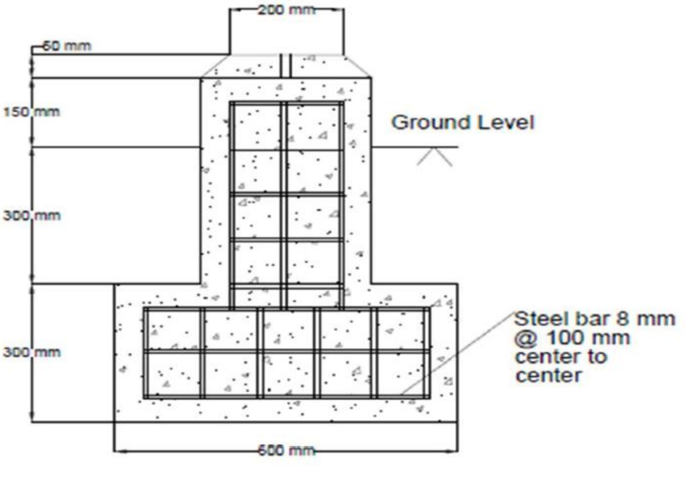


Figure 36: Dimensions of the Monument

Figure: 37: Survey Monumentation

4.3.3 Survey Control Network

GNSS Ground Control Survey operations consist of Establishing a Schedule of Operations, Pre-Survey, GNSS Data Collection, Data assessment and Initial Processing, and Computation.

Initially,7 Master Control Points has been established in the project area with proper monument. 3 hours of Static and Continuous DGPS observation has also been conducted over these Master Control Points.

Figure 38: Master Control Network

Master control network

Point ID	Latitude	Longitude	Remarks
MCP 1	30°43'57.96" N	76°46'46.49" E	Near to ISBT Chowk. Junction of Himalaya Marg and Udyog Path. Chowk location in between 22B, 21A, 17F, 18
MCP 2	30°45'7.38" N	76°43'47.13" E	It is located inside of Chandigarh Water Plant. Near to Grain Marcket at Sector 39.
MCP 3	30° 42' 19.1235" N	76° 44' 4.3832" E	It is located on a roundabout in between Jail road and Sarovar path at Sector 50. Near to Sargodha Residential Apartments.
MCP 4	30°41'57.25" N	76°48'10.67" E	It is located inside of Sampark Center building. Near to Hallomajra Chowk.
MCP 5	30°43'9.96" N	76°50'27.40" E	It is located on top of Govt. Sr. Secondary School at Mani Majra Rd, Subhash Nagar, Manimajra, Chandigarh.
MCP 6	30°45'30.37" N	76°49'21.06" E	It is located on top of Govt. Sr. Secondary School at Kaimbwala Village.
MCP 7	30°46'50.13" N	76°45'47.91" E	It is located on top of Govt. Sr. Secondary School at Khuda Lahore.

Table 10: Details of Established MCP's

In additional to Master Control Points, the Control Network densified by establishing Secondary Control points to collect subsequent check points. 23 such points were established in and around the project area and was tied with Master Control Network. The Master and Secondary Control network covered only 115 Sq.km (Approx.) of the project area, as the remaining 25 Sq.km

(Approx.) area covered by wild dense forest. All these secondary control network was marked on the permanent structure.

Figure 39: Secondary Control Network

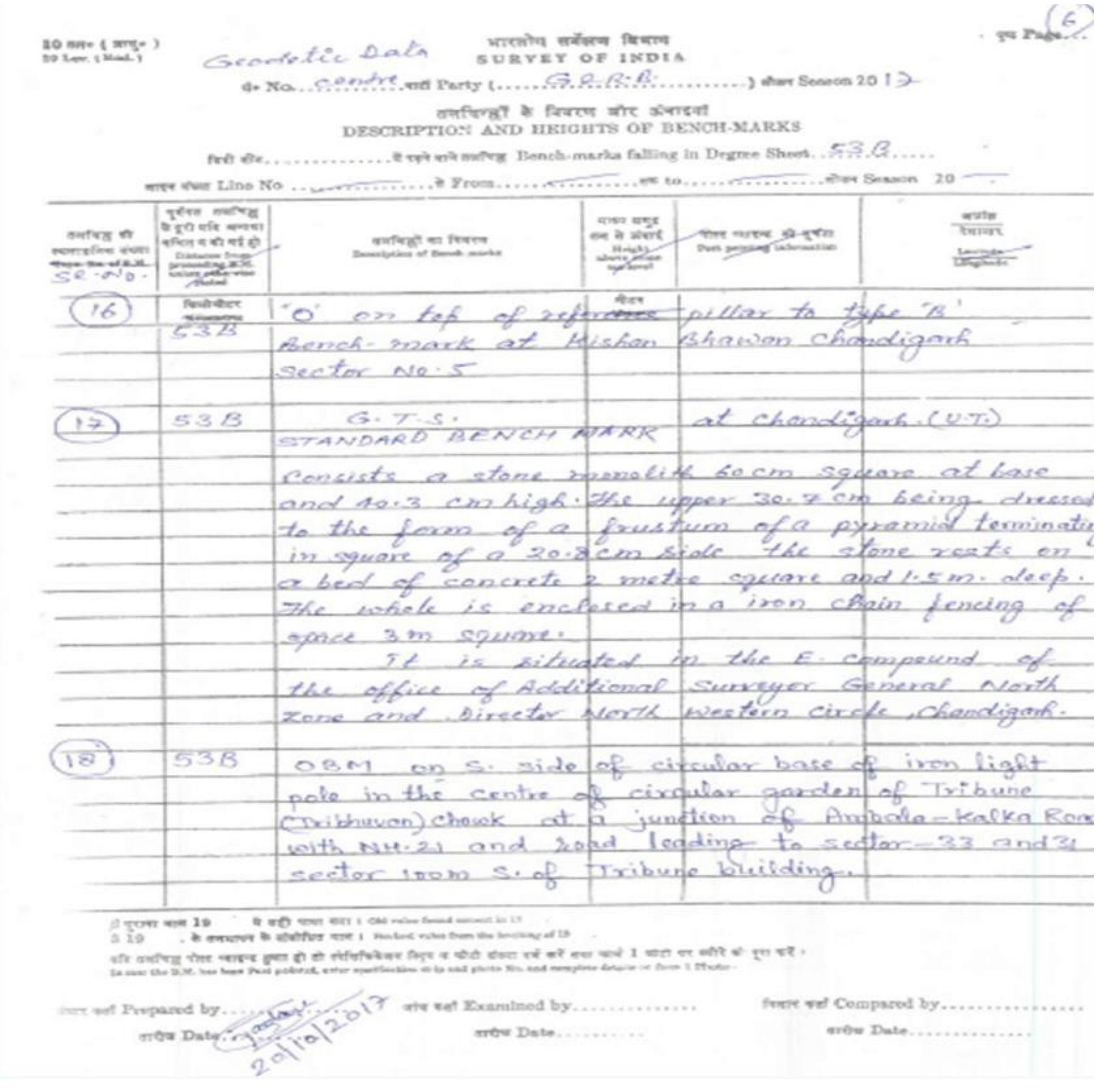
4.3.4 Local Height Transformation

The General Procedures for Local vertical adjustment is as follows:

1. Identifying all reliable SoI Levelling BMs surrounding / within the project area
2. The selected BMs must have the following coordinate information:

WGS-84 Geodetic Coordinates (i.e. Latitude, Longitude & Ellipsoidal Height). This was observed using GNSS.

3. Height above SoI Vertical Datum (i.e. MSL). This was obtained from SoI. UTM Grid Coordinates (i.e. Northing and Easting, Ortho Height) of the BMs computed using the WGS-84 Geodetic coordinates and EGM 2008 model.
4. A second order transformation model that accounts for the spatial distribution of BMs was developed between the local vertical datum (i.e. SoI MSL) heights and the Ortho Heights as computed above.
5. The height transformation model developed above for localized height transformation was used for LiDAR data height transformation from EGM 2008 derived Ortho Height to MSL. The figure shows the details of Benchmarks received from Geodetic and Research Data Supply Centre, Survey of India, Dehradun on 30th of October 2017.



Geodetic Data
SURVEY OF INDIA
No. Centre Party G.&.R.B. Season 2017
DESCRIPTION AND HEIGHTS OF BENCH-MARKS
Bench-marks falling in Degree Sheet 53 B
Line No ... From ... to ... Season 20

Sl. No.		Description of Bench-marks	Height		
(16)	53 B	'O' on top of reference pillar to type 'B' Bench-mark at Kishan Bhawan Chandigarh Sector No. 5			
(17)	53 B	G.T.S. STANDARD BENCH MARK at Chandigarh (U.T.) Consists a stone monolith 60 cm square at base and 40.3 cm high. The upper 30.7 cm being dressed to the form of a frustum of a pyramid terminating in square of a 20.8 cm side. The stone rests on a bed of concrete 2 metre square and 1.5 m. deep. The whole is enclosed in a iron chain fencing of space 3 m square. It is situated in the E. compound of the office of Additional Surveyor General North Zone and Director North Western circle, Chandigarh.			
(18)	53 B	OBM on S. side of circular base of iron light pole in the centre of circular garden of Tribune (Tribhuwan) Chowk at a junction of Ambala–Kalka Road with NH-21 and road leading to sector–33 and 31 sector from S. of Tribune building.			

Prepared by ... Date 20/10/2017 Examined by ... Date ... Compared by ... Date ...

Figure 40: SOI Benchmark Details

The Chandigarh area features 24 benchmarks, according to information provided by Survey of India. On the thorough site assessment, just 4 of the 24 such Benchmarks were stable and accessible on site.

Level transferring from Survey of India (SOI) Benchmarks to the project survey control point was done in order to adjust to the local vertical datum (Mean Sea Level). Additionally, the MSL value was transferred to chosen MCP/SCP at 5-kilometer intervals throughout the project area. With a loop closure of 12 mm and a double-tertiary levelling technique, the level transferring was carried out using an auto/digital levelling instrument, where "k" denotes the loop length in km of the closed loops.

Figure 41: Available SOI Benchmark's at Project Site

4.4 AERIAL LIDAR SURVEY

4.4.1 SMOD & DGCA Permission

The key task involved in Aerial LiDAR Survey was to obtain necessary permission from Ministry of Defense (MOD) and Director General of Civil Aviation (DGCA) for flying and acquiring Aerial LiDAR Data.

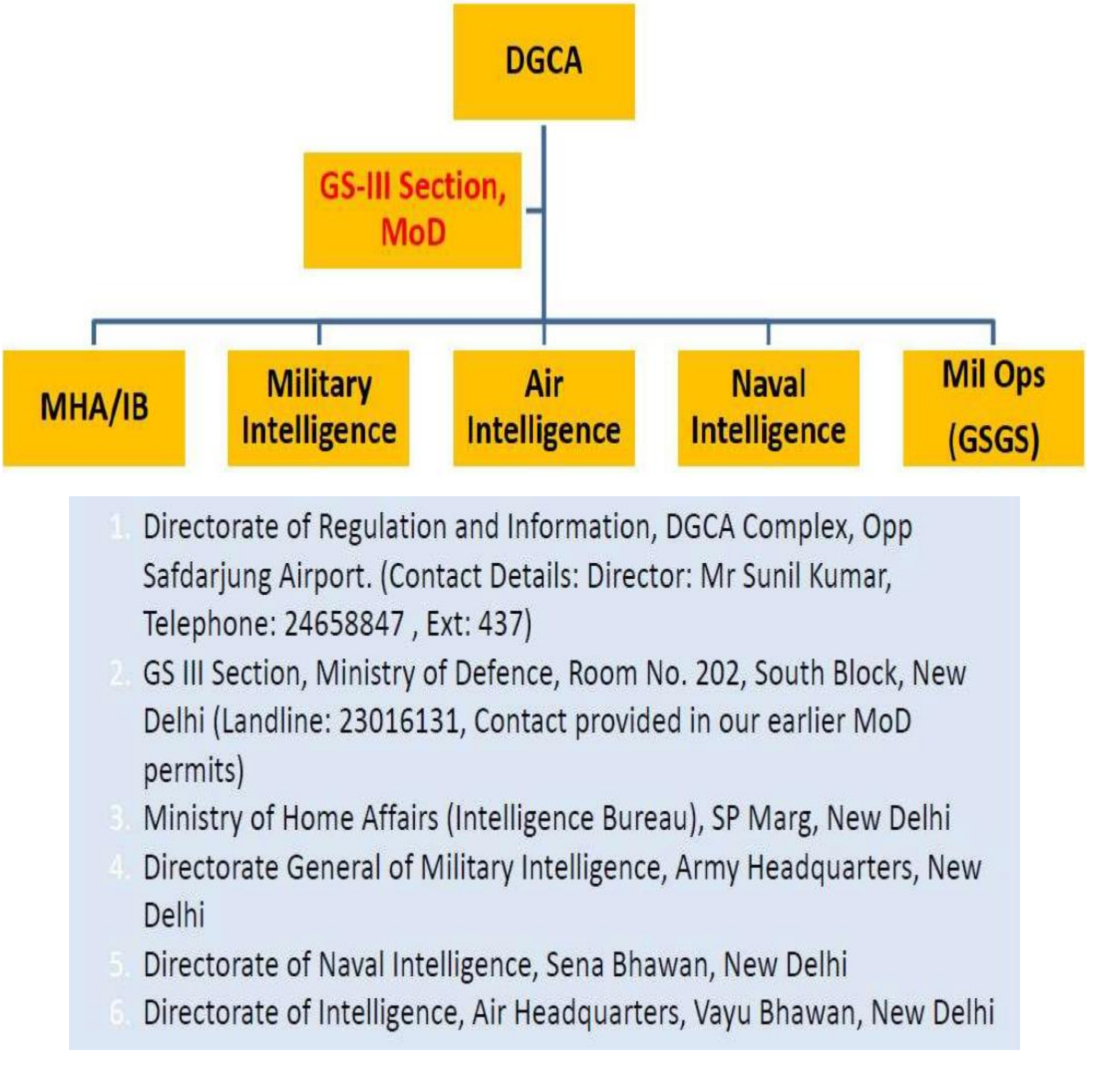


Figure 42: MoD Permission Nodal Agency

4.4.2 Aircraft Review and Operation Base

Fleet of aircraft, LiDAR sensor and cameras meet the most demanding requirements regarding accuracy, resolution and deliverables. . LEPTON had an agreement with Global Vectra Helicorp Limited(GVHL). The existing permissions were used to take this study further with respect to recharge potential study.

Figure 43: GVHL Aircraft

Geokno adopted a rotary wing platform over a fixed wing platform. This was based on the following:

1. The biggest advantage of rotary wing platform is the ability for takeoff and land vertically. This allows to operate with in a smaller vicinity without airport runway.

2. Due to their lower speeds and lower altitudes the resultant point density and photo image resolution were high.

3. The project area involved the controlled air space due to Chandigarh airport vicinity. Rotary wings allowed to attempt quick turn by covering the planned flight lines.

4.4.3 Flight Planning

Flight planning was considered a crucial aspect of Airborne LiDAR surveys to contribute to total Quality Assurance (QA) experience.

Flight plan optimization includes route, altitude, speed, and fuel optimization considered during the planning.

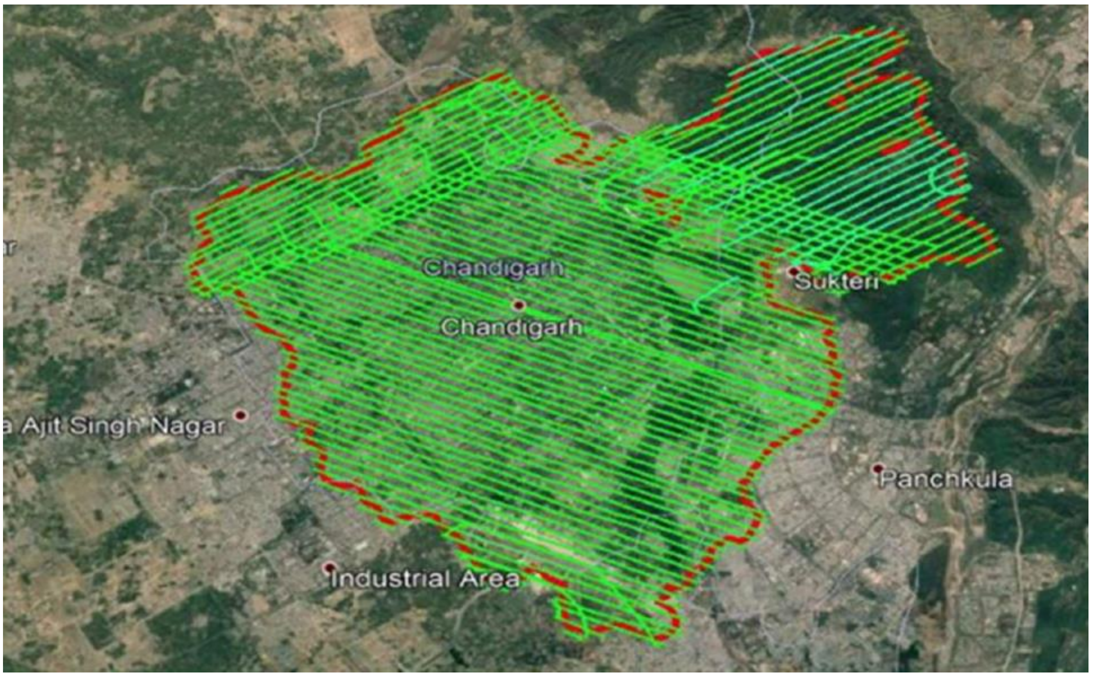


Figure 44: Flight plan for Chandigarh Project Area

IGI Plan was used for flight planning, and we performed a simulation exercise to determine the flight lines and other flying characteristics. This allowed us to obtain LiDAR and/or picture data that suited our requirements at the lowest possible cost.

The interactions between the LiDAR scanner, camera, aircraft, navigation sensors (GNSS and IMU), topographical characteristics, and other elements are examined during flight planning.

The generated flight plan was exported for use by the flying crew and sensor operator with CCNS5. The capturing procedure followed the planned flight routes. Every project's flight planning is organised based on an analysis of the DEM (Terrain Conditions) for the study area.

Table 12 below provides a quick summary of the project's flight planning criteria.

S No	Mission Parameters	
1	Above Ground Level (AGL)	400 Meter (1312 Feet)
2	Flying Hours	11 Hours
3	Times Per Turn	90 Seconds
4	Pulse Repetition Rate	400 KHz
5	Speed	70 knots
6	Foreword Overlap	80%
7	Side Overlap	60%
8	Point Density(Per Square Meter)	16 points/sq.m
9	Ground Sampling Distance (GSD)	4 cm

Table 11: Flight Planning Parameter

4.4.4 Aerial Data Capturing

In April 2018, the entire Chandigarh, U.T., was the subject of an aerial survey. The poll was carried out during survey-friendly daylight hours. The Chandigarh Project Area was covered in eight flying missions. The LiDAR flying team kept daily logs while collecting the survey data. These flight logs include details on the flying circumstances, sensor configuration, date, project, lines flown, start and stop timings for each line, and any other remarks and attributes that might be pertinent for that specific sortie.

The positional coordinates of the airborne sensor and the height of the aircraft have been continually recorded throughout the LiDAR data collection mission in order to precisely calculate the laser point position (coordinates x, y, and z). An onboard differential GNSS unit detected the position of the aircraft twice per second (2 Hz). An onboard inertial measurement unit (IMU) measured the pitch, roll, and yaw (heading) of the aircraft 400 times per second (400 Hz). Aerial flying took place between March 19 and March 24, 2013.The climatic conditions during the flying period are depicted in Figure 4.23 below.

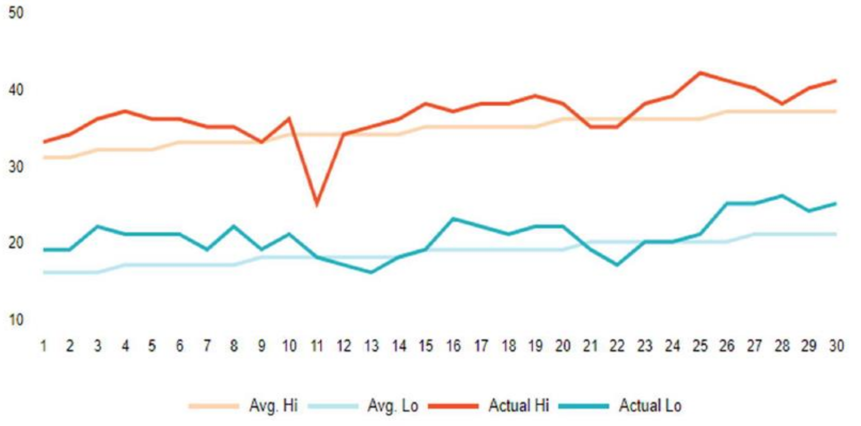


Figure 45: Temperature Statistics during Month of Flying

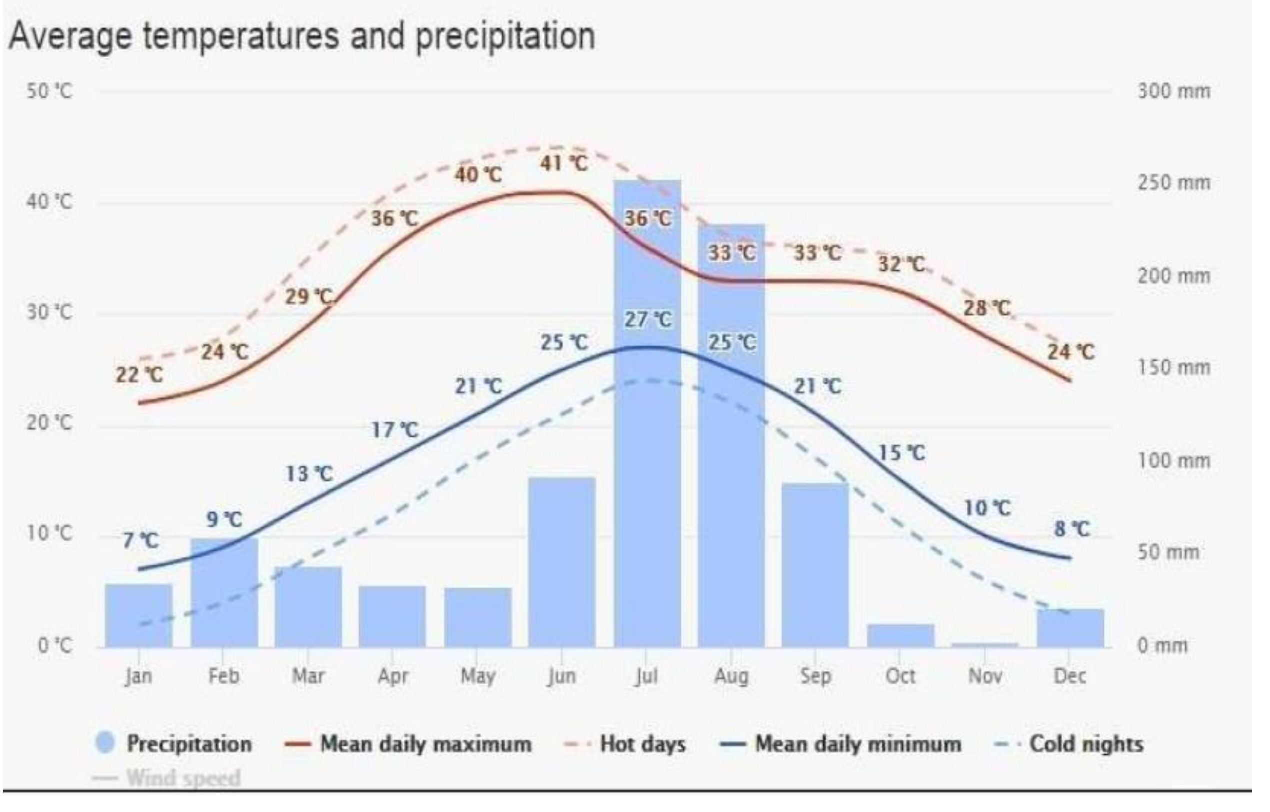


Figure 46: Average Temperature and Precipitation Graph for the Study Year

Data were given to the security personnel, who were in charge of daily data security, after flying activity. The external hard drive was used to store the collected data.

The hard discs were properly sealed and disguised by the in-charge security officer in order to ensure high security. The security officer and the aerial navigator duly signed the data submission form as acknowledgement of the aforementioned actions.

4.4.5 Aerial Data Pre-processing

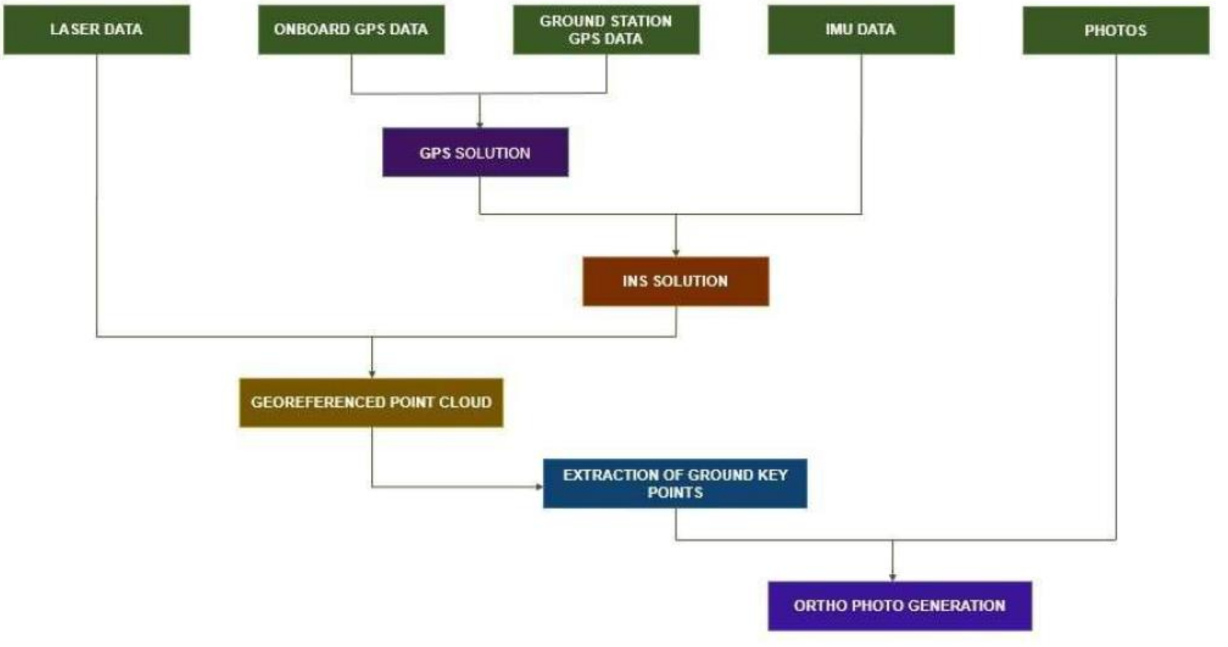


Figure 47: Aerial Data Pre-processing

4.4.6 Aerial Survey-ed Data Vetting

Security Vetting was an event in which the Aerial LiDAR Data Captured were vetted by the Survey of India along with the Ministry of Defence and other Nodal agencies from DGCA in the presence of the Security officer. The Security Vetting for Chandigarh Project was held at Survey of India, Western Printing Groups, Palam Village Road, Near Railway Crossing, Delhi Cantt.

4.5 DATA STORAGE

Aerial and Mobile LiDAR data was stored in the external Hard Drives. The external Hard Drives were used so that immense amount of data could be stored and data could be handled safely and swiftly.

1. Hard disks of R Series: Data obtaining from the field team were in raw format and thus the hard disks containing this data were mentioned with R series such as R1, R2 and so on.
2. Hard disks of P Series: Data after conversion from raw format to a usable format, the processed data obtained were stored in the hard disks mentioned P series such as P1, P2 and so on.
3. Hard disks of O Series: Ortho Photographs were processed separately and stored in separate series of Hard Drives. Ortho Photographs hard disks were mentioned with O series such as O1, O2 and so on.

4.6 AERIAL AND MOBILE LIDAR SURVEYED DATA QA/QC

LiDAR is a survey technique which does not require ground control points, but does require independent test points to verify the quality of the final data. Geokno collected sufficient number of test points as Test Point Site which are distributed across the project site. The process to coordinate the Test Points is summarized in below Figure 4.26.

1. Each Test Point Site have a Test Point Site Survey Mark (TPSSM) tied to the Project Datum.
2. Each TPSSM have an Ellipsoidal Height and an Orthometric Height (using EGM 2008) computed relative to the Project Datum.
3. At least 20 Test Points was coordinated relative to each TPSSM.

For Aerial LiDAR Test Point Sites was on clear flat ground to maximize their value as ground truth points.

At each site, additional test points were collected on various types of ground surfaces and vegetation covers, as per ASPRS conventions to allow an assessment of DTM accuracy under a variety of land use categories. (Jonathan D Paul, 2020)For Mobile LiDAR Test point sites was on features available throughout the project area. The features include Electric poles, paint markings, sign boards, roundabouts, culverts, Kilometer stones, Hectometer stones, OFC stones, Medians, Bridges, Guard pillars, water tanks, tunnel and pipelines. (Wai Yeung Yan, 2018) (W.G.M., 1998) (Lemmens) (Jonathan D Paul, 2020)

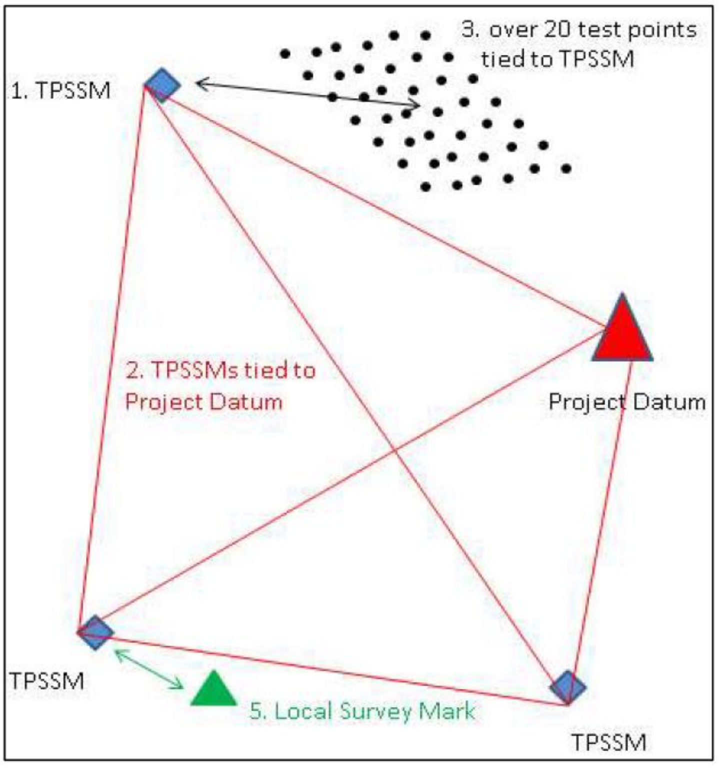


Figure 48: Test Points Processing

4.7 FUNDAMENTAL HORIZONTAL AND VERTICAL ACCURACY VALIDATION

Utilising test points gathered at test point site locations, the horizontal and vertical accuracy validation was performed. For this reason, 45 test point site sites were chosen at random throughout the study. At these site locations, a GNSS receiver was used to collect a total of 1683 test points. The Post-Processing Kinematic (PPK) observation mode was used to collect these test points with reference to the survey control stations. As these Test points are connected to the Survey control stations, the accuracy of these Test points was reached to within 1 cm.

For the purpose of accuracy validation, the test points were gathered at 45 test point locations, of which the best and most appropriate 30 test point locations were utilised.

4.7.1 AERIAL LIDAR DATA-FUNDAMENTAL ACCURACY VALIDATION

a) Vertical Accuracy Validation

The accuracy evaluation was completed in accordance with ASPRS Standards. Comparing the test points gathered at test sites yields the Fundamental Vertical Accuracy (FVA; see Figure 36).A test site was a level, open region with access to the LiDAR initial return. A total of 30 sites were found in the project area, which equates to at least one site for every 5 sq km of the project area. A total of 20 to 30 test points were gathered at each test site. Easting, Northing, and Height from the local

MSL datum were calculated for each test point. The DGPS survey of these sites makes this possible. The ellipsoidal height measured by DGPS of these test points was first converted to the orthometric height using EGM 2008, and then these orthometric heights were converted to the heights from local MLS datum using the local vertical datum transformation model (which was separately developed using the MCP).

Over each LiDAR point in the test site, a TIN model was built. By calculating the deviation of the TIN surface from corresponding test points, the difference in vertical height between the test point and the LiDAR data was calculated. To create statistics for determining FVA, vertical deviations were thus measured. Below are a few comparative' micro station views.

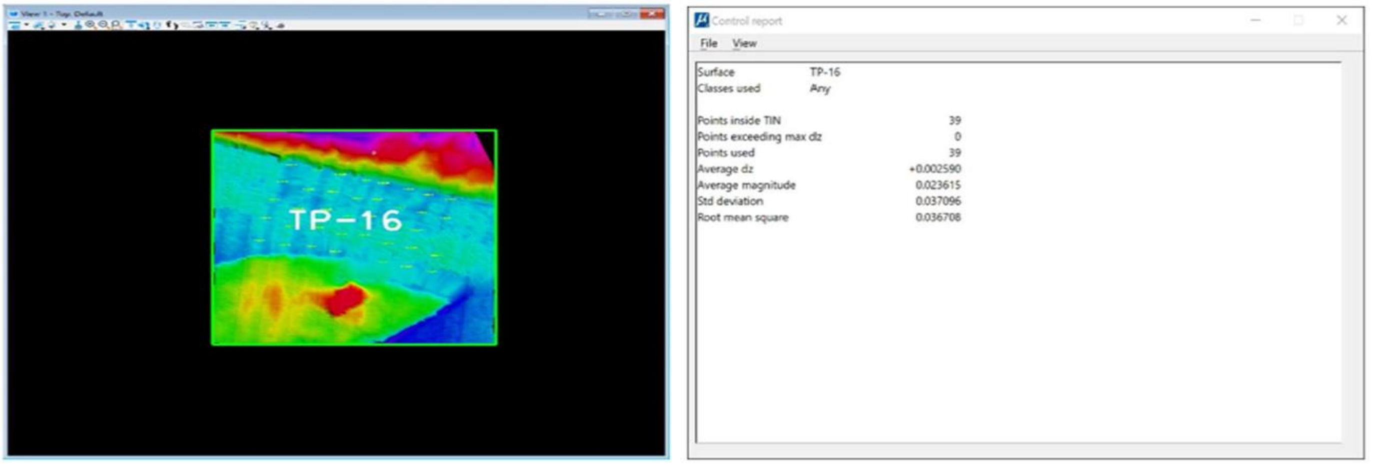


Figure 49: Micro station view of TIN Surface and Control Report of Test Point

b) Horizontal Accuracy Validation

The Fundamental Horizontal accuracy is determined by comparing the test points collected at test sites. In each test site a well-defined point, which could be easily and reliably identified or extracted in LiDAR data, was observed using DGPS survey. The Easting and Northing observed in the field were compared with the Easting and Northing observed by LiDAR data for such point. The micro station views of a few comparisons are shown below. The Green dots on the Figure 37 are the check points collected at the test site location using GNSS and Levelling. (Gottfried Mandlburger, 2019) (Brown) (W.G.M., 1998)

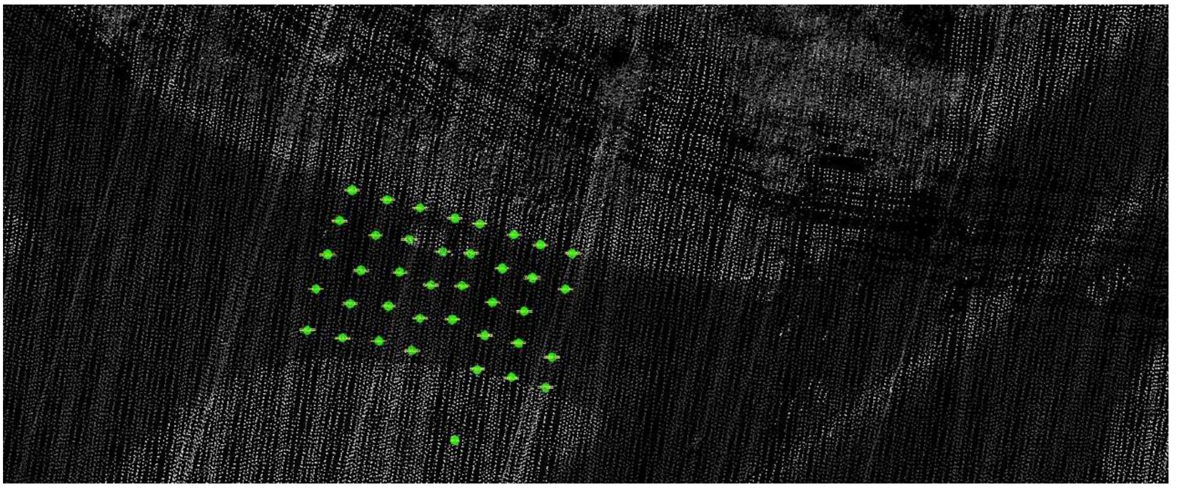


Figure 50: The Micro station view of Test Point Site Location 16

c) Spatial Distribution Validation

The spatial distribution validation of aerial data makes sure that the point cloud data is distributed uniformly across the project area. To see if the dataset has any gaps linked to the flight acquisition, the Project area was examined. The overlap between the runs was checked visually. There are no holes to be filled. There is overlap between every flown run and every other run. Figure 38 shows the AOI with a thick red buffer line around it and green colour lines for the trajectory coverage. It is obvious that the trajectories encompass the whole AOI. Flight line numbers recorded on data log sheets were used to assess the data coverage.

During the pre-processing stage, the point density criteria were checked. The amount of points per square meter was calculated randomly at different location throughout the Area of Interest. In these analysis, the point density at all the location is meeting or exceeding

16 points per square meter. Point density reduction could take place in the following situations:-

1.Lower reflection due to high absorbing material.

2.Terrain circumstances, like water bodies or steep terrain.

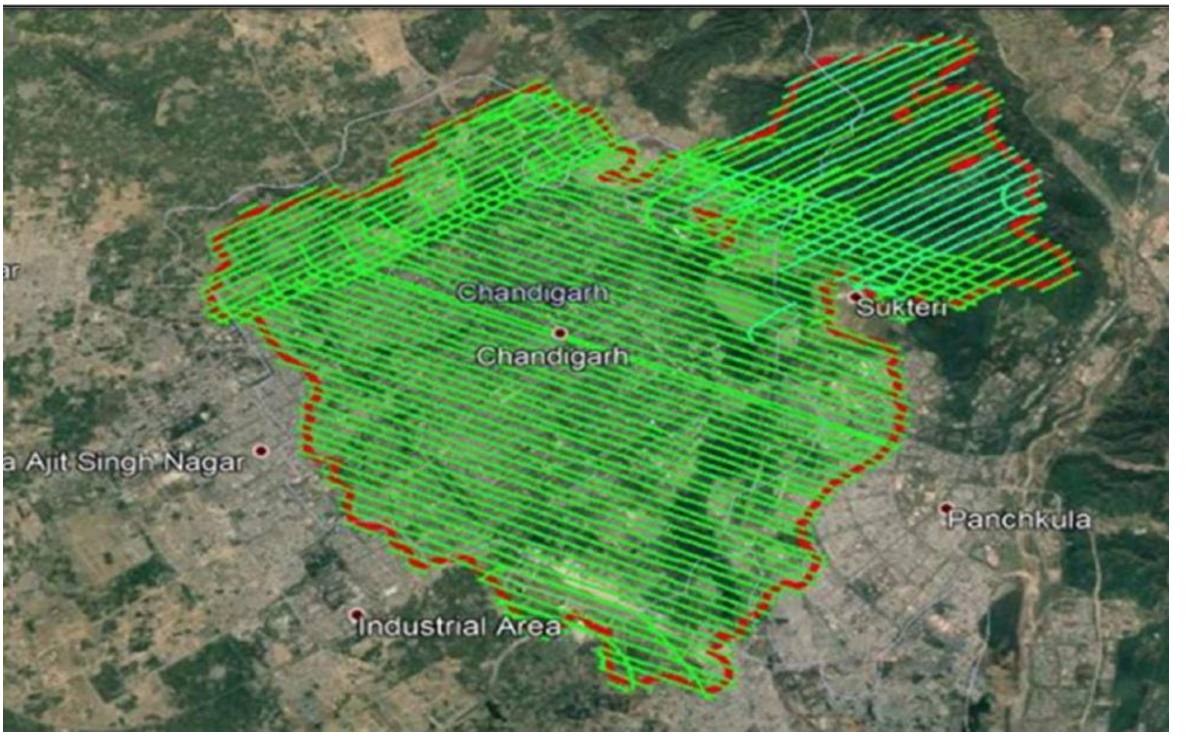


Figure 51: Flight Line Courage

Figure 4.27 depicting the point cloud coverage for the whole area of Interest (represented with thick yellow colour on the outside).The different colours inside the below area of boundary represent the flight path and the LiDAR data covered. (Jonathan D Paul, 2020) (K.A., 2008) (Lemmens) (Murty, 2004) (Gottfried Mandlburger, 2019)

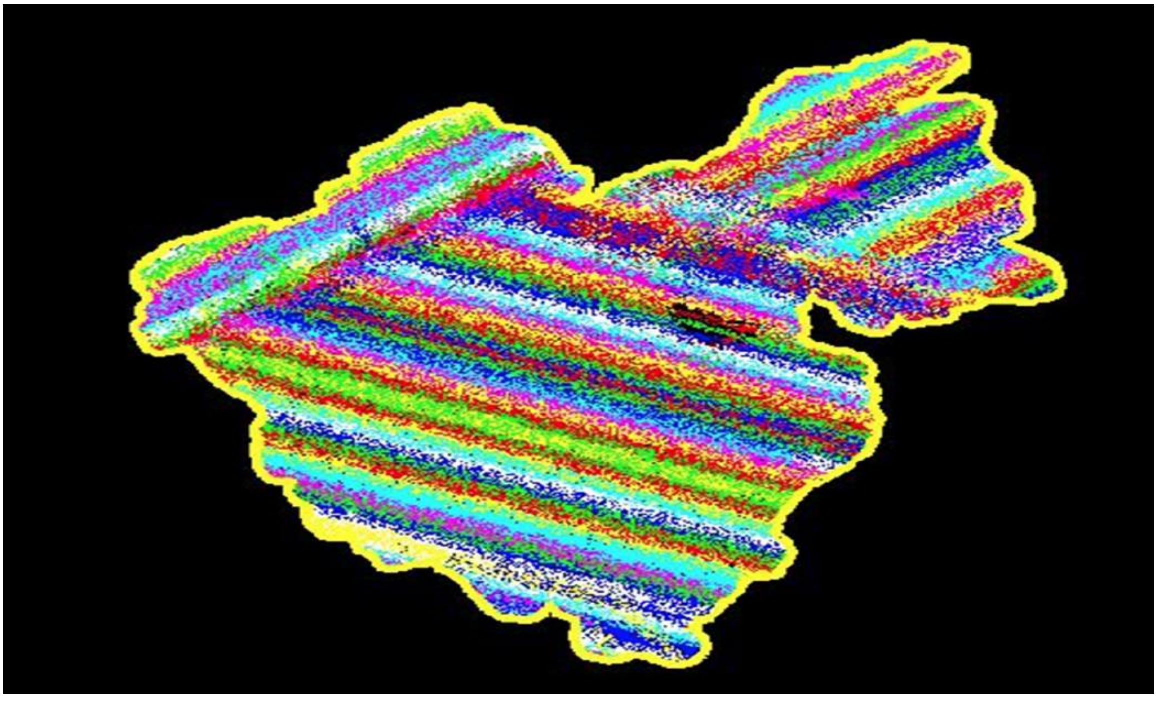


Figure 52: Aerial Point Cloud Coverage

4.8 QUALITY ASSURANCE PLAN- DATA PROCESSING METHODOLOGY

GIS Database preparation project for entire Chandigarh City have been envisioned using Aerial LiDAR Survey and vehicle mounted Mobile LiDAR Survey to produce the following Deliverables.

1. 1 Classified Point Cloud data with 1 km x 1 km Grid in. LAS format.
2. Topographic Map with 1:500 scale.
3. Contour Map at 30 cm interval (Contour Interval = 3* RMSEz).
4. Digital Surface Model (DSM) at 0.5 m Grid.
5. Digital Elevation Model (DEM) at 0.5 m Grid.
6. OrthoPhoto with a GSD of 5 cm.
7. Geo- tagged, time-stamped 360 Degree Panoramic imageries.

This document details about the processes, methods and other suitable precautions taken during the Data Processing, Final Deliverables Production phase and the checklist to verify that the deliverables meet the required RFP Specifications.

4.8.1 METHODOLOGY FOR GEODATABASE PREPARATION FROM AERIAL LIDAR LIDAR SURVEY

The process of deriving mapping products from Aerial LiDAR and Mobile LiDAR survey summarized as follows:

1. Spatially corrected LiDAR Point Cloud generation by using standard LiDAR preprocessing software such as RiProcess, GraftNav, Aero Office, MM Process, Micro Station, Terrascan and Terra Match.

2. The following types of errors were computed from the raw point cloud and suitable corrections were applied to calibrate the point cloud:

2.1. Heading – to eliminate the displacement error of point-cloud along x-y plane.

2.2. Roll – to eliminate the displacement error of point-cloud along y-z plane.

2.3. Pitch – to eliminate the displacement error of point-cloud along the x-z plane.

2.4. dZ – to eliminate the vertical displacement errors of point-cloud

3. Aerial and Mobile LiDAR Data was merged with common control points.

4. Aerial and Mobile LiDAR survey data was checked for coverage, accuracy and completeness as per Standard Quality Assurance/ Quality Control (Q.A/ Q.C) procedures using the Test Points collected in the field.

5. Sufficient number of test points as Test Point Site which spread across the project site.

6. For Aerial LiDAR Test Point Sites was on clear flat ground to maximize their value as ground truth points. At each site, additional test points were collected on various types

of ground surfaces and vegetation covers, as per ASPRS conventions to allow an assessment of DTM accuracy under a variety of land use categories.

7. For Mobile LiDAR Test point sites was on features available throughout the project area. The features include Electric poles, paint markings, sign boards, roundabouts, culverts, Kilometre stones, and Hectometre stones, OFC stones, Medians, Bridges, Guard pillars, water tanks, tunnel and pipelines.

8. Terrascan was used to classify the point-cloud data into various classes as per RFP specifications in to number of classes (ASPRS Standards).

9. Digital Elevation Model was prepared from the LiDAR classified point cloud, as classified as “Ground only”. This process employees Point to TIN and TIN to Raster process.

10. Hydro-flattening was done as per USGS Base Specifications for natural and man-made water bodies.

11. Digital Surface Model was generated using First Return Aerial LIDAR Point Cloud data after Noise Removal due to sensor movement, angular reflectivity of the terrain features and all the edges was validated and reconstructed using standard mapping software. Final DSM was generated with the required resolution.

12. OrthoPhoto was generated using TerraPhoto Software with Aerial Triangulation, Image rectification with respect to the LiDAR DEM, Seam line Generation, Mosaicking, Colour Corrections and Final OrthoPhoto production process.

13. Features was extracted by using the classified LiDAR Point Cloud data and ortho photographs in standard mapping Softwares and procedures.

14. The extracted features were validated with Orthophotographs for accuracy and completeness.

15. Standard CAD software were used to prepare the layers as per RFP Specifications and the Colours, Symbology was performed as per AMRUT Guidelines.

16. Topology Building and Validation was performed in Standard GIS software or Micro station software.

17. After, Topological validations, CAD Drawings were converted in Shape files.

18. Attributes collected from Aerial LiDAR Survey, Mobile LiDAR survey and Field attribute collection and through collateral information was added to the respective features.

19. All the Deliverables produced was added to the Geodatabase except Geo-tagged, time stamped 360 Degree Panoramic Imagery.

The detailed flowchart of methodology for Geodatabase Preparation explained in figure 4.31 below.

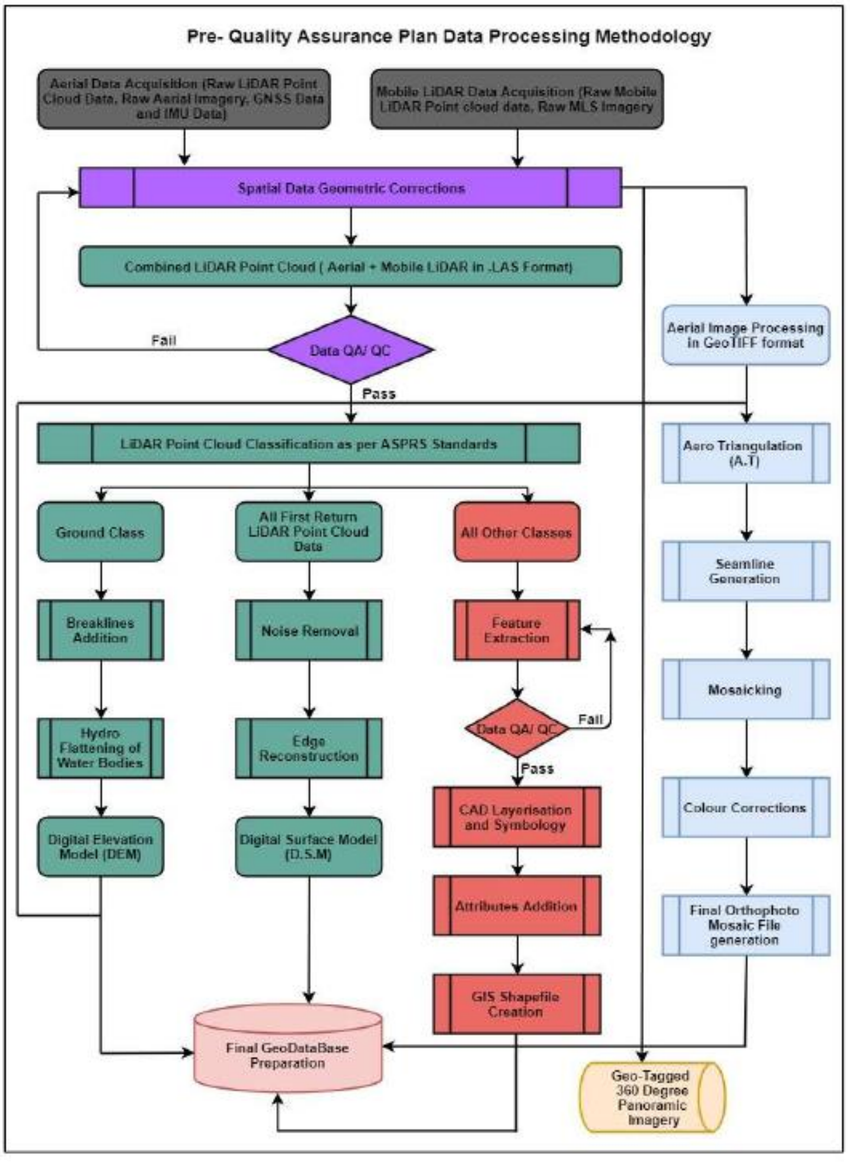


Figure 53: Pre-quality Assurance Plan

The Brief Methodology for feature extraction, CAD Layerization, Topology Building and Validation, CAD Drawings to GIS Shape files conversion, Attribution and Labelling and addition to Geodatabase explained below after Aerial LiDAR and Mobile LiDAR Data Pre-processing stage.

4.8.2 Features Extraction

Features Extraction at 1: 500 scale was completed using Geo-Referenced Aerial LiDAR Point Cloud, Aerial Orthophotographs, Mobile LiDAR Point cloud and Geo-tagged and time stamped 360-degree panoramic imagery using appropriate software respectively by Data Production teams. This vector data forms the basis for topographic map production.

The features extracted was exported to standard CAD package for further processing and Layerization as per RFP Specifications and AMRUT Standards and Guidelines.

4.8.3 CAD Layerization

Standard CAD package is versatile for Plotting, Annotation and Layerization and Symbology. Our Project RFP Specifications along with AMRUT Design Standards and Guidelines for GIS based master plan preparation was used as standard for setting the following parameters.

1. Layer Name
2. Color
3. Line Type
4. Line Weight
5. Symbolization

784 unique layers was captured and color coded. The extracted features were checked for completeness with the help of Geo-referenced ortho imagery. Refer Figure 4.32.

4.8.4 Topology building and Validation

Topology describes the inter relationships between connected vector features (Points, Lines and Polygons). Topologically correct data is very much required detecting and correcting digitization errors in feature extraction phase and enables GIS Analysis.

4.8.5 Topographic Map Preparation

All the features were captured from combined point cloud resulting in merging of Aerial LiDAR and Mobile LiDAR Data. A small mapping tool, developed by Geokno software development team was used to extract planimetric features from the classified Aerial and Mobile LiDAR Point Cloud data and Orthophotographs. After completion of Topology validation, the CAD Drawings was divided in to 1 KM*1KM Tiles or as per the RFP Specifications and Grids was made along with the Index drawings. Every drawing was allotted a unique identifier and standard cartographic elements such as North Arrow, Scale, Labels, Legends, Scale and Project Tile.

4.8.6 Geodatabase Creation

Geodatabase is collection of geographic datasets of various types in single folder based on the user defined schema. Geodatabase offers various advantages when compared to having the files as separate. It enables quick enforcement of rules and conditions across various datasets in single place and avoids duplication of edits and offers data storage savings considerably. AMRUT Guidelines and Design Standards were used as common base for Geodatabase preparation and attributes collected from Geo-Tagged Panoramic Imagery, Field collected and collateral data provided by the client were added in respective layers.

4.8.7 GIS based database preparation as per AMRUT guidelines/Standards

Aerial LiDAR and Mobile LiDAR Survey is a versatile method for Existing Land Use/ Land cover map preparation and forms the base data for other important inputs aiding in better informed planning and decision making.

a) GIS layer specifications

The following feature layers was created from the data captured after Aerial LiDAR and Mobile LiDAR survey of Chandigarh city. AMRUT Standards for GIS based Master plan preparation – Designs and Standards was used for Layerization in CAD/ GIS software.

The layers were created from the Mobile and Aerial LiDAR survey data of Chandigarh. Thenumber of layers to be formed from the data was as per the requirement of various department of Chandigarh administration. All the layers to be digitized from the data and strictly follow the guidelines of AMRUT issued by the MOUD.

b) Unique Coding scheme

The first two characters of the code represent the Class and next two characters represent the Sub class.784 numbers of unique layers with their geometry were generated in the Geodatabase. The Color Scheme and symbology done with best color scheme & suitable symbology.

c) Attributes Collation

The features listed above extracted from Aerial LiDAR and Mobile LiDAR data using appropriate software such as Terrascan. Attribute information collection is an important process in the mapping project. The Extracted features imported in to standard CAD software and Layerization and symbolization carried out as per the RFP Specifications. Attribute List was prepared for each feature. (Gottfried Mandlburger, 2019) (Brown) (Wai Yeung Yan, 2018)

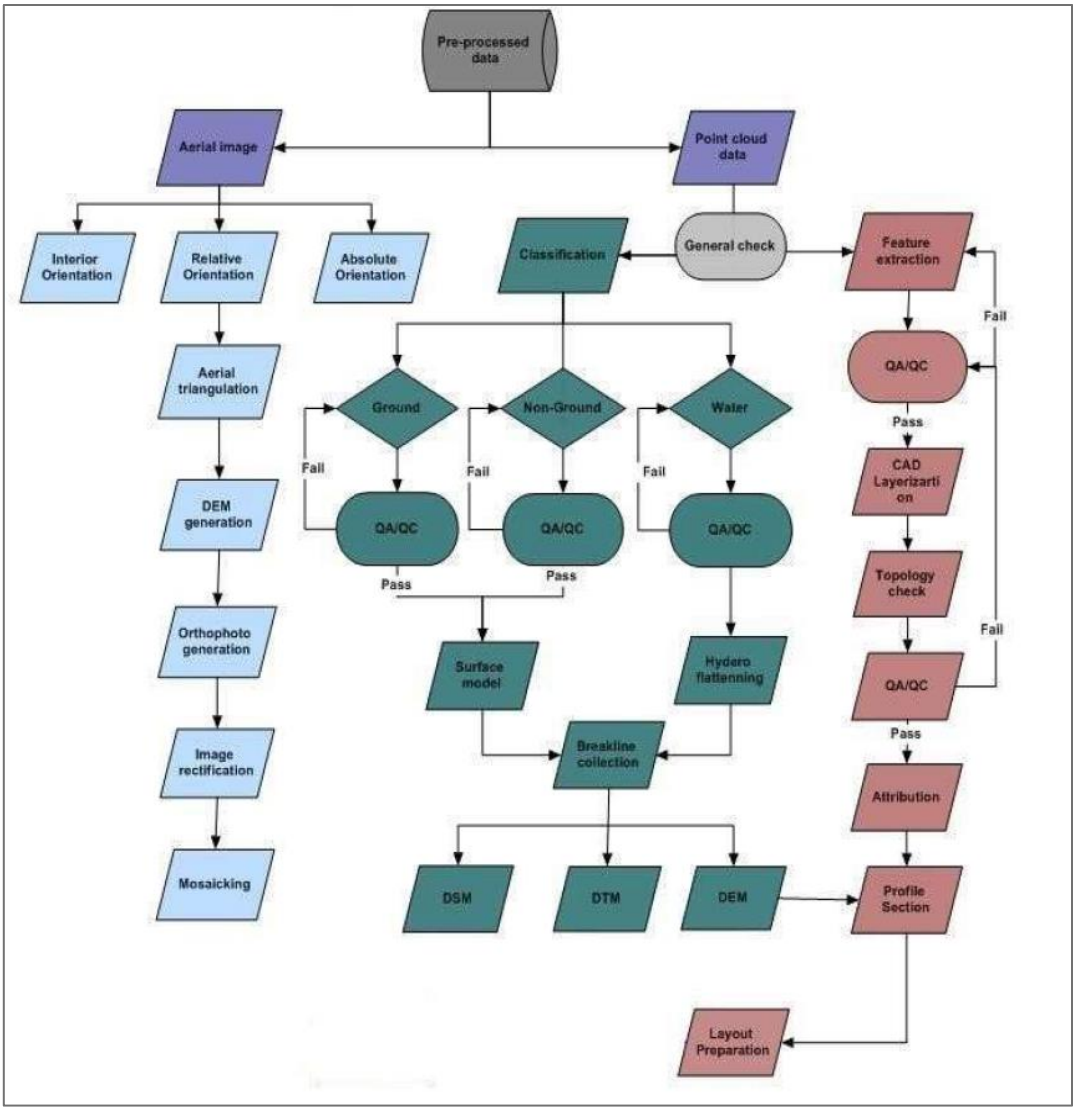


Figure 54: Lidar Post-Processing Flow Chart

The process of deriving mapping products from LiDAR survey data can be summarized as follows:

1. Pre-processed data was in WGS84 datum, and projected to the UTM projection system (UTM 43N).

2. Terrascan was used to classify the point-cloud data into various classes as per RFP (ASPRS Standards).

3. Digital Elevation Model was prepared from the LiDAR classified point cloud, as classified as “Ground only”. This process employees Point to Tin and Tin to Raster.

4. Contouring and DTM/DEM generation was achieved through the use of established processing techniques in the TerraModeler software.

5. OrthoPhoto was generated using TerraPhoto and LPS software.

6. Planimetric details was extracted by using the classified LiDAR data and ortho photographs in standard mapping softwares and procedures.

4.8.8 Unclassified Point Cloud

The spatially corrected LiDAR data which includes all returns was recorded in a single class called Unclassified LiDAR data. This data divided into 0.5km by 0.5km tiles in LAS format.

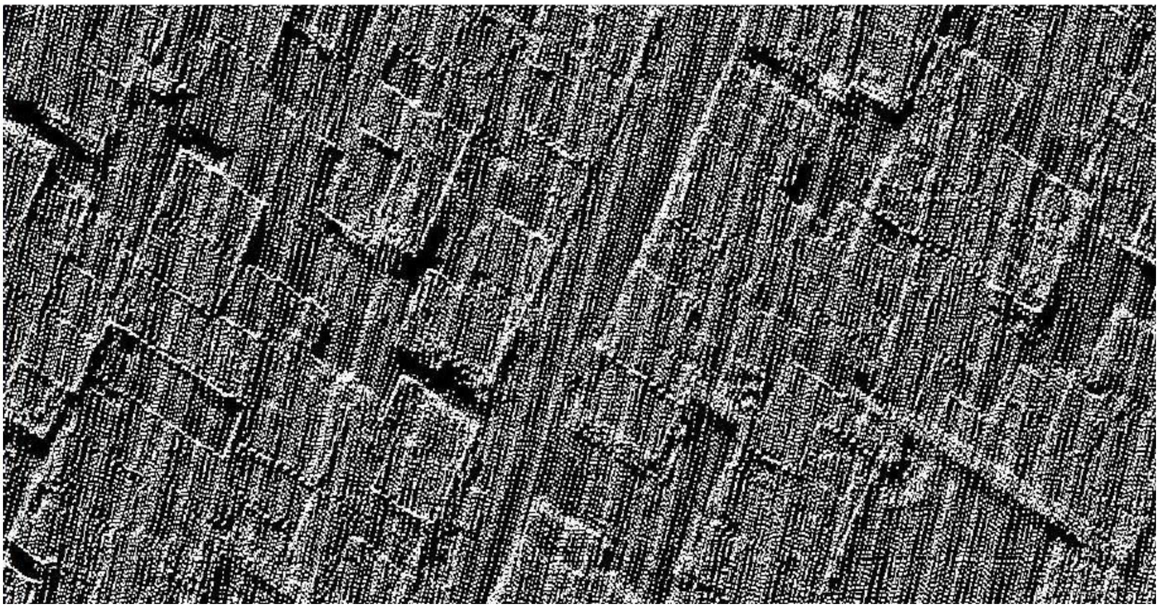


Figure 55: Unclassified Point Cloud

4.8.9 Classified Point Cloud

The LiDAR Point Cloud classified as per following ASPRS Standards shown in Table 14 below.

S. No	Point class	Description
1	Unclassified	Created, never classified
2	Default	Unclassified
3	Ground	Bare ground
4	Low vegetation	0-0.3m(essentially sensor noise)
5	Medium vegetation	0.3-2m
6	High vegetation	2m>
7	Building, Structure	Buildings, houses, sheds, soils etc.
8	Low/High points	Spurious high/low point return
9	Model key points	Reserved for 'model key points' only
10	Water	Any point in water
11	Bridge	Any bridge or overpass
12	Not used	Reserved for future definition
13	Overlap points	Flight line overlap points
13-31	Not used	Reserved for future definition

Table 12: Point Classes as per ASPRS Standards

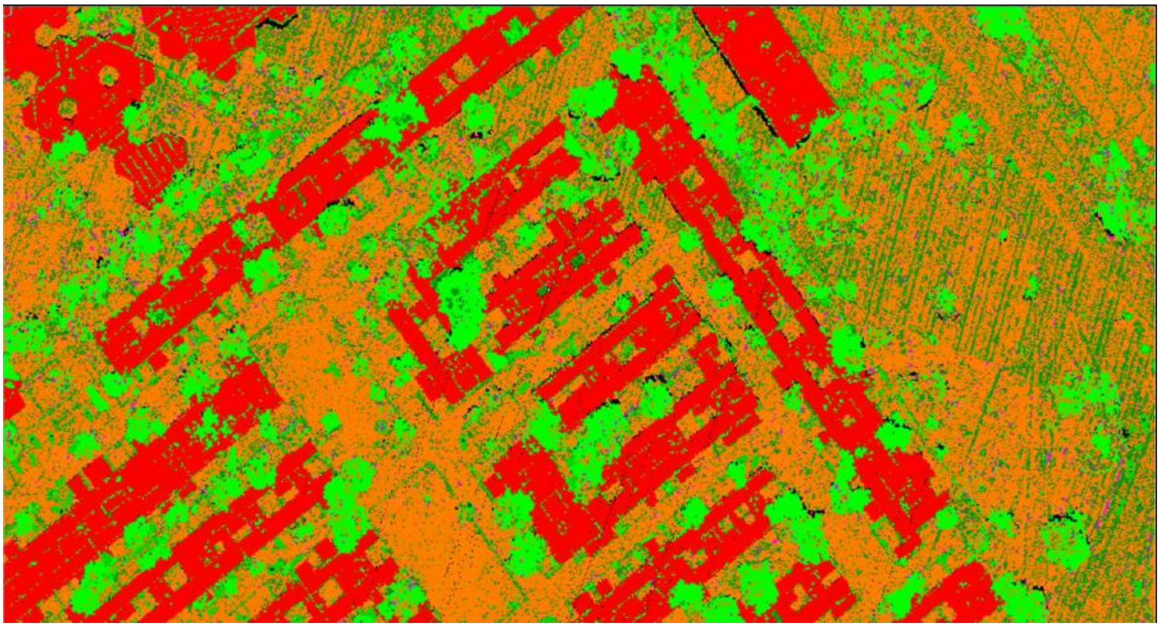


Figure 56: Classified Point Cloud

4.8.10 DIGITAL SURFACE MODEL

Digital Surface Model was generated from the "first return" LiDAR points. This data included ground and non-ground points such as vegetation, buildings. Technically, it resembles the elevation of the top most feature of the earth surface. DSM generation employed a Point to TIN and TIN to Raster process with Natural Nearest Neighbour Interpolation. Void areas were coded using a unique “NO DATA” value. The DSM was generated in ESRI Floating point grid format and it was in 1km*1km tiles with 0.5m grid interval.

Figure 57: Digital Surface Model

4.9 DIGITAL ELEVATION MODEL

Digital Digital Elevation Model generated from the LiDAR mass point data classified as “ground only”, hence it defined the” bare earth” ground surface. DEM generation employed a Point to TIN and TIN to Raster process with Natural Nearest Neighbour Interpolation. Hydro flattening has to been done for natural and man-made water bodies and water courses. Void areas were coded using a unique “NO DATA” value. The DEM was generated in ESRI Floating point grid format and it was in 1km*1km tiles with 0.5m grid intervals.

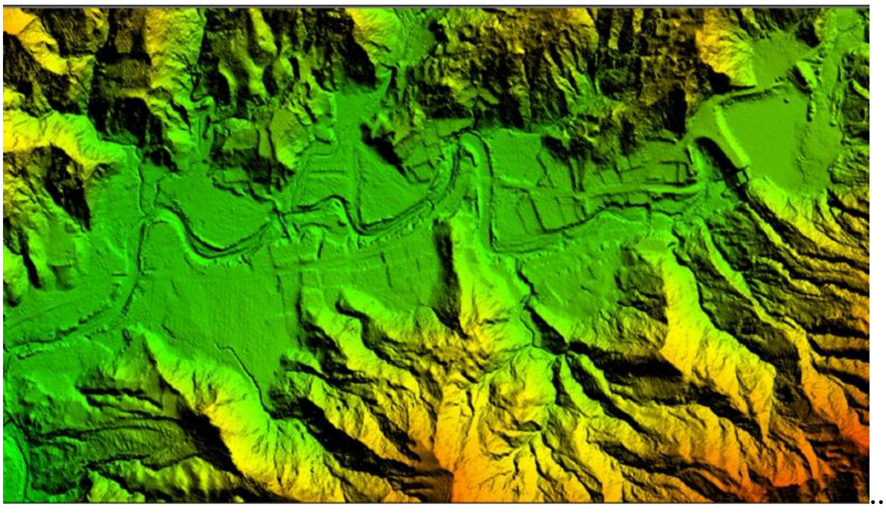


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Figure 58: Digital Elevation Model

4.10 CONTOUR MAP

A TIN model was generated from DEM grid data and Break line using TerraModel applications and in-house developed tools. Following steps were used to edit the contour files and to create the final files.

1. The DTM data, mass points and break lines which was classified from LiDAR data was imported into the TerraModel environment to generate the TIN.
2. The contour generation tools with the various parameters was used to generate the contours as per RFP specified intervals.
3. Generated Contours was thoroughly checked and corrected to adhere contour topological standards.
4. Major and Minors contours was properly layered and their elevations was labelled.
5. The delivered contours were free from any topological errors such as spikes, crossings, etc.
6. The contours were generated according to a layering schema that fits the Database Dictionary and the Data Model so that the conversion to Shape files (or any other GIS Format) takes place smoothly and accurately.

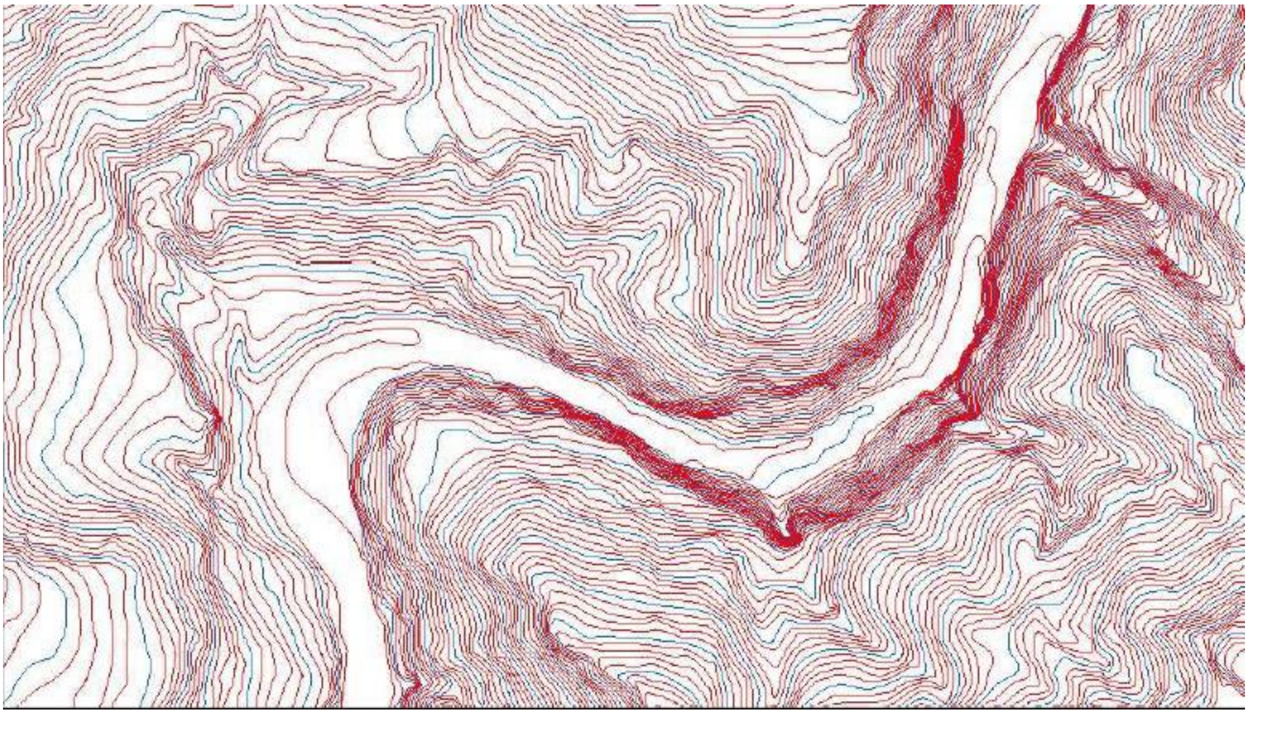


Figure 59: Contour Map

4.11 ORTHO PHOTO

4.11.1 Digital OrthoPhoto Generation Overview

Radiometric correction algorithms and routines to process large amounts of data with efficiency and extremely high levels of quality and accuracy. Large amounts of available production capacity to ensure rapid response. Effective quality control and quality assurance routines to ensure first-time-right delivery.

The ortho rectification process is to correct all the distortions due to the aerial acquisition (using the AT result) and the variations of the ground surface (using the final DTM). The production of the OrthoPhoto followed two steps:

1. Pre-processing at low resolution creating a reference quick look.
2. Finalization at full resolution ortho rectified photographs.

4.11.2 Ortho Rectification and Mosaicking

All the images were properly stitched with well distributed manual and automatic tie points. Every blocks were thoroughly inspected to ensure all the tie points were measured at necessary locations before performing bundle block adjustments.

The Digital Elevation data was used to rectify Ortho Photographs using TerraPhoto software.

The rectification process was used the Cubic convolution resampling technique to ensure high accuracy and image quality.

Seamlines were automatically generated, but they were manually verified and edited before using them in the Mosaicing process. Mosaicked Orthophotographs were exported into blocks which were 10km X 10km, then all the necessary color corrections were carried out.

This color correction process includes removing of scratches, static marks, any noticeable blemishes and any defects caused due to out of focus. Final Orthophotographs were radiometrically and geometrically corrected to ensure consistency with adjacent files without obvious distinction between them. Finally, mosaicked Orthophotographs was divided into 1km tiles in Geotiff format as mentioned in RFP. The accuracy of the Ortho Photos was 5cm GSD. (Brown) (Board D. j., 2022) (Jonathan D Paul, 2020) (Lemmens) (K.A., 2008)

Figure 60: Ortho Photo tile

4.11.3 Topographic Map Production

Initially segregation of the required features which was necessary to create 1:500 scale topographical map done. A small mapping tool has been developed by Geokno software development team used to extract planimetric features from the classified LiDAR data and Orthophotographs.

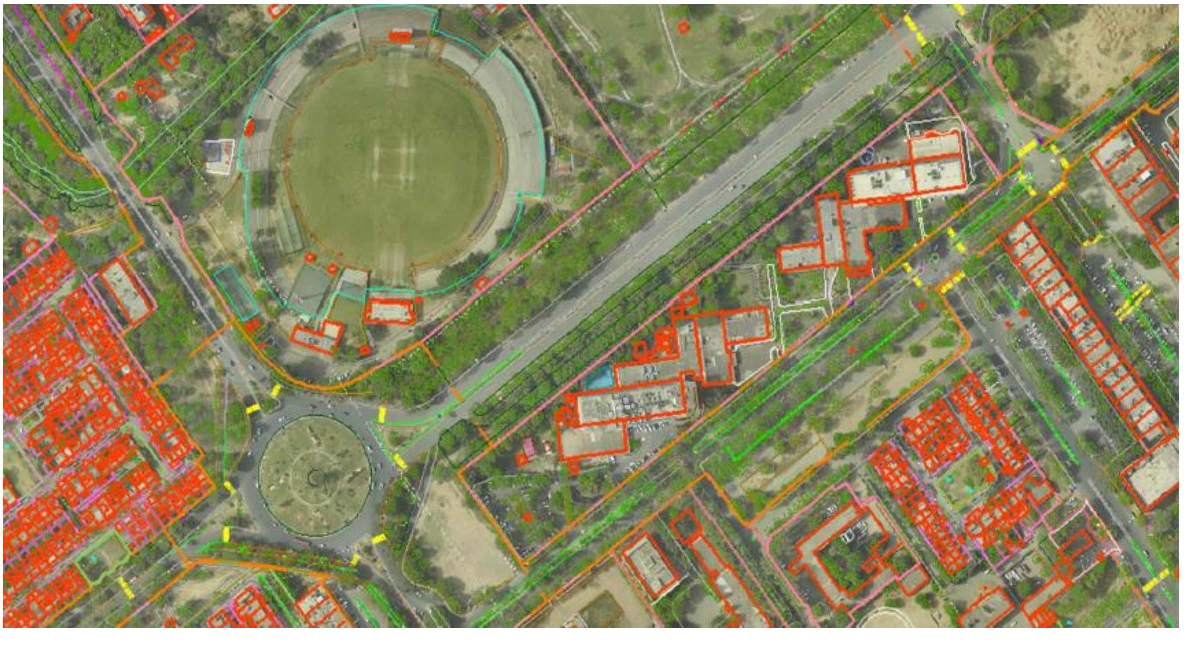


Figure 61: Topographic Map Production

4.11.4 Geographic Information System

A Geographic Information System (GIS) software is being used for this study. This software helps in storage, manipulating, analysing and presenting spatial or geographic data.

The software supports shapefiles, coverages, personal geodatabases, dxf, MapInfo, PostGIS, and other formats. It also integrates web services like Web Map Service and Web Feature Service, allowing users to access data from external sources. The digitized layers followed the guidelines set by AMRUT (Atal Mission for Rejuvenation and Urban Transformation) issued by the Ministry of Urban Development (MOUD). A total of 784 unique layers with their corresponding geometry were generated in the Geodatabase.

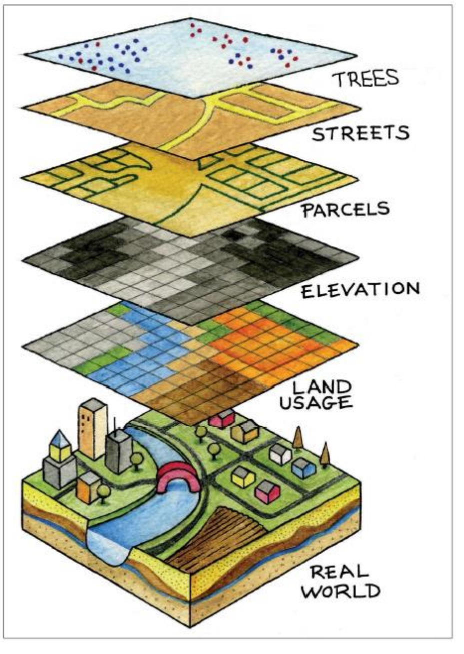


Figure 62: GIS Map into Real World

4.12 DATA VALIDATION AND VETTING

Primarily Deliverables were submitted to Administration on 07-01-2021. After the data Submission, the important task was to validate and freeze the data as per requirement of the departments. In coordination with SPIC and SVC Team, Geokno finalized the validation protocol.

The Final GIS map was divided into 20 strips for easy validation and vetting of data. Each strip was checked and verified more than 3 times by SPIC and SVC to ensure correctness and quality of the map with respect to topology and geometry. According to validation protocol data has been checked and verified by all the departments during one-to-one meetings. All the department shared the attribute information related to their department and attribute information has been incorporated into final GIS map. After departmental check and validation, all 20 strips were merged together and

the final merged GIS map was prepared. After merging the map, AMRUTH Coding system was applied on all the feature and coding completed. Coded Map was checked and validated again by SPIC and SVC. The finally coded map was checked by the
departments. The Final GIS Map was thereafter submitted to IIT Kanpur for 3rd Party vetting on 1st April-2022 as directed during the meeting by Director, Information and Technology. The final map has since been returned to Chandigarh Administration duly vetted by IIT Kanpur. (Gottfried Mandlburger, 2019) (Brown) (Jonathan D Paul, 2020)

……………………………… **END OF CHAPTER 4** ……………………………….

CHAPTER 5: RAINWATER HARVESTING IN SECTOR 26, CHANDIGARH (DETAILED STUDY)

When examining all the layers at the city level, the scope of work appears to be extensive and impractical to accomplish within the given timeframe. Since all sectors in Chandigarh are designed based on the same parameters, analyzing the details of one sector can provide sufficient information for calculating water resources at the city level. Therefore, Sector 26, situated in the northeast corner of Chandigarh, was selected for a comprehensive study due to the presence of an aquifer below 20m in this area.

Sector 26, which serves as the study area, is located in the southeastern part of Chandigarh (refer to Map 1). This region is situated on the newer alluvial plains of Sukhna Choe (nullah). Sectors 6, 7, and 27 surround Sector 26 on the north, west, and east sides, respectively. However, the southern extension of Sector 26 exhibits unplanned development, oil spillage from heavy vehicles in the grain markets, and an inadequately maintained stormwater drain network. Consequently, this particular area has been excluded from the present study. (board, 2023)

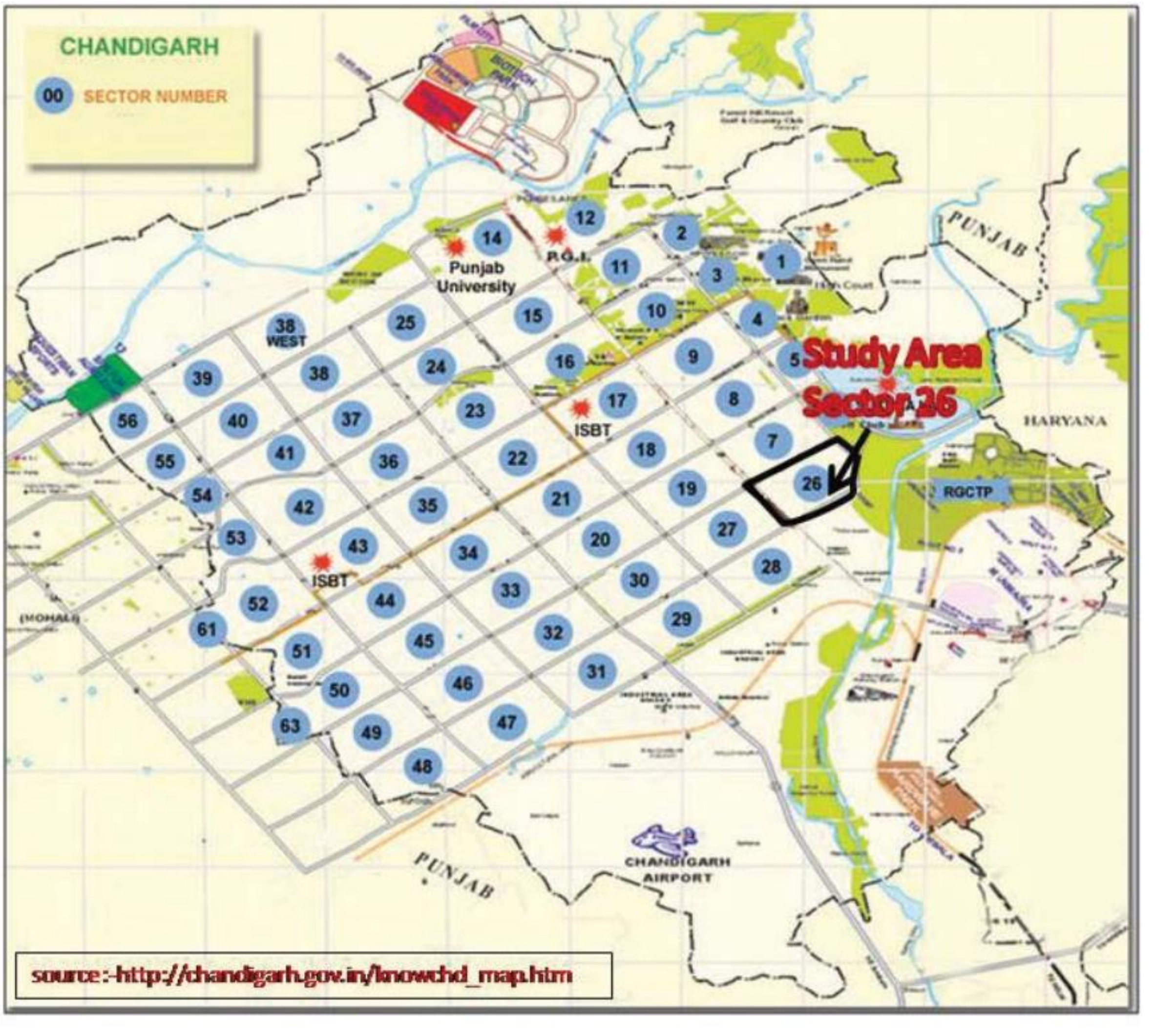


Figure 63: Key Plan Demarcating Sector 26 in the Map of Chandigarh

5.1 LANDUSE PATTERN

The map below displays the comprehensive land use of Chandigarh, illustrating the different land categories. The study area, specifically Sector 26, encompasses a total area of 1007472.94 sq m (248.95 acres). Upon analysing the map, it was observed that the sector consists of a mix of land uses, including habitation, open areas, and parks.

A thorough examination of the sector revealed that institutions occupy 81 percent of the area, while roads cover 11.2 percent. Commercial areas account for 4.3 percent, open areas make up 3.3 percent, and residential areas constitute the remaining 0.2 percent. Notably, there are significant unpaved areas within the institutional zones. Consequently, these areas present an opportunity to implement rainwater harvesting techniques to capture runoff from rooftops, paved surfaces, and unpaved areas. (Board C. G.) (board, 2023)

5.2 GEOLOGY, SOIL AND HYDROGEOLOGY

The study area is situated on the plains. Generally, the area has three prominent layers of sand, pebbles and gravel. These layers are interspersed with presence of clay at regular intervals. Logs obtained from the Municipal Corporation of Chandigarh (MCC) show presence of sand and clay across various locations within sector 26. There are two types of aquifer systems present: a shallow aquifer and a deep aquifer with presence of water at 20 mbgl and 60mbgl respectively

5.2.1 Groundwater Supply

The utilization of private tubewells has been prohibited in Chandigarh. The Municipal Corporation of Chandigarh (MCC) provides water by utilizing a combination of surface water and groundwater sources. The water is extracted from deep aquifers situated at a depth of 100 meters below ground level (mbgl). Across both urban and rural areas, there are a total of 219 tubewells, out of which 200 tubewells are designated for urban water supply. Specifically, within sector 26 of the city, there are 5 tubewells among the 200 that cater to the water requirements.(board, 2023)

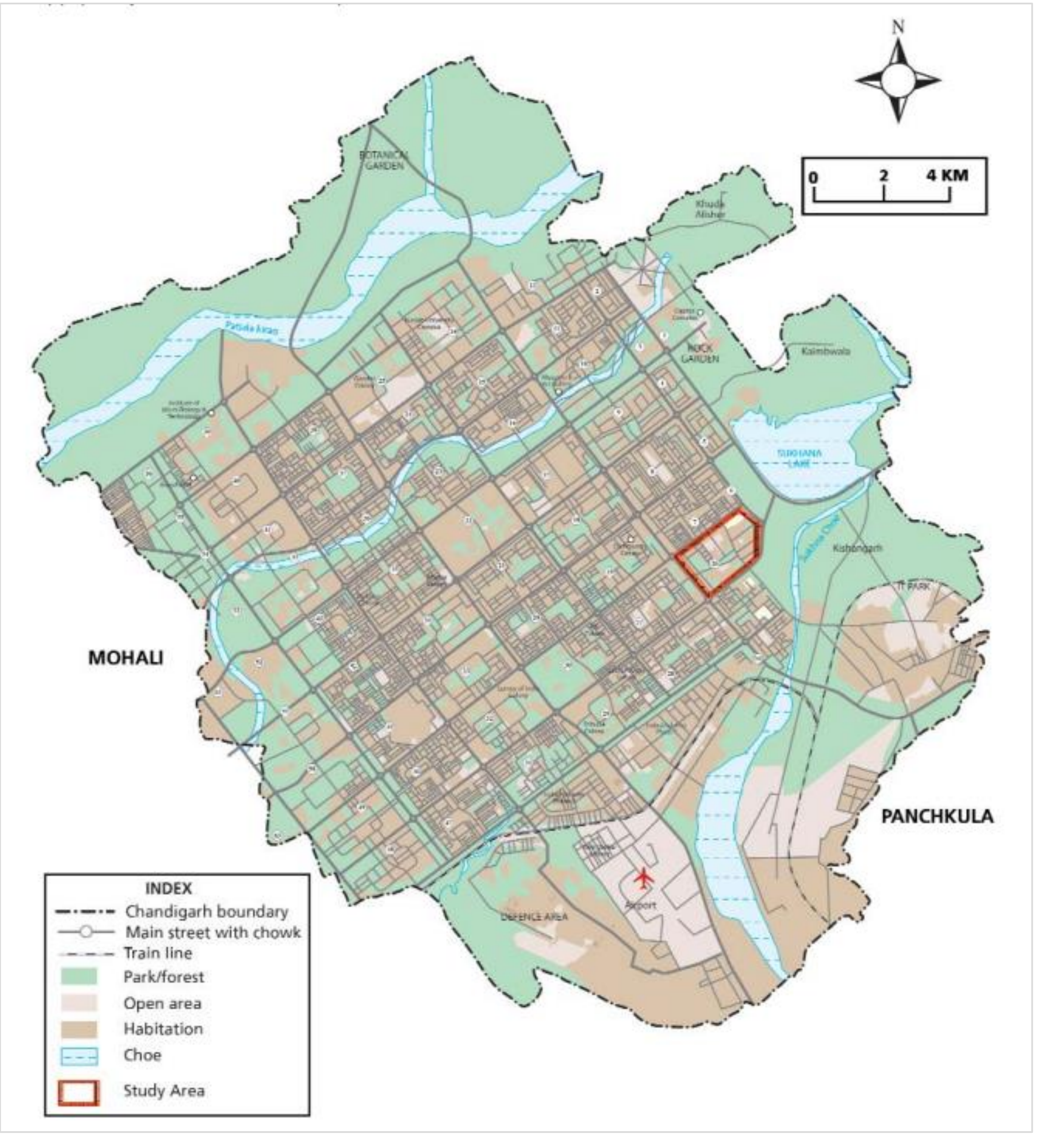


Figure 64: Land use Map of Chandigarh, Source: Chandigarh Municipal Corporation

Figure 65: Land use Map of Sector 26 of Chandigarh, Source: Chandigarh Municipal Corporation

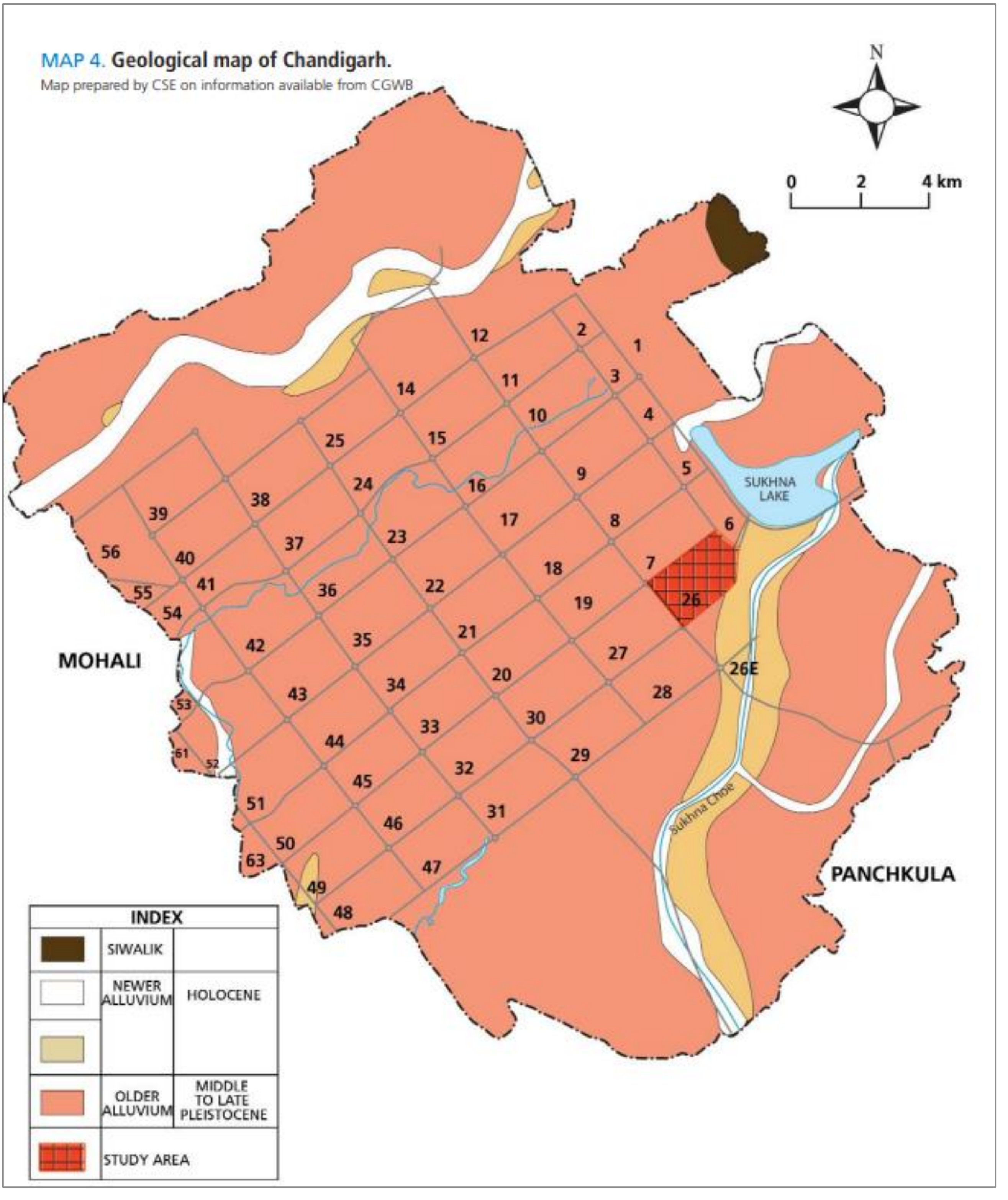


Figure 66: Geological Map of Chandigarh, Source: CGWB report

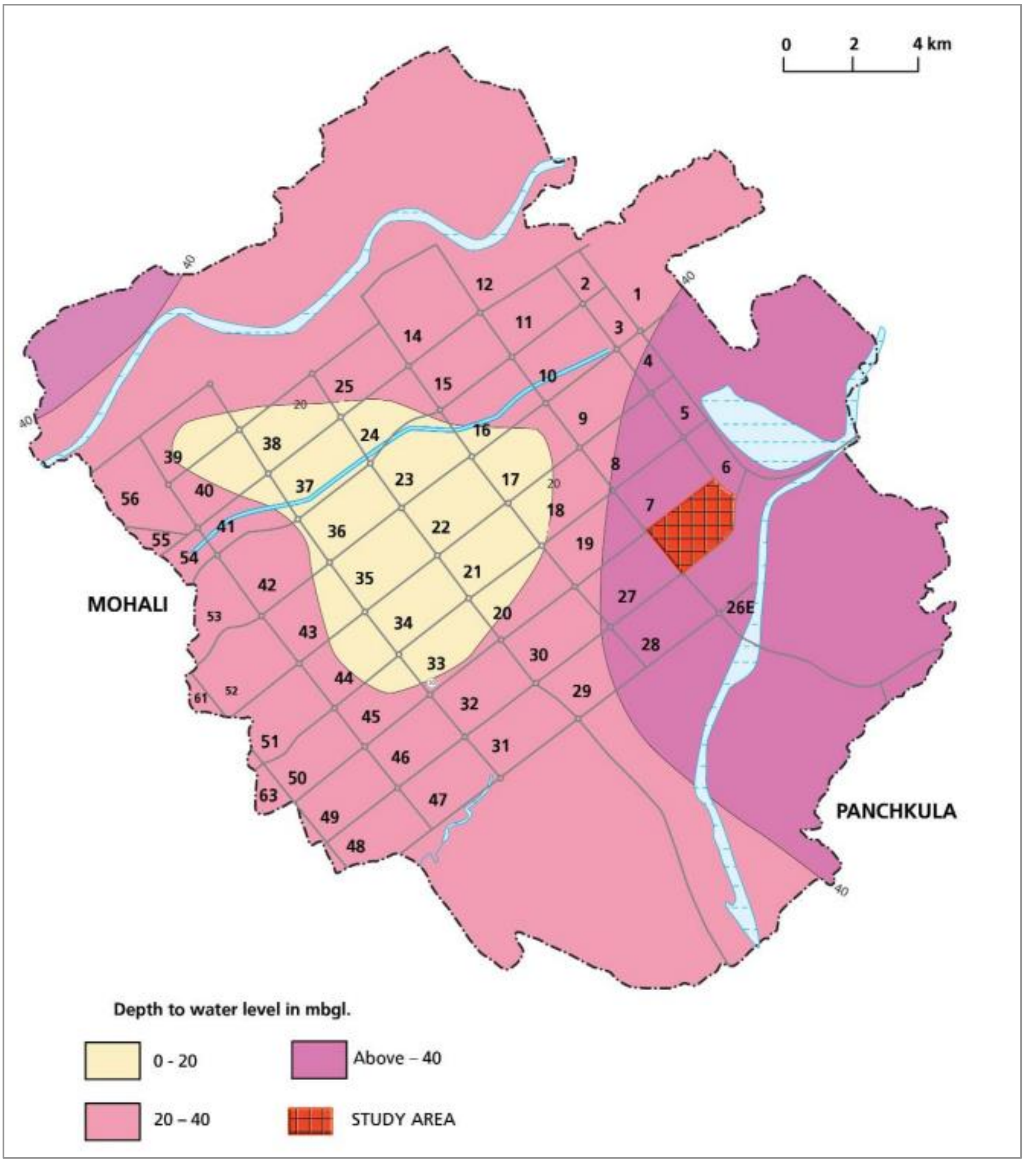


Figure 67: Pre-monsoon Groundwater Level in Deep Aquifer of Chandigarh

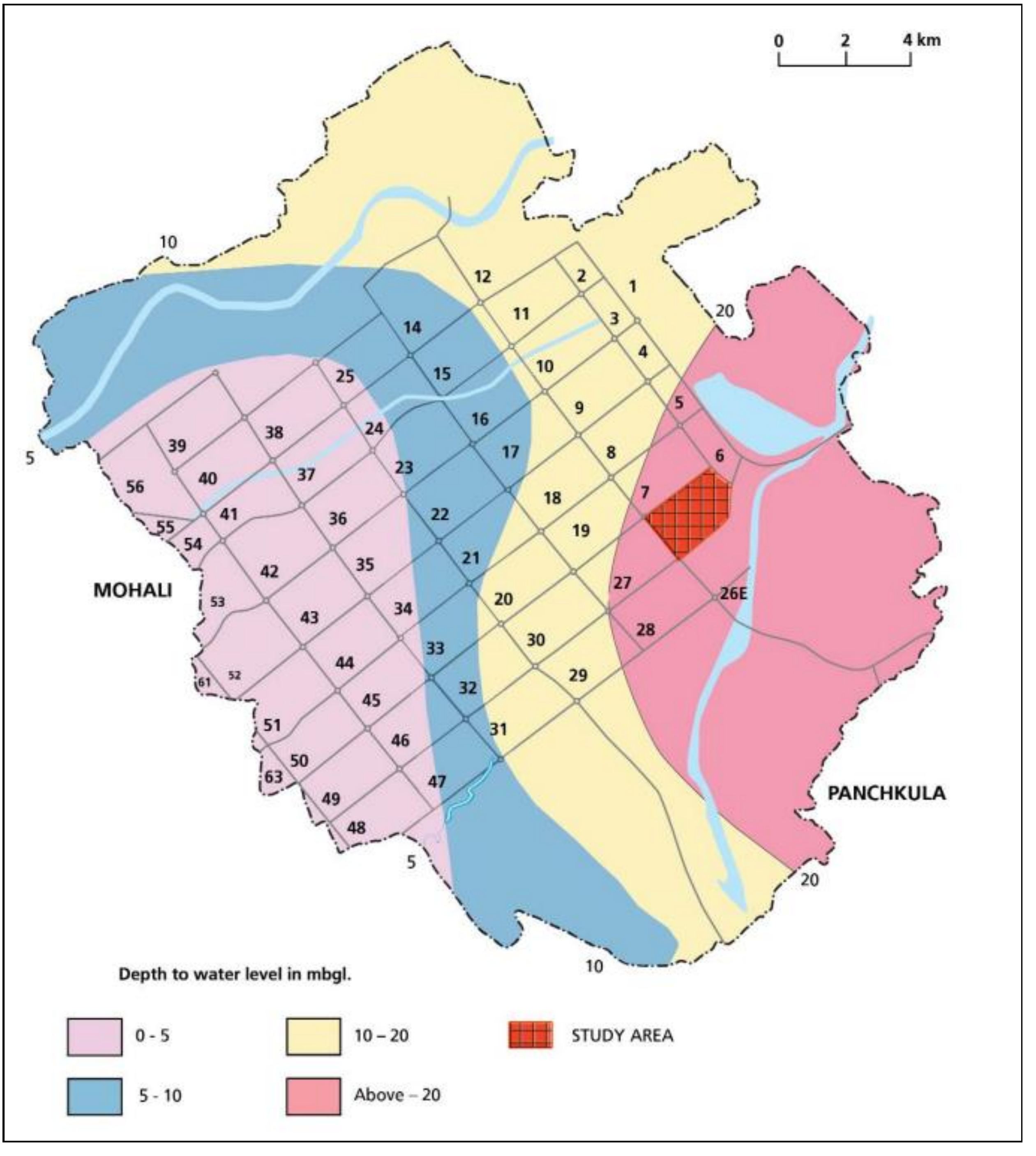


Figure 68: Pre-Monsoon Groundwater Level in Shallow Aquifer of Chandigarh

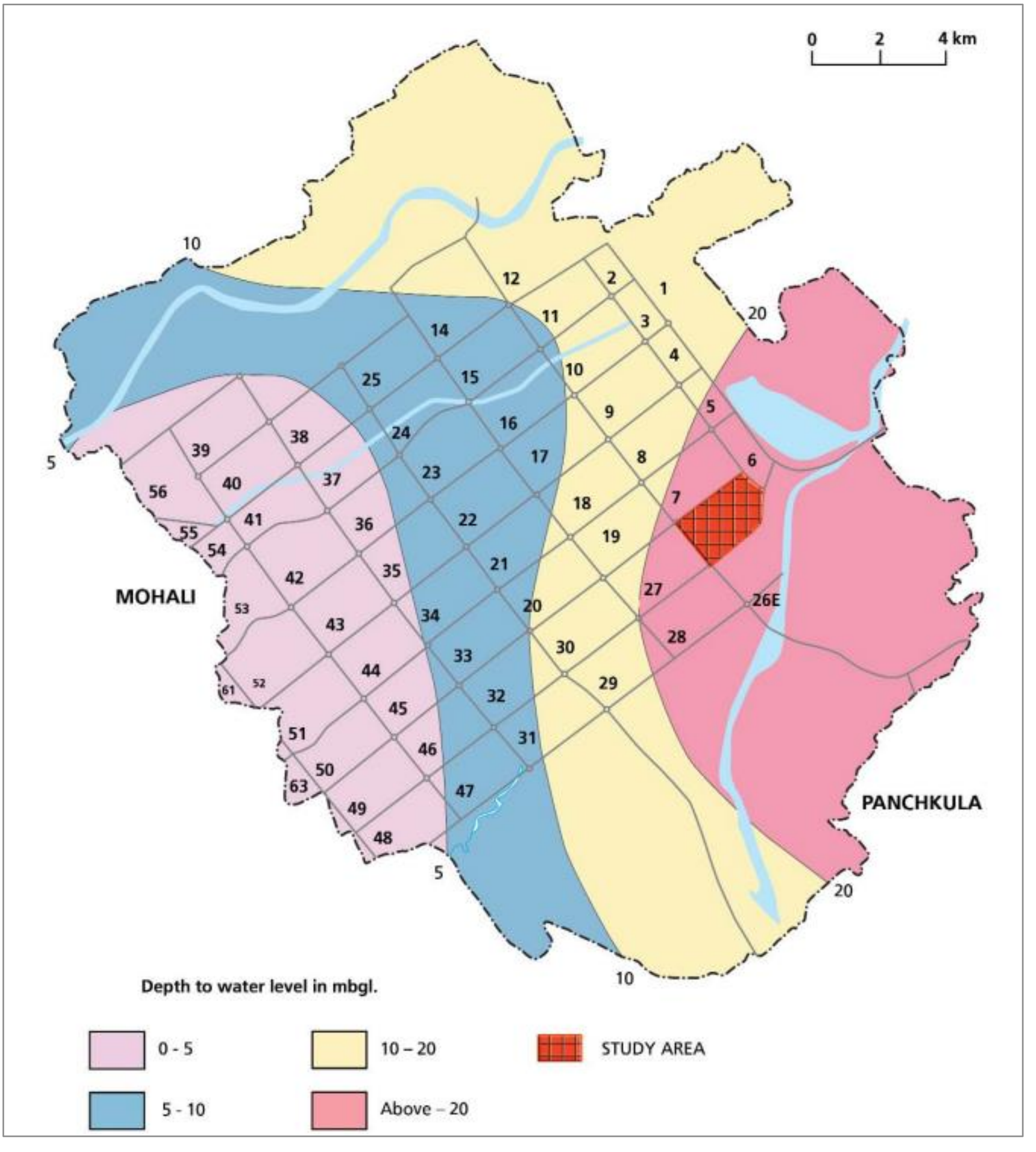


Figure 69: Post-Monsoon Groundwater Level in Shallow Aquifer of Chandigarh

5.4 PLANNING AND DESIGNING RWH STRUCTURES USING STORM WATER DRAINS IN SECTOR 26

5.4.1 Stormwater Drain Network

The stormwater drains in sector 26 is parallel to the main roads of the sector. The tail ends of the drains have been constructed along the choke. The network of the drain is well laid and is covered. The stormwater drains of all the institutional, commercial plots and roads are clean and hence the runoff water can be collected to recharge the aquifers. This will not just tackle the groundwater decline but also solve the flooding problem in the area.

Figure 70: Stormwater Drain Inlet near the Road Capturing the Run-off from both Institutional Area (behind) as well as from Roads.

TABLE 1: Planning of recharge structures along the stormwater drains (Refer Map 9)

S. No.	Stormwater stretch	Number of recharge structures
1	A to C	13
2	C to E	6
3	F to G	3
4	H to I	4
5	I to J	10
6	J to K	4
7	L to M	1
8	N to V	4
9	T to U	4
10	U to W	5
11	S to W	5
12	W to D	5
13	M to G	7
14	W to B	2
15	R to S	1
TOTAL		82

Table 13Planning of recharge structures along the stormwater drains

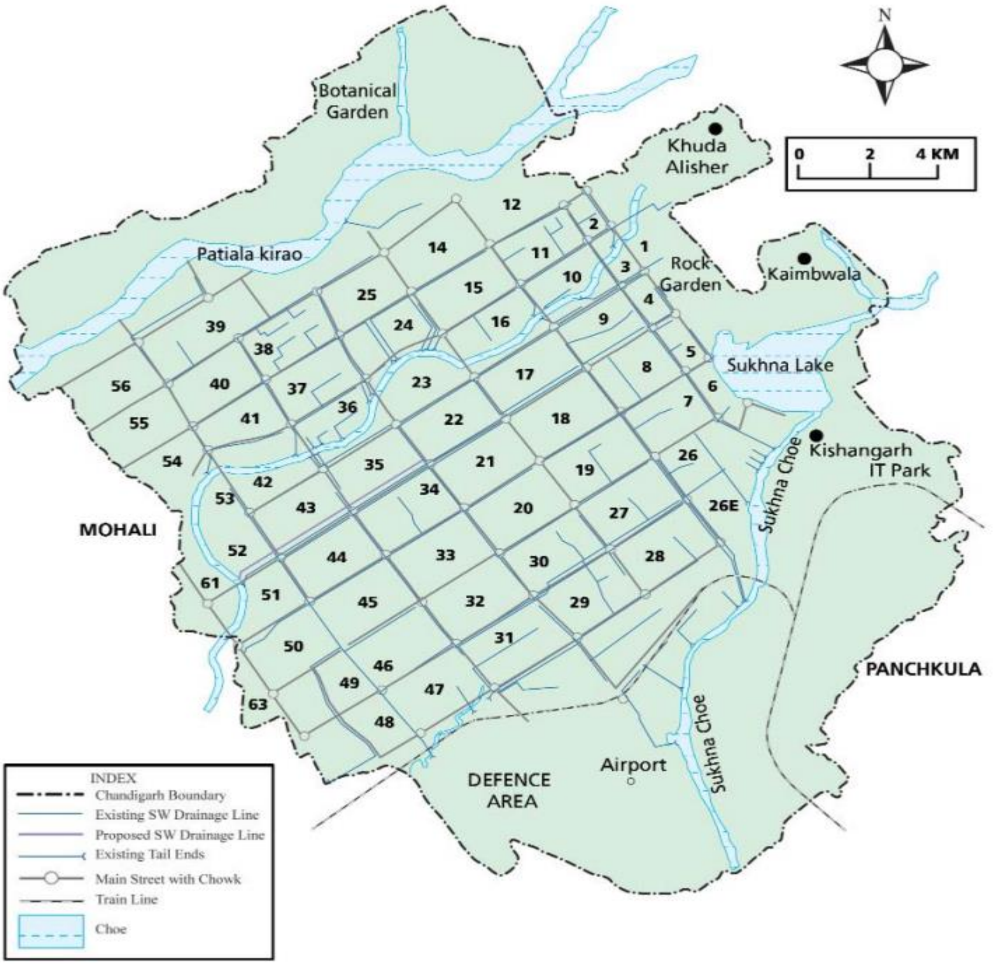


Figure 71: Map showing Stormwater Drain Network for City of Chandigarh

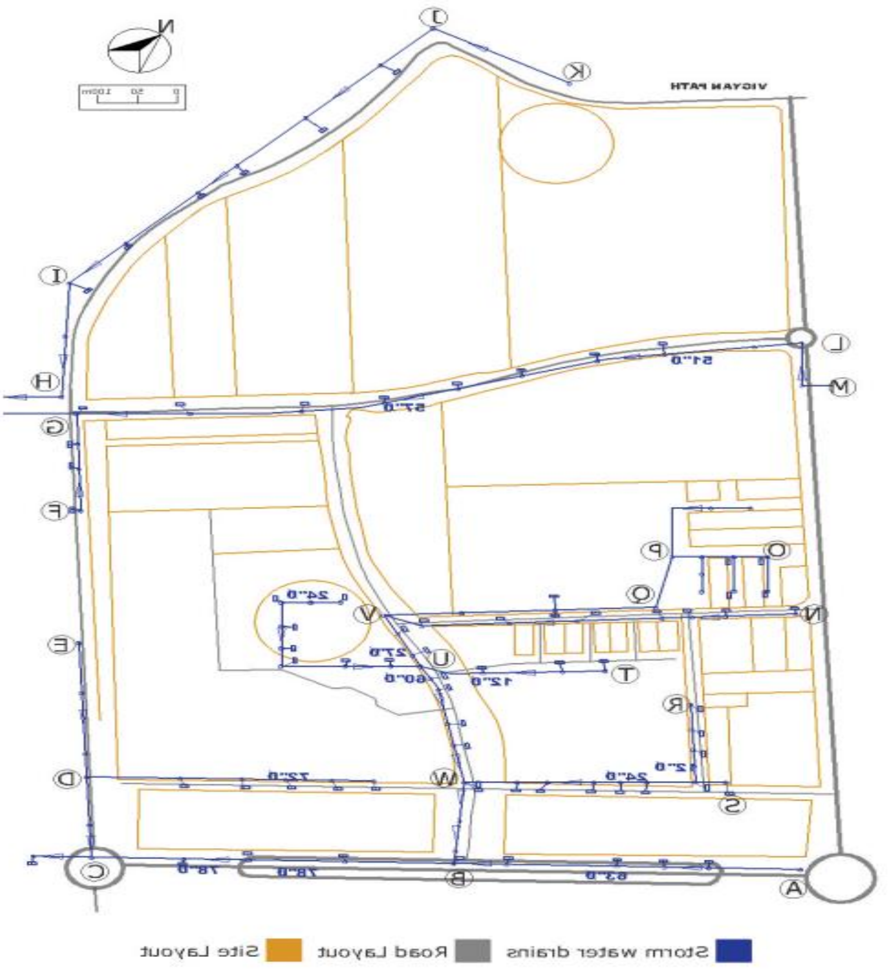


Figure 72: Stormwater drain network for sector 26, Chandigarh

5.4.2 Methodology for RWH in Stormwater Drain Network

As per CGWB website and CPWD manual.

5.4.3 Structure of a Typical Recharge Well

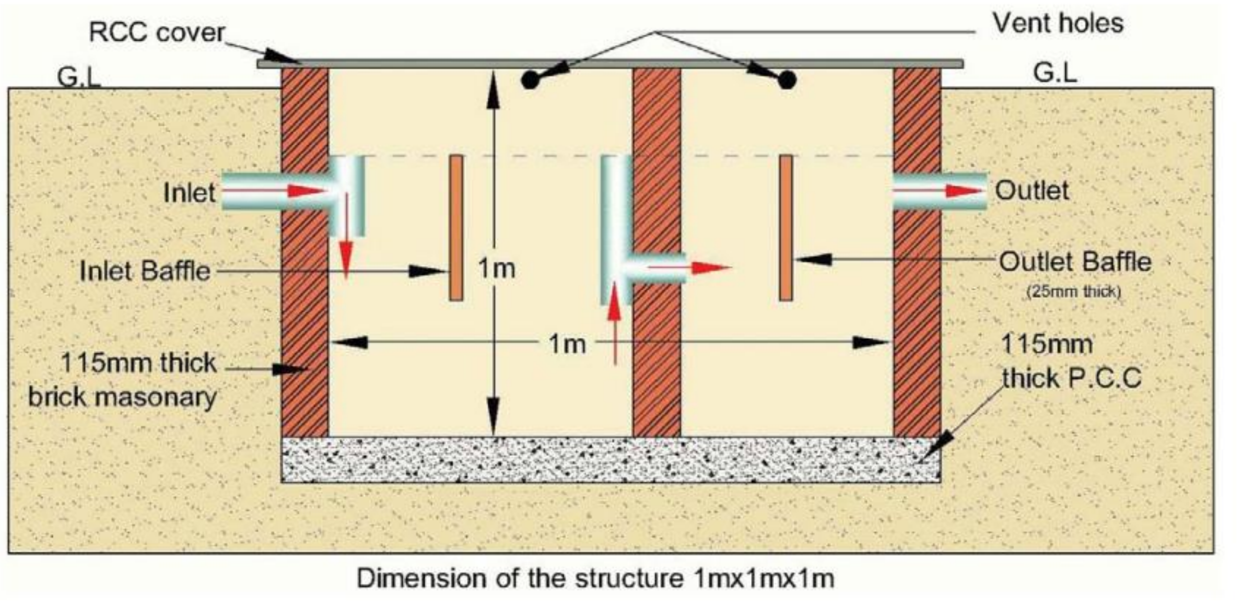


Figure 73: Cross Section of the Oil Trap

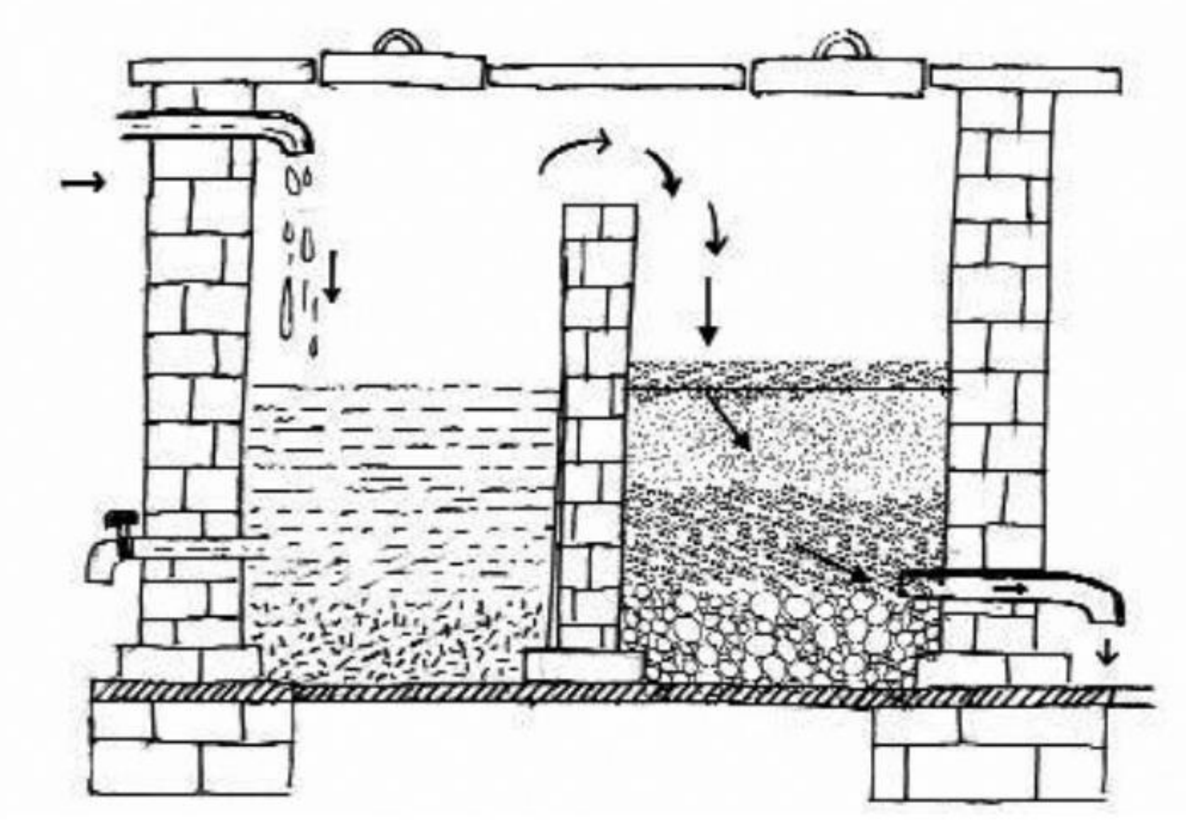


Figure 74: Cross section of typical desilting chamber, arrows marking flow of water

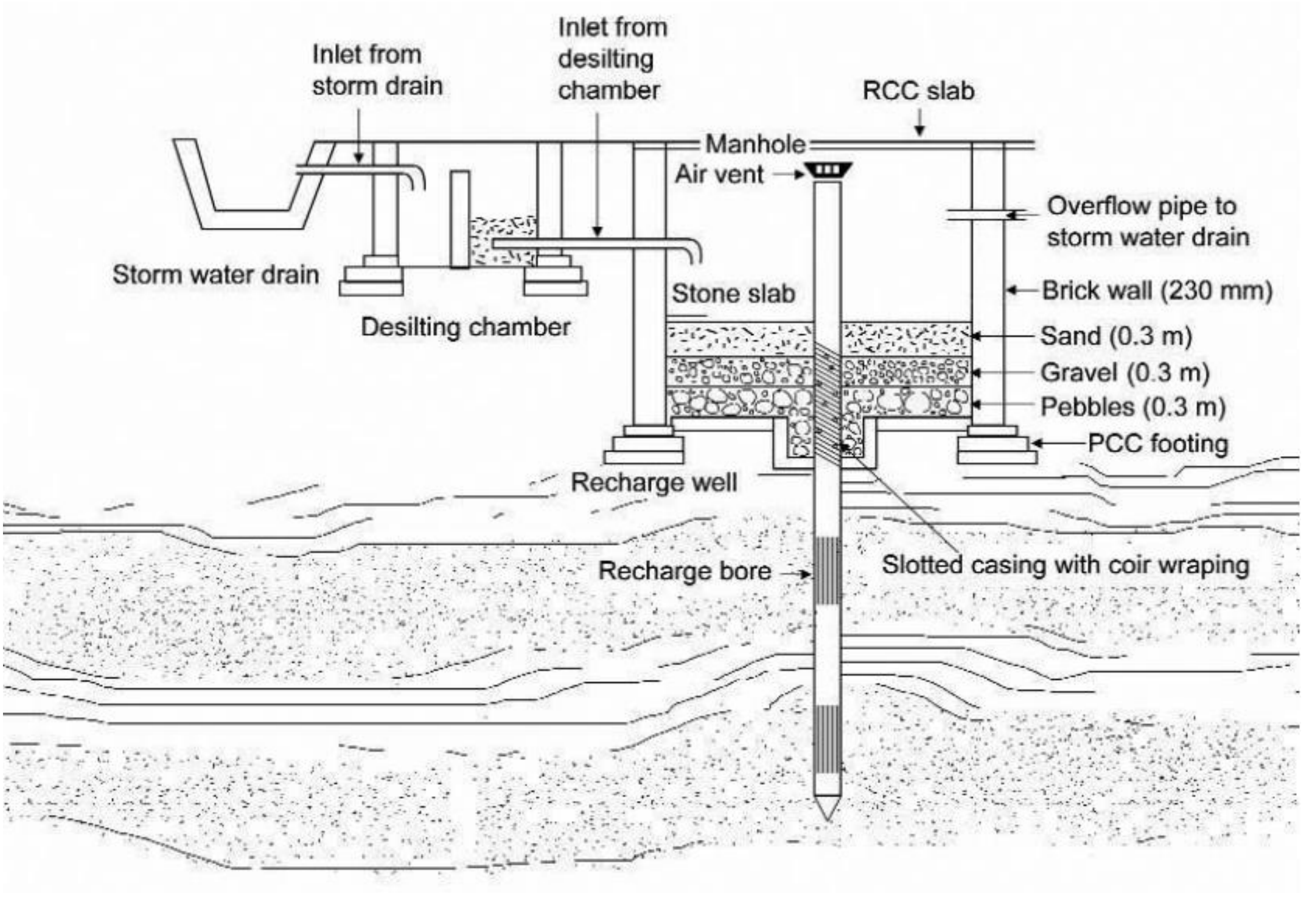


Figure 75: Cross section of recharge borewell with desilting chamber

5.5 Calculation Sheet

The estimated water recharging is calculated as below:

Total Area under Parks and Greens: 2,80,000 sqm.

Total Length of Roads:7226 m

Rainfall (in mm): 120 mm

Run-off coefficient for Greens: 0.2

Run-off coefficient for Concrete: 0.8

Volume of Run-off: Run off coefficient X Area X peak rainfall

- Run off from Green area = 0.2 X 2,80,000 X 0.12 = 6720 m3
- Run off from Non green Area = 0.8 X 6,80,000 X 0.12 = 65,280 m3
- Total Run off to be managed = 72000 m3

As per guidelines, pit having volume of 15 minutes retention time of peak discharge should be made. Total recharge volume of pit should be = 16320 m^3

Recharge pits size (conventional): 2m diameter, 10m deep, Volume of pit = 31.4 m^3

No. of pits required to match run off flow = 16320/31.4 = 520 No.

Total 520 number of pits can be made in green area spread over 2,80,000, which means 1 pit every 580 m^2

In order to avoid water logging peak discharge should be managed through rainwater harvesting pits. Along with 520 numbers of pits, creation of shallow recharge zones have been made in addition to RWH pits and recharge basin in low lying locations. All storm water drains can be connected to these zones to increase the recharge efficiency.

5.7 Borewell Logs for Sector 26, Chandigarh

Bore well logs for sector 26, Chandigarh (Depth shown in metres below ground level)

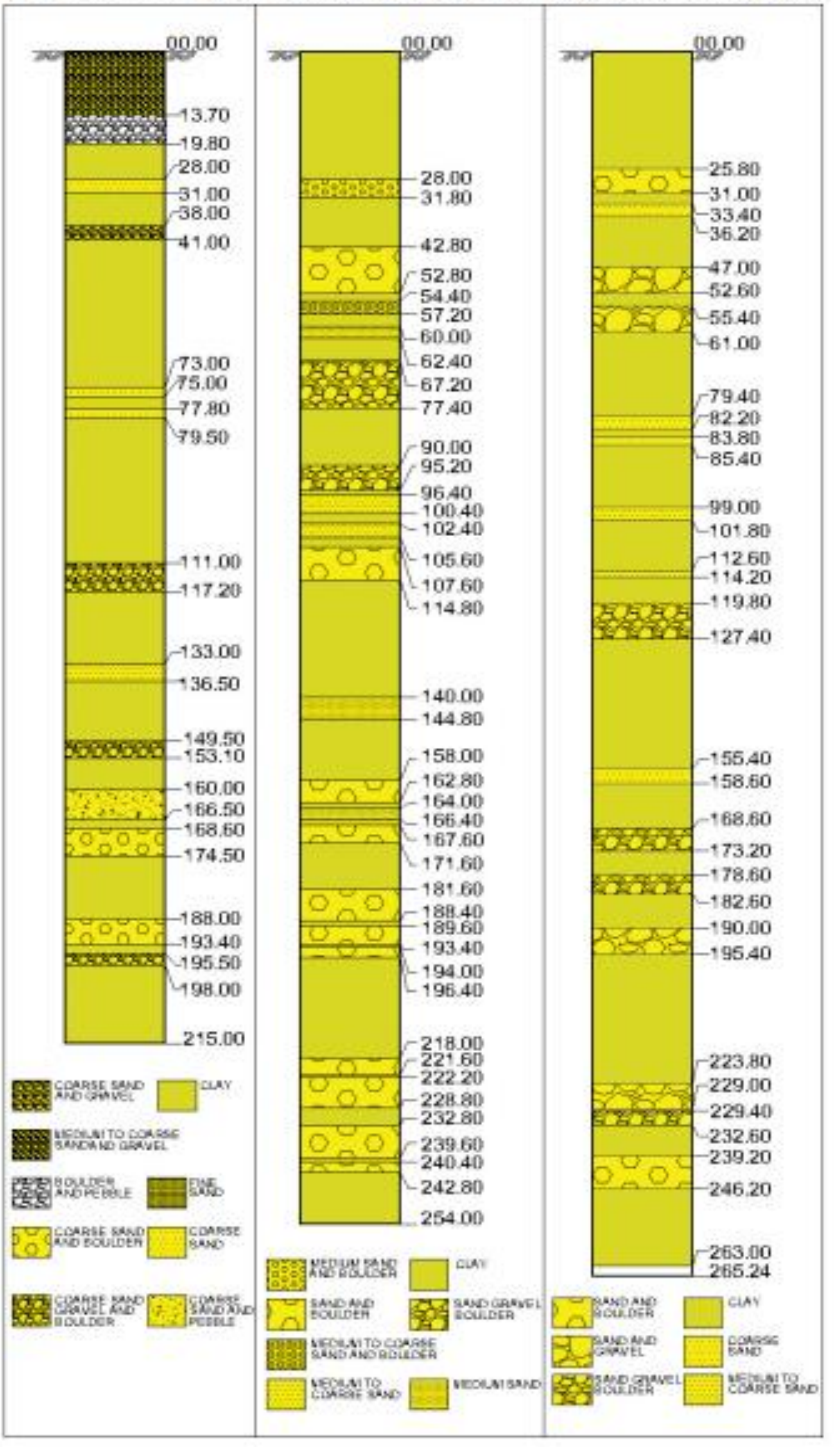


Figure 76 Borewell Log 1

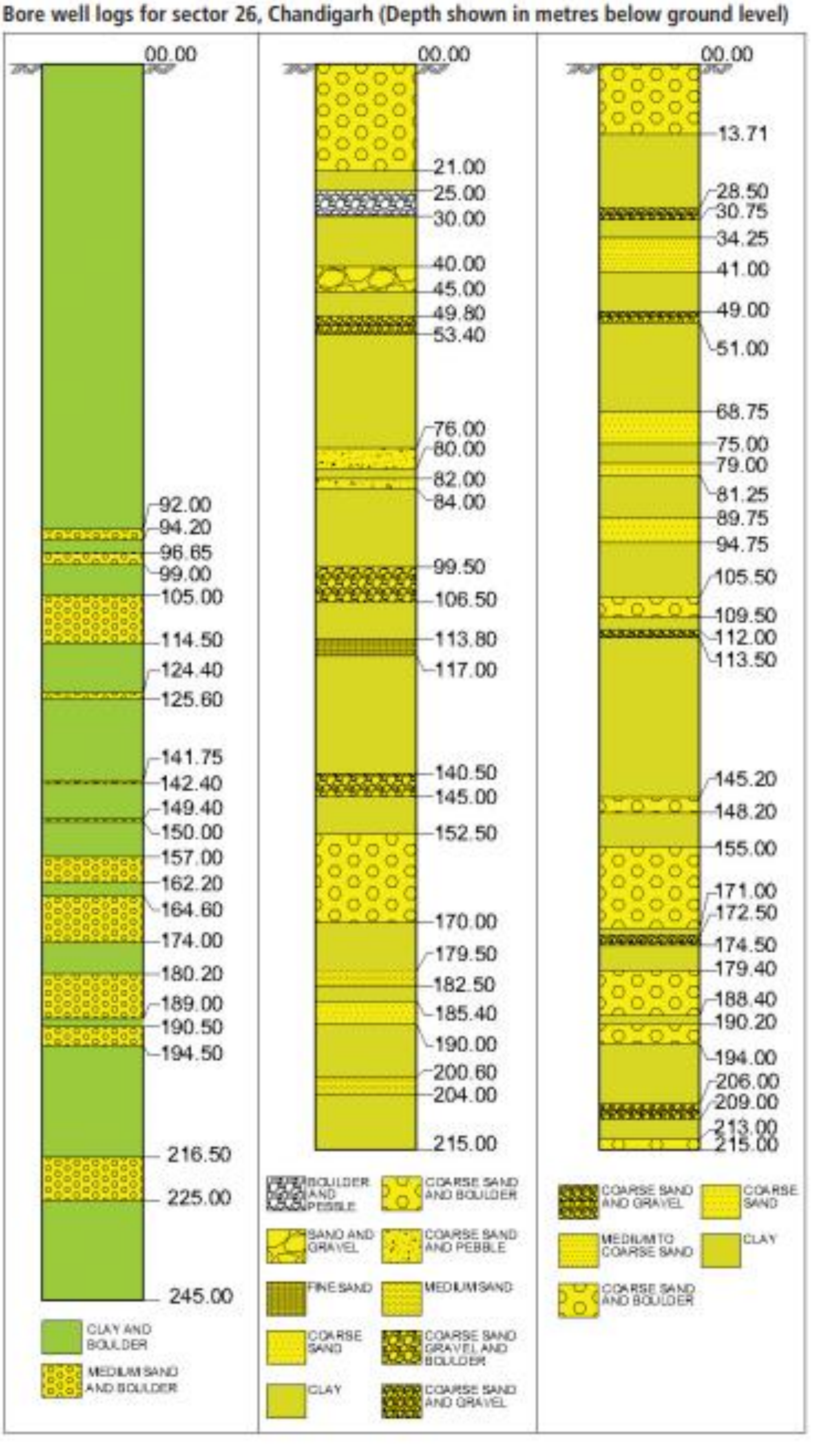


Figure 77 Borewell Log 2

5.7 IDENTIFICATION OF LOCATION FOR RWH PITS

The previous section explained the macro scale analysis of geophysical layers, and further, volume of surface run-off that needs to be catered for recharging. But demarcating exact location of recharge pit is dependent on the GIS layers measured by LIDAR data points.

Case 1: Junction of Sector 26

Figure 78: Google Earth Imagery of Junction 1

While the contours are the most important layer to identify the slope of area, Chandigarh is mostly a flat terrain. So, we need more than just the contour layer to identify the flow direction of surface run-off. The additional layers include: Aspect, Flow Direction, DEM (Digital Elevation Model), and classified data point cloud.

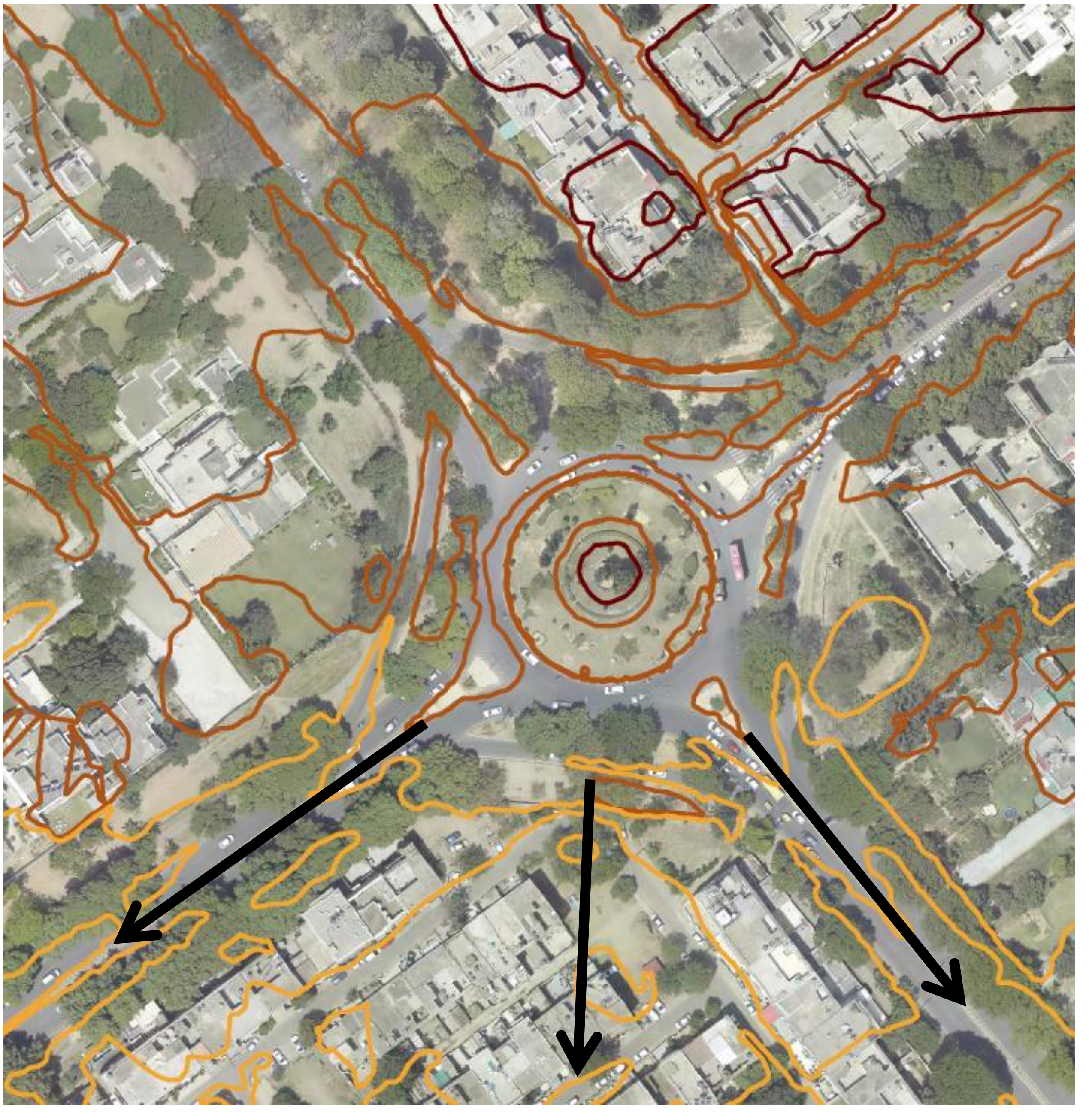
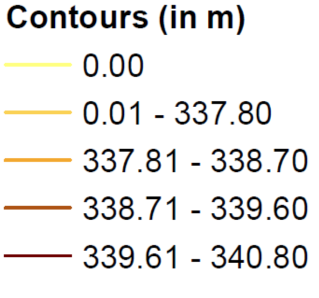


Figure 79: Map showing Contours of the Junction 1



The arrows on the map identify the direction of slope of Junction 1.

Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. The aspect map of the junction depicts the flow direction in three regions mainly, a) Northwest, Northeast and South.

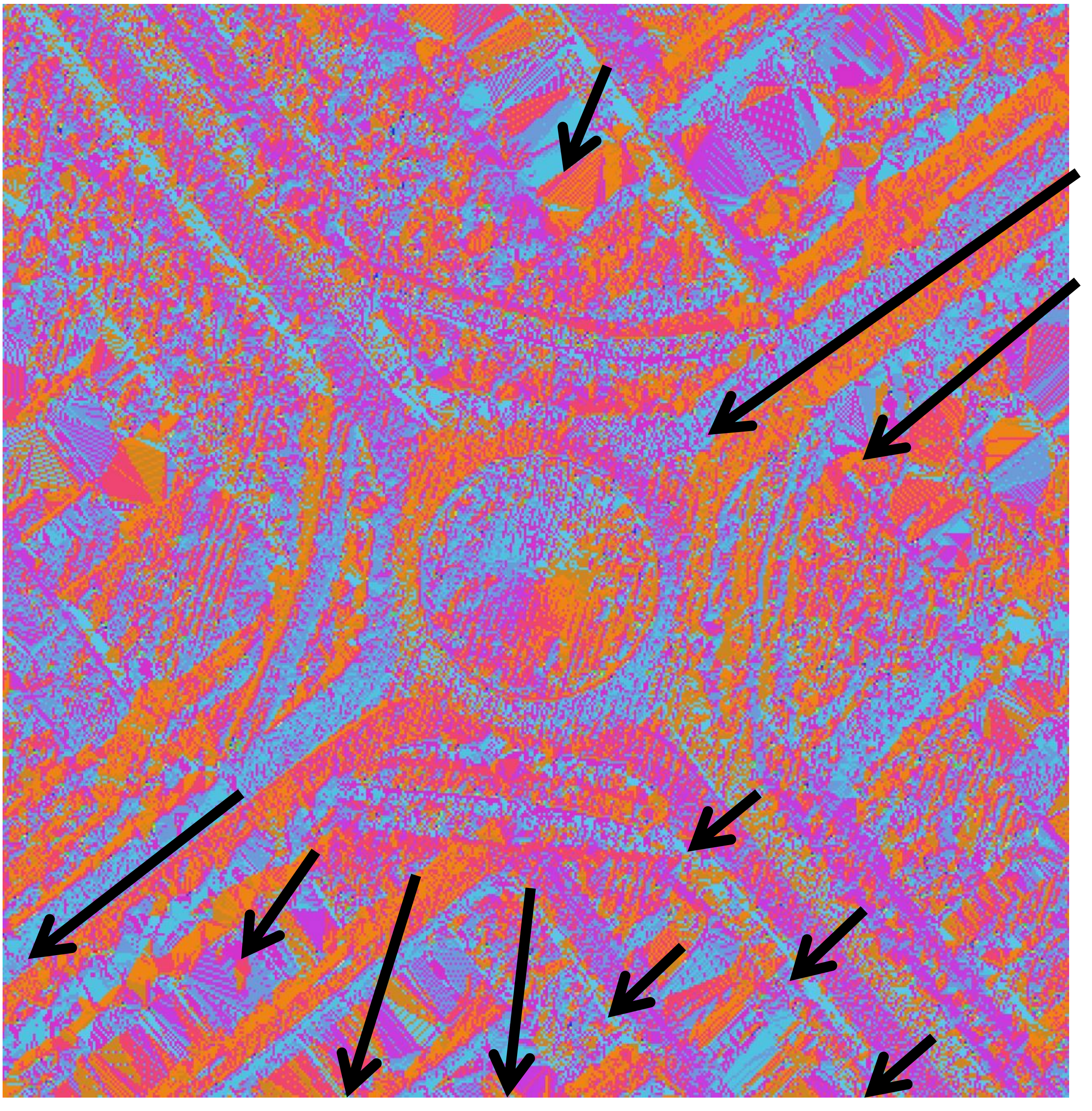
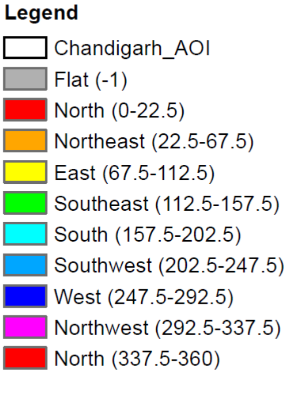


Figure 80: Aspect Map of Junction 1

The flow direction returns unique values (powers of 2), while aspect returns a continuous range of floats. Therefore, The dorection of flow for surface run-off now can be demarcated more precisely from south west and south in conjunction with the stormwater drain lines running through the area.



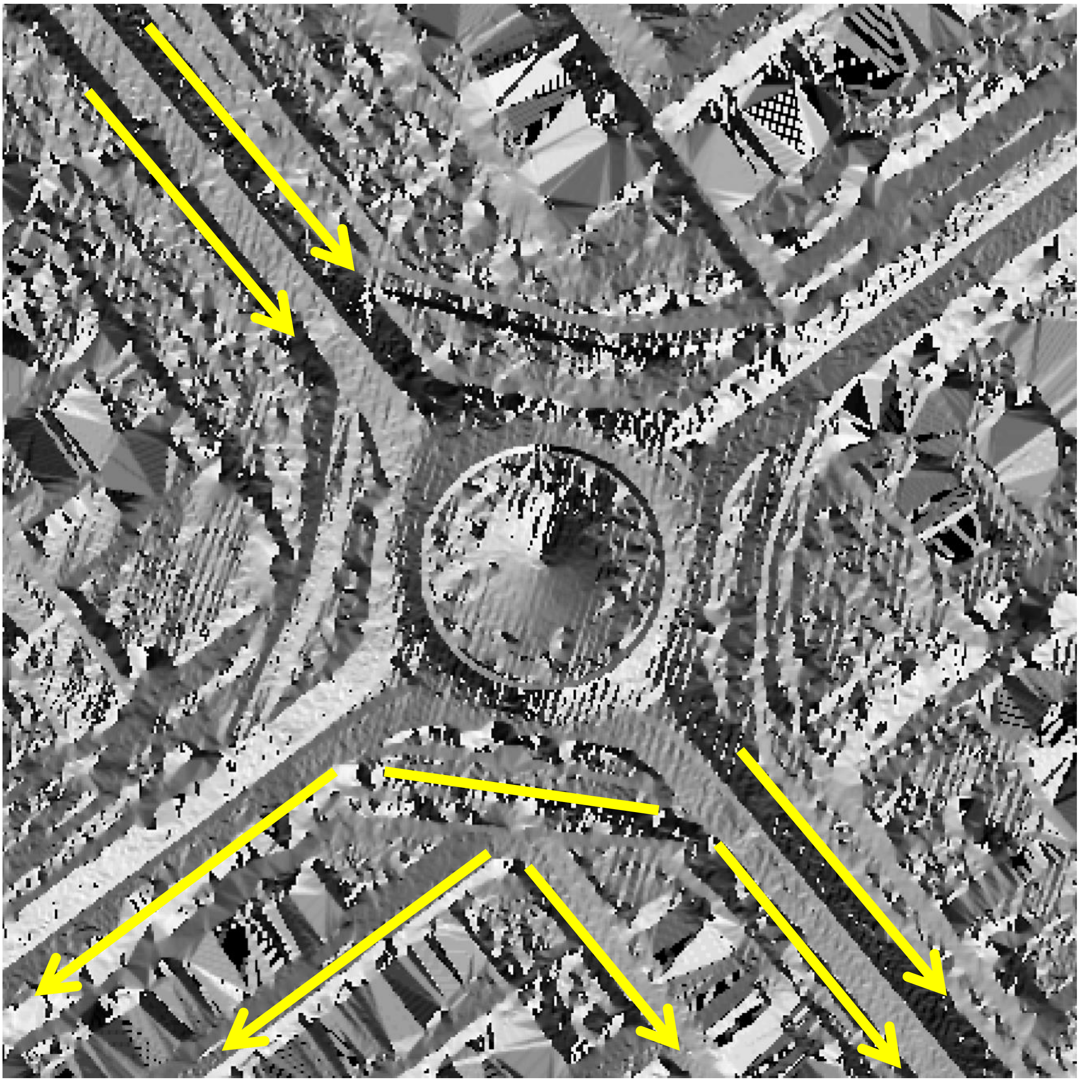
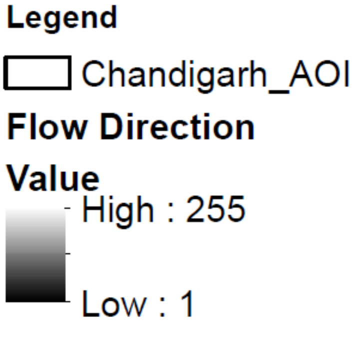


Figure 81: Flow Direction Map of Junction 1

The DEM provides a visual depiction of the elevation changes in the area, and is more detailed representation of terrain's topography. This allows to observe the elevation changes and patterns more clearly, as the contour lines provide a visual reference for understanding the terrain's characteristics.



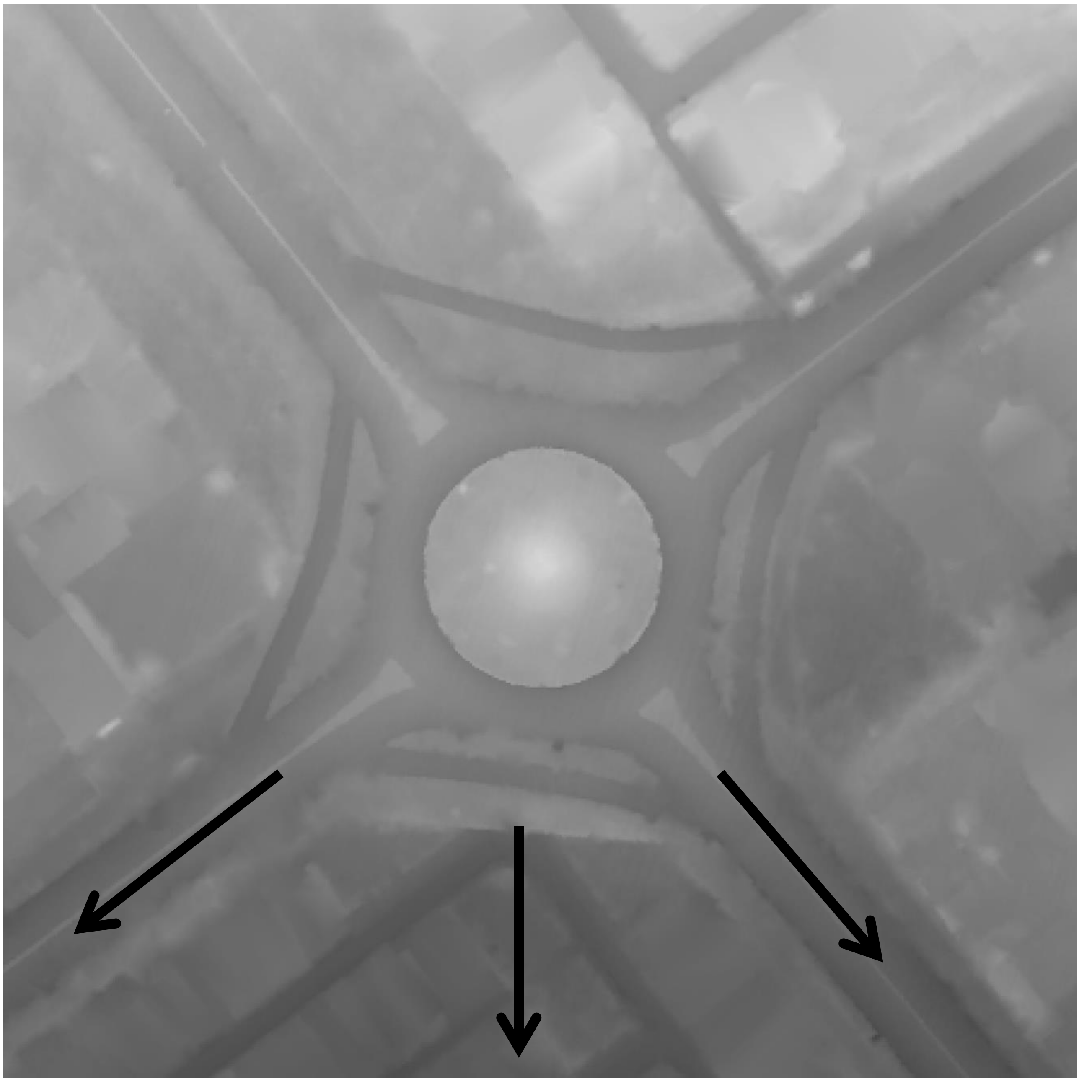
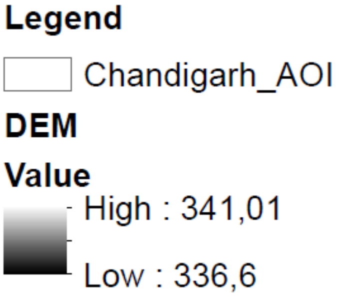


Figure 82: DEM Map of Junction 1



The Lidar Data pointcloudtells the areas give the clear ground area available for intervention.In the direction of flow, we can now identify exact locations for creating recharge pits.

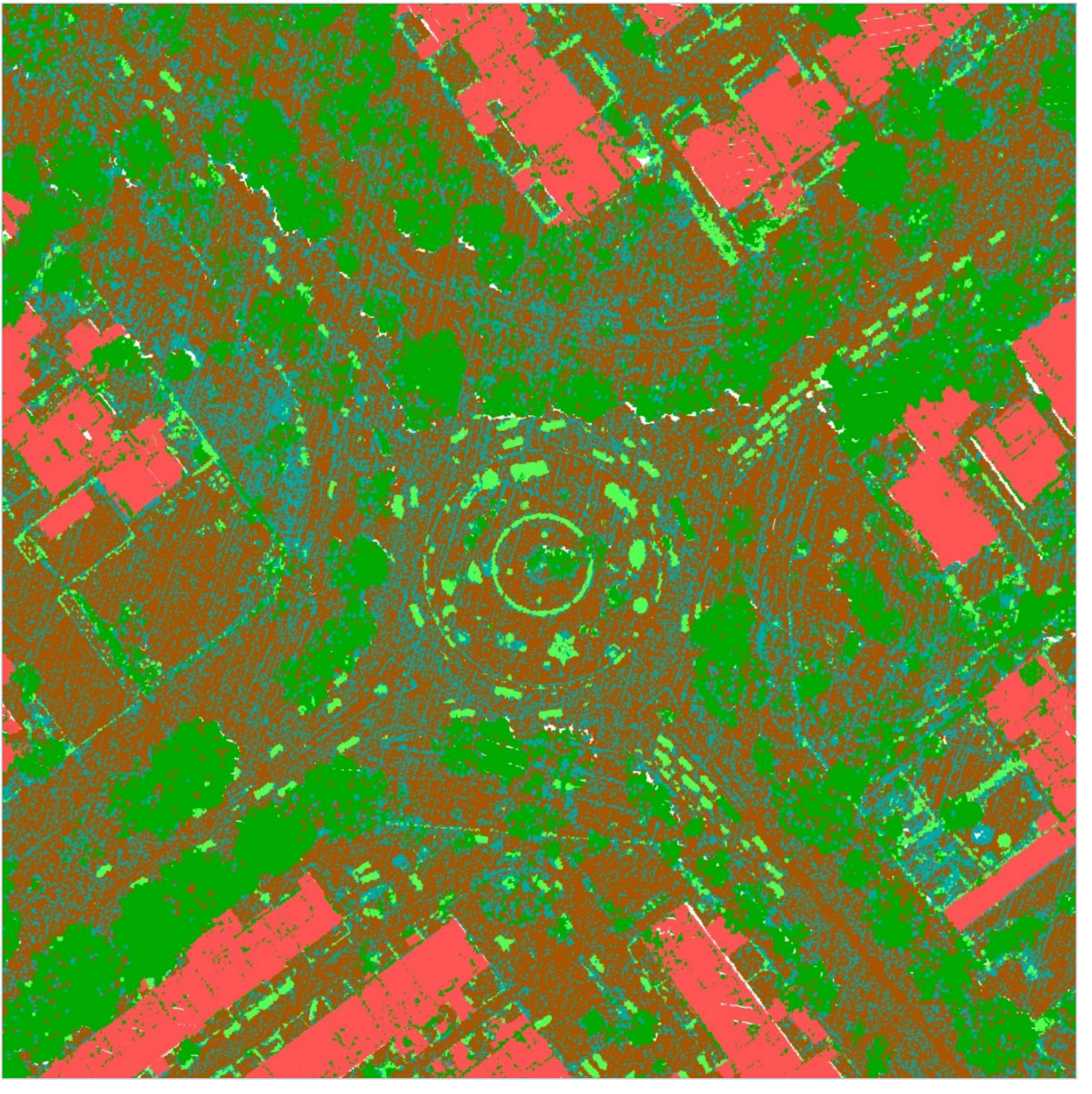


Figure 83: Lidar Point Data for Junction 1

5.8 RESULTS AND DISCUSSION

The extractions from five layers in the previous section, i.e. topography, DEM, contours, aspect and flow direction, when overlaid on one another distinctively map out some points on the Lidar Point cloud. These locations are possible spots for creating recharge pits, or basins. As calculated in section 5.5, total 520 number of recharge pits need to be made, which might not be possible in the living sectors. Therefore, these pits can also be clubbed in the form of recharge basins in the non-paved areas falling along the flow direction.

Pits and basins together shall have the holding capacity equal to the run-off volume during flash rains (considering the safety factor).

………………………………. **END OF CHAPTER 5** ……………………………….

CHAPTER 6: CONCLUSION

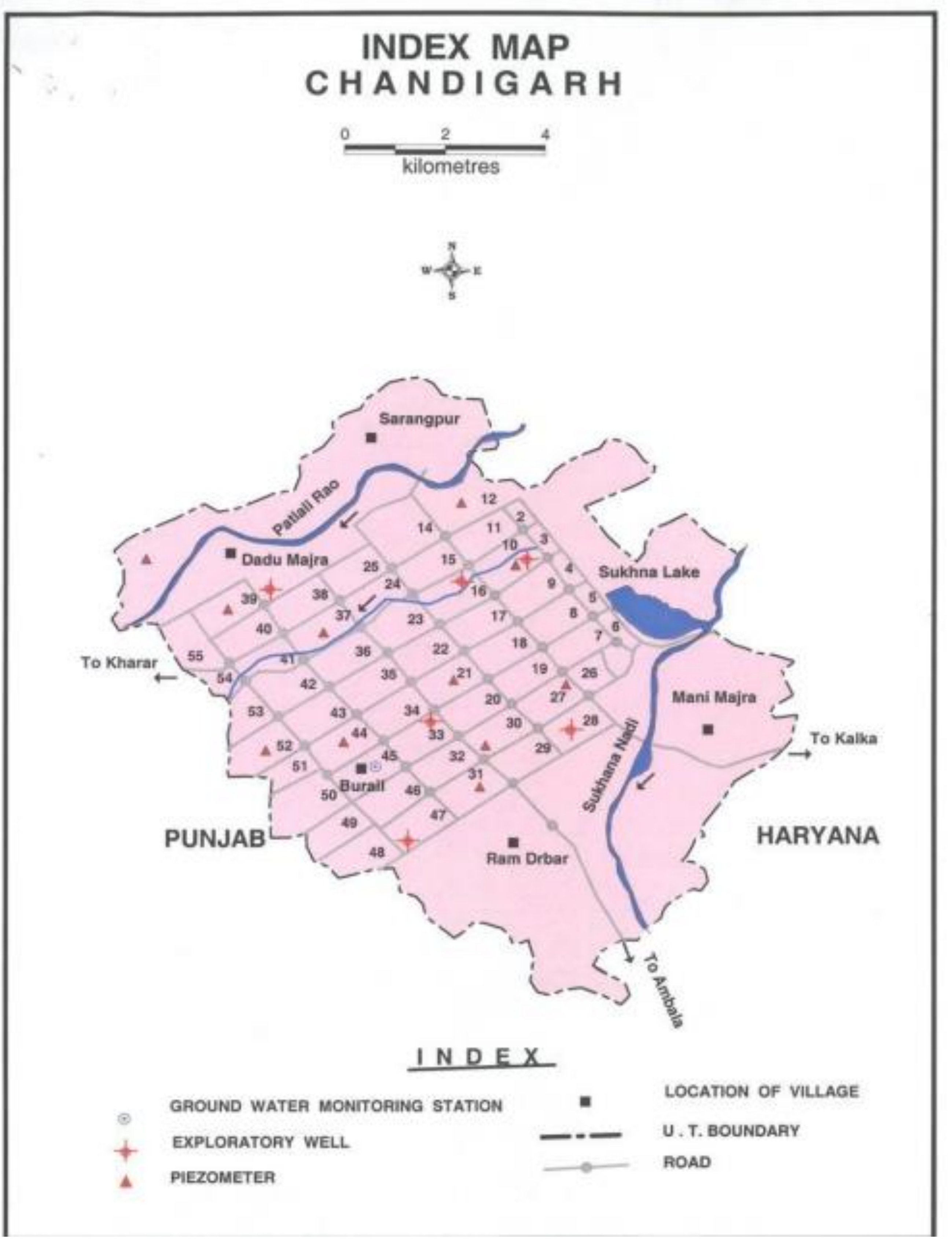
The study produced some notable findings and altered some beliefs about rainwater harvesting systems, which were previously thought to be a chaotic process.

• Depending on what occurs above ground, the subsurface strata are constantly altering and evolving. Situations change as a result of new construction activity, changes in water extraction methods, basement construction, etc. Comparing LIDAR technology to more traditional approaches of analysing geophysical strata reveals greater accuracy and shorter processing times. It is a vector-based technique that takes everything into account in three dimensions as opposed to two.

• A prominent example of integrating recharge and extraction management for a metropolis is the aquifer management case study of Delhi. Given the severe water deficit and declining groundwater levels in the city, it is urgent to develop water resilience at the neighbourhood and city levels.By strategically placing the recharge pits, RWH pits, and trenches, it is possible to prevent water logging from rapid rains while also recharging the groundwater. Due to climate change, the frequency of flash showers has increased during the last ten years. In the dry months of the year, it is imperative that surface run-off be carefully managed and used. • The pilot in sector 26 revealed that Chandigarh is a more reliable planned city than other cities. The first week of May provided a peek of the effects when two days of untimely flash rain placed the technocrats in a bind. Sector 26 had significantly less water logging than the rest of the area, and the water channelled itself quite smoothly. However, after at least one monsoon season, the effect on subsurface layers and groundwater levels will be apparent.

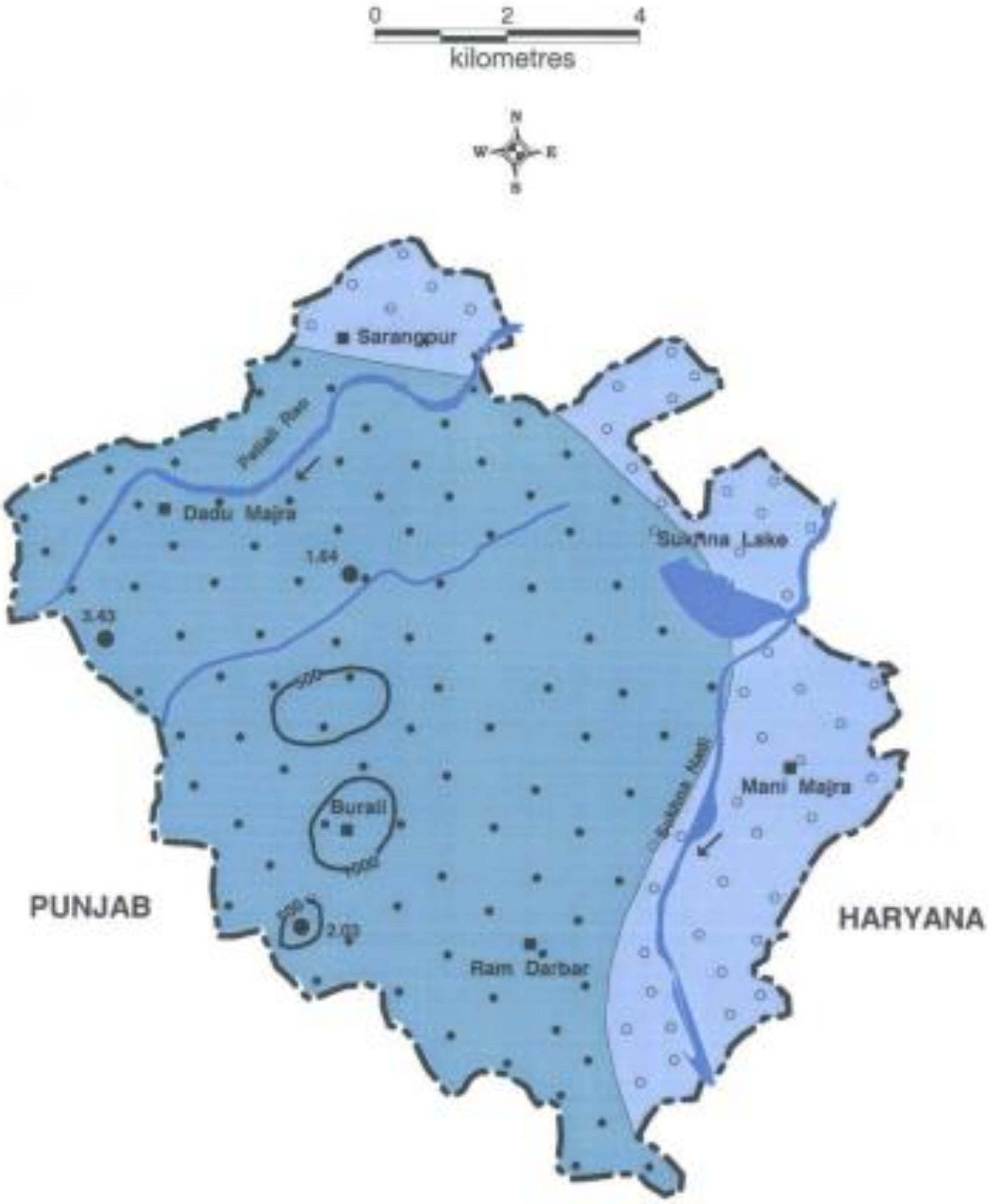
ANNEXURES

1. GEOPHYSICAL LAYERS OF CHANDIAGRH



HYDROGEOLOGY

CHANDIGARH

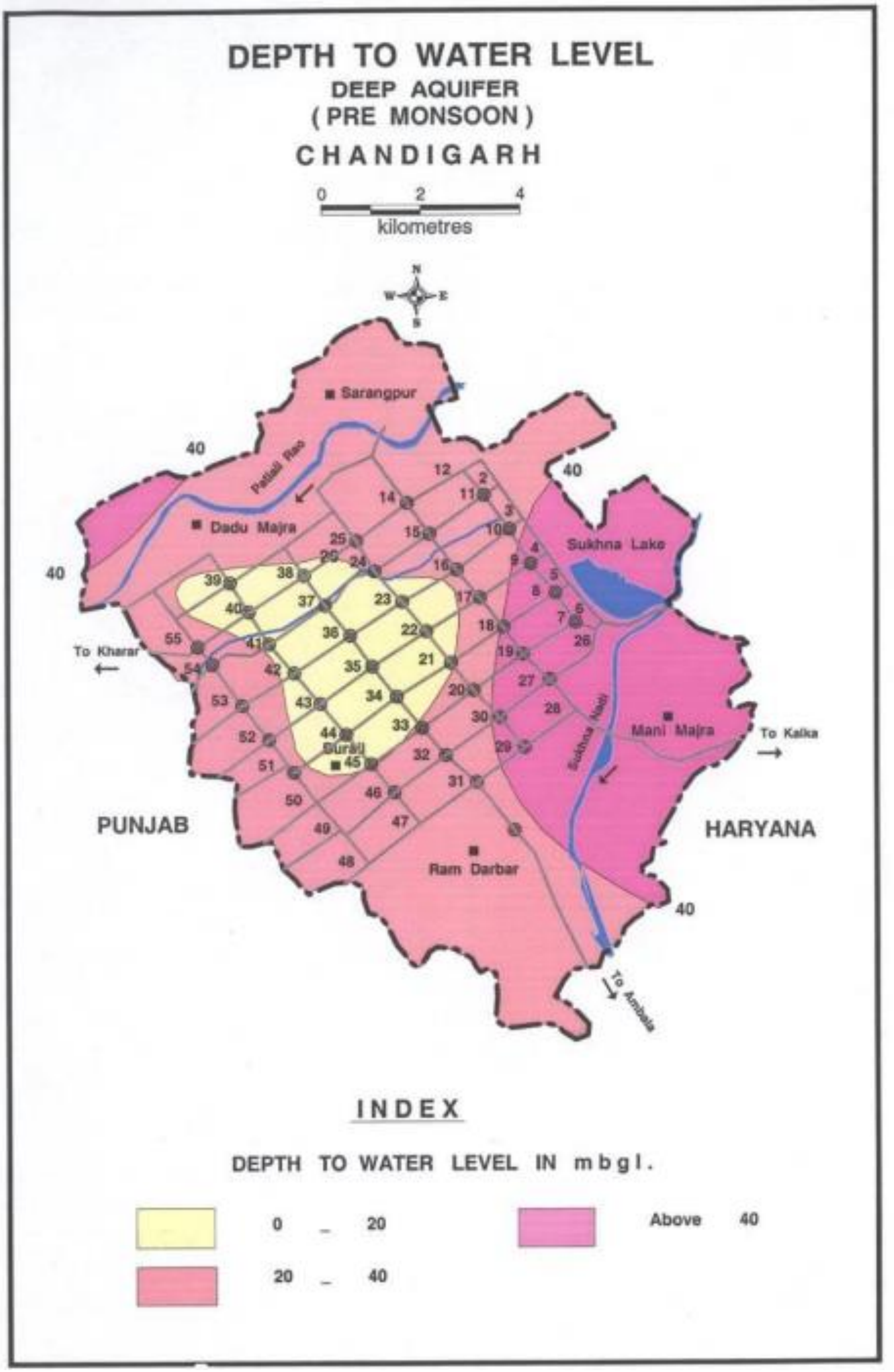


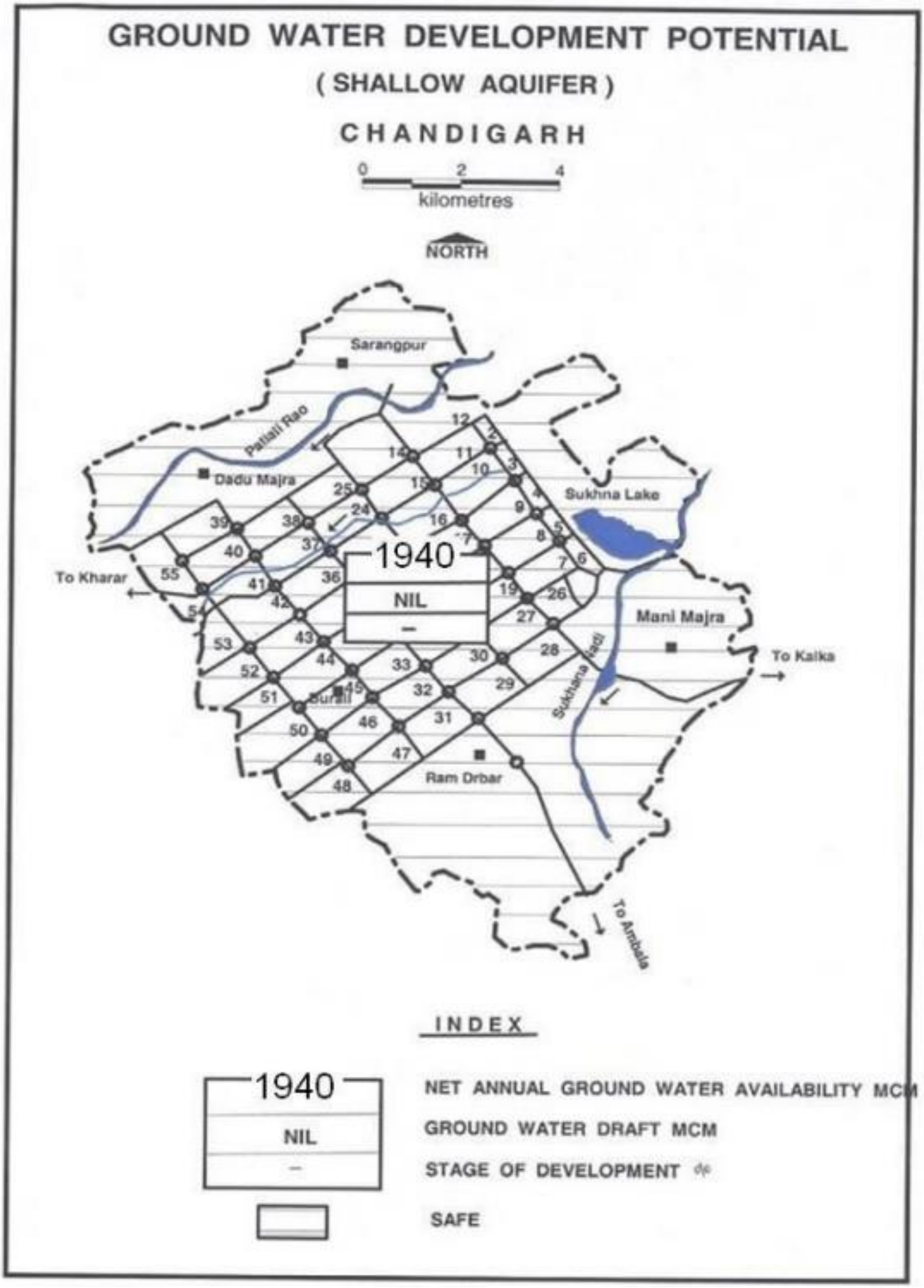
INDEX

	WELLS FEASIBLE	RIGS SUITABLE	DEPTH OF WELL (m)	DISCHARGE (lpm)	SUITABLE ARTIFICIAL RECHARGE STRUCTURES
Soft Rock Aquifer	Tube Wells	Reverse / Direct Rotary	25 – 400	300 - 1000	Recharge Trench with Injection Well
Soft Rock Aquifer	Tube Wells	Percussion / Odex	100 – 300	More than 500	Recharge Trench with Injection Well

500 Electrical Conductivity (Micromhos / Cm at 25°C)

3.43 ● Iron more than permissible limt (1.0 mg / l)

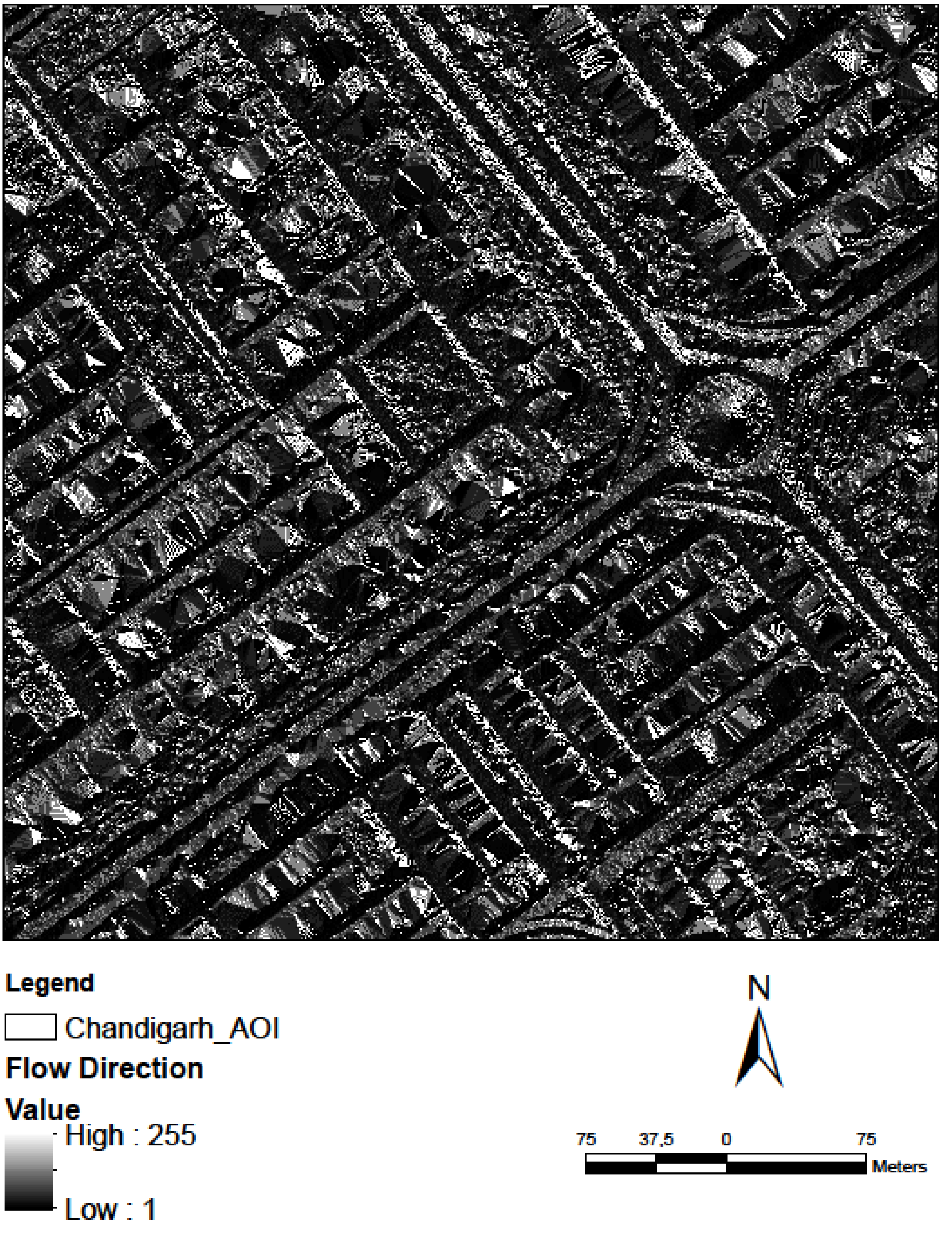

DEPTH TO WATER LEVEL
DEEP AQUIFER
(PRE MONSOON)
CHANDIGARH
0 2 4
kilometres
Sarangpur
Patiali Rao
Dadu Majra
Sukhna Lake
To Kharar
To Kalka
Mani Majra
Sukhna Nadi
Burail
Ram Darbar
PUNJAB
HARYANA
To Ambala
40
INDEX
DEPTH TO WATER LEVEL IN m b g l.
0 – 20
20 – 40
Above 40

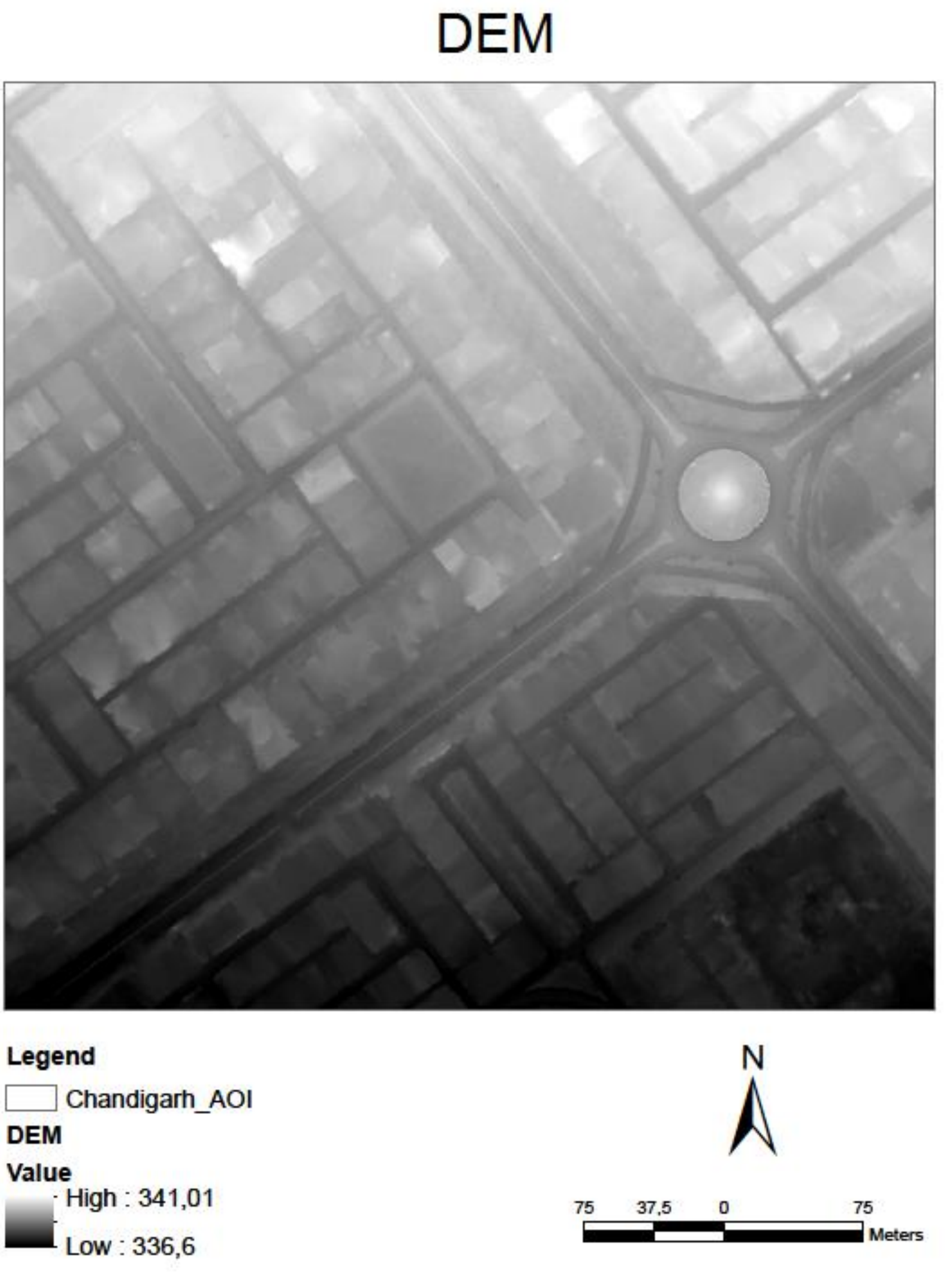

GROUND WATER DEVELOPMENT POTENTIAL
(SHALLOW AQUIFER)
CHANDIGARH
0 2 4
kilometres
NORTH
Sarangpur
Patiali Rao
Dadu Majra
Sukhna Lake
Mani Majra
To Kharar
To Kalka
To Ambala
Burail
Ram Drbar
Sukhana Nadi
1940
NIL
–
INDEX
1940
NIL
–
NET ANNUAL GROUND WATER AVAILABILITY MCM
GROUND WATER DRAFT MCM
STAGE OF DEVELOPMENT %
SAFE

2. LIDAR MAPPING LAYERS FOR CHANDIGARH

Orthophoto 5cm

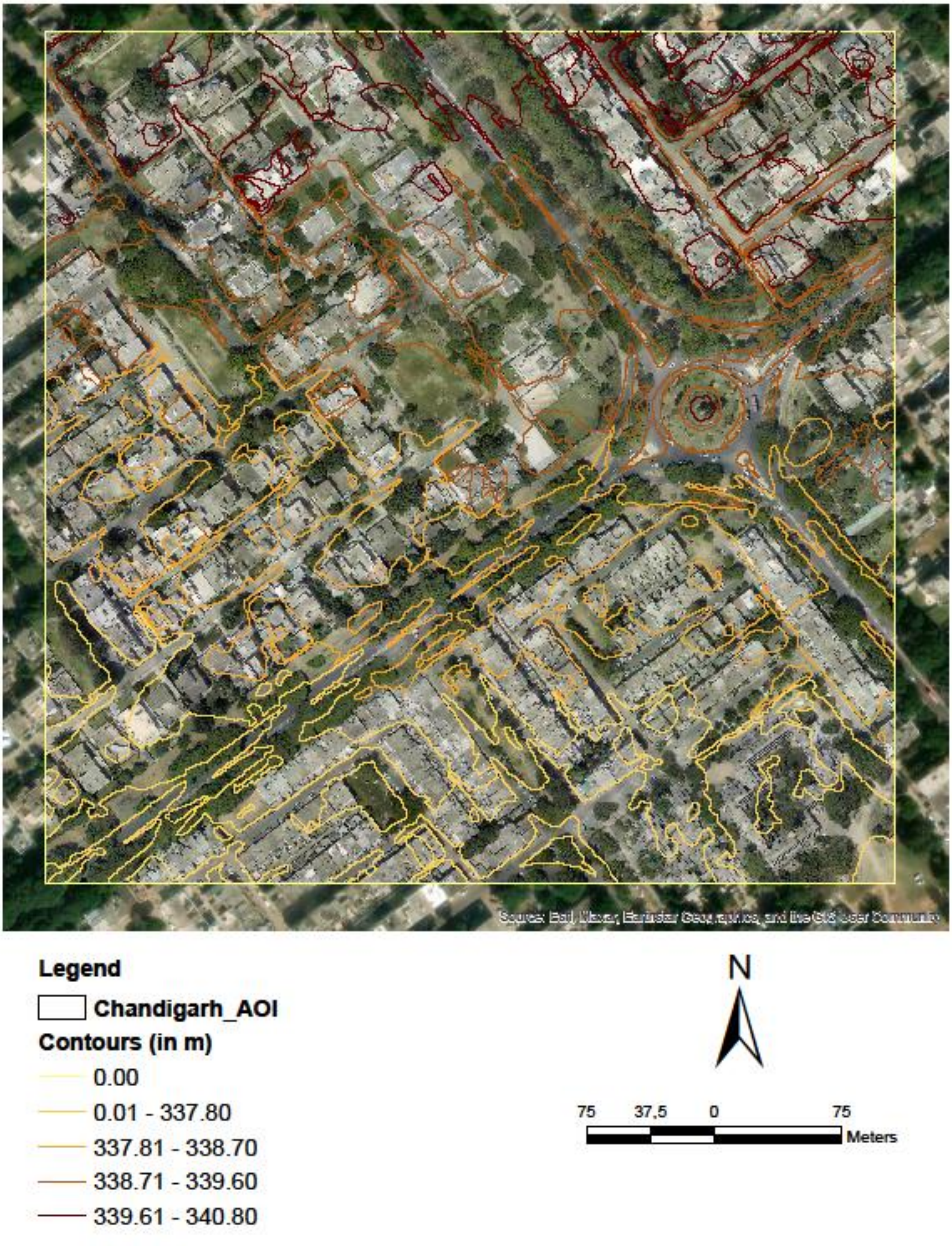
Flow Direction



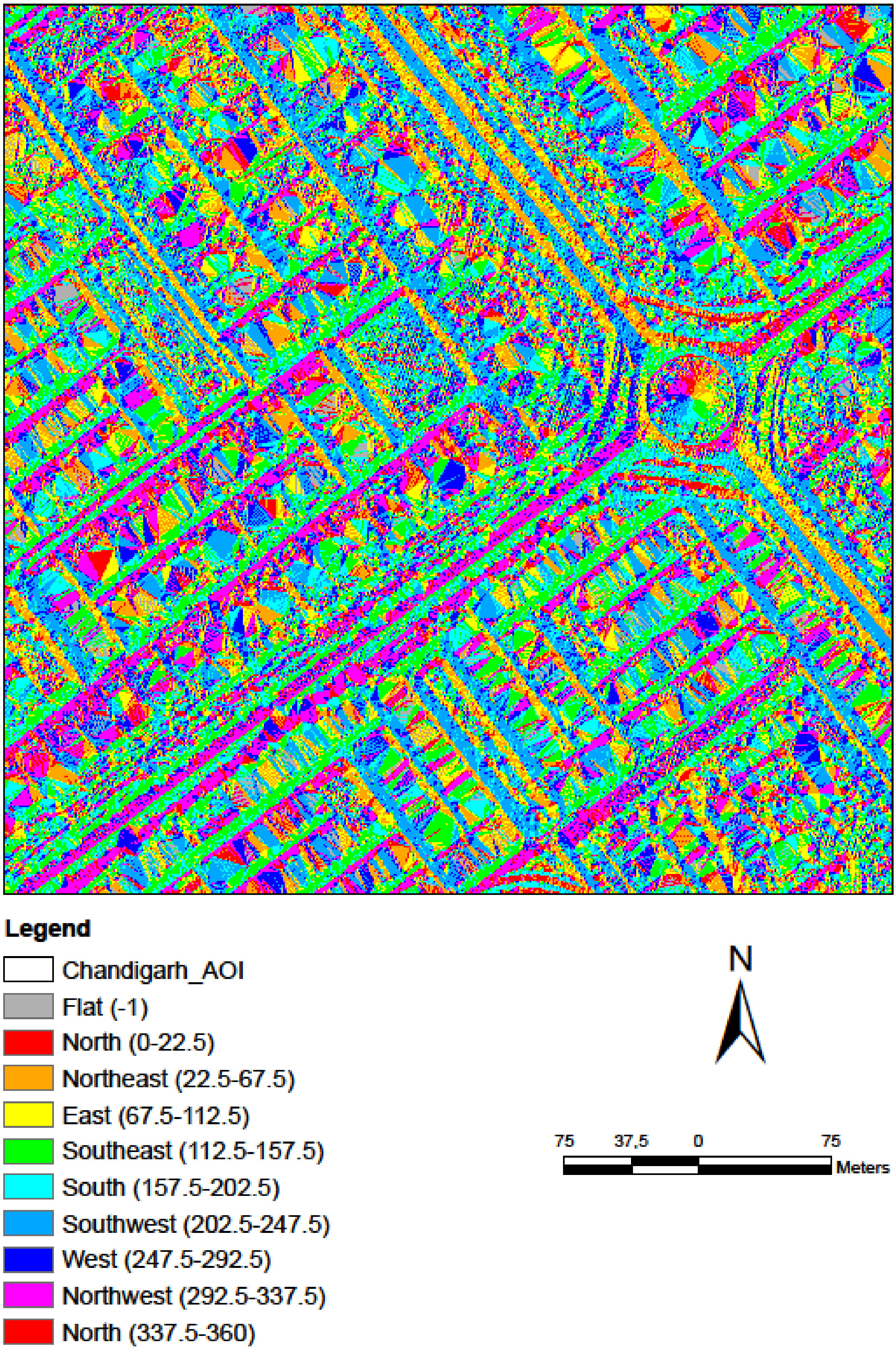


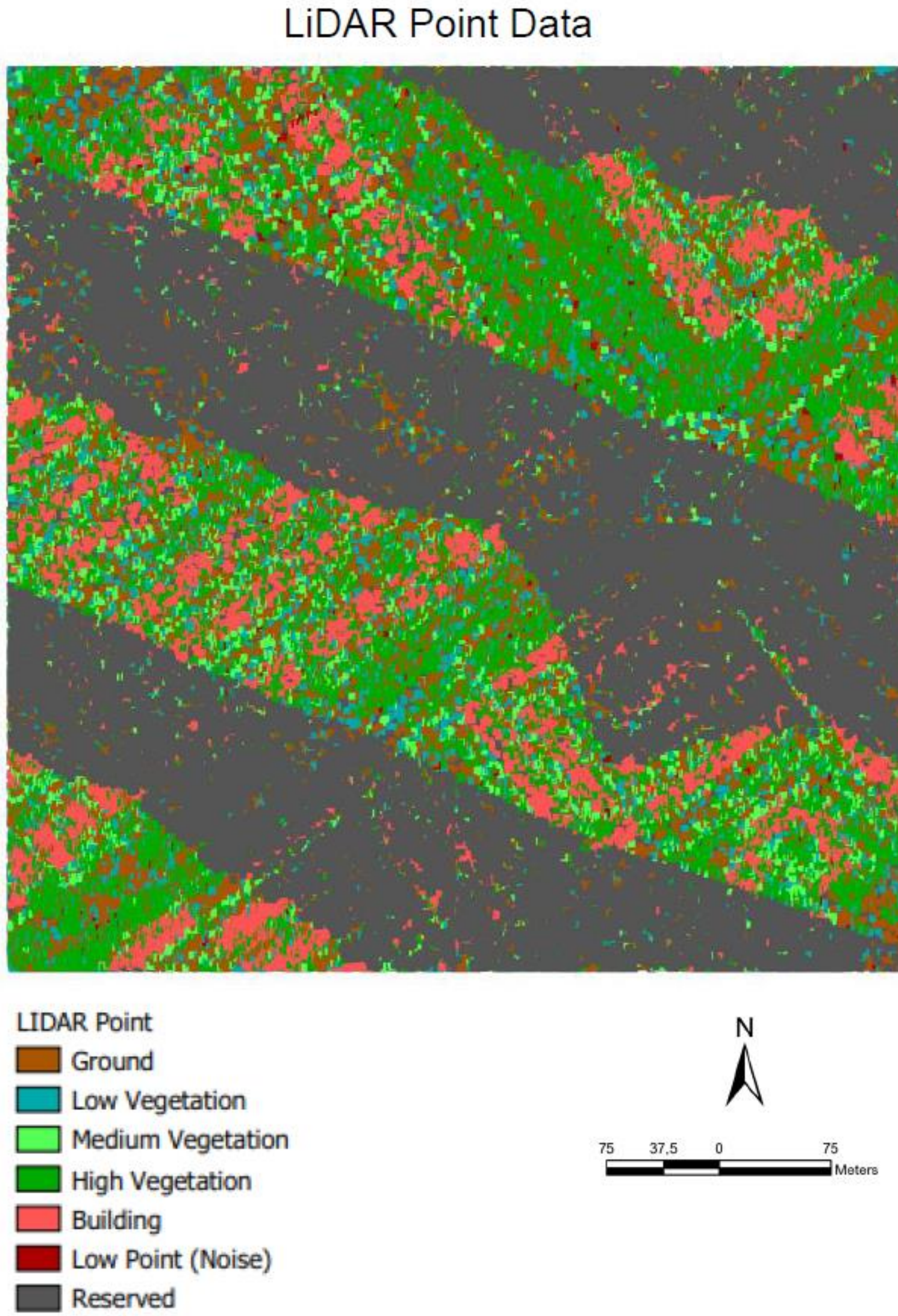
DEM
Legend
Chandigarh_AOI
DEM
Value
High : 341,01
Low : 336,6
N
75
37,5
0
75
Meters

Contour


Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
Legend
Chandigarh_AOI
Contours (in m)
0.00
0.01 - 337.80
337.81 - 338.70
338.71 - 339.60
339.61 - 340.80
N
75
37.5
0
75
Meters

Aspect


Legend
Chandigarh_AOI
Flat (-1)
North (0-22.5)
Northeast (22.5-67.5)
East (67.5-112.5)
Southeast (112.5-157.5)
South (157.5-202.5)
Southwest (202.5-247.5)
West (247.5-292.5)
Northwest (292.5-337.5)
North (337.5-360)
N
75 37,5 0 75
Meters


LiDAR Point Data
LIDAR Point
Ground
Low Vegetation
Medium Vegetation
High Vegetation
Building
Low Point (Noise)
Reserved
N
75
37,5
0
75
Meters

3. LIDAR STUDY ATTRIBUTE TABLE

Feature Type	Class(LULC)	Sub_Class	Attribute_Fields																						
LULC	Road	Cycle Track	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Foot Path	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Primary Road V1	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Primary Road V2	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Primary Road V3	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Secondary Road V4	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Tertiary Road V5	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Internal Road V6	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Service Lane SL	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	IT Park Road	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Primary Intersections	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Secondary Intersections	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Village Rural Primary Road	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Village Rural Secondary Road	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Village Rural Tertiary Road	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Village Phirni Road	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Village Abadi Road	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Parking Connecting Road	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Zebra Crossing	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Land Parcel - Road Flyover	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Grey Top	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Grey Top - Mud	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Kerb Land	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Primary Road Signage Type - 6	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	Road	Slip Road	Code	ID	Class	Sub_Class	Sector	Ward_No	Construction Material	Carraige_Width	Right_of_Width	Ground_Height	RZ_6am 11pm	FP_Width	Junction_Name	Junction	Road_Name	Shape_Length	Shape_Area						
LULC	ROW		Code	ID	Class	Sub_Class	Sector	Ward_No	Road_ID	Road_Name	Construction Material	Right_of_Width	Ground_Height	Junction_Name	Junction	Shape_Length	Shape_Area								
LULC	Bridges	Culvert	Code	ID	Class	Sub_Class	Sector	Ward_No	Width	Length	Construction Material	Ground_Height	Shape_Length	Shape_Area											
LULC	Bridges	Under Pass	Code	ID	Class	Sub_Class	Sector	Ward_No	Width	Length	Construction Material	Ground_Height	Shape_Length	Shape_Area											
LULC	Bridges	Foot over Bridge	Code	ID	Class	Sub_Class	Sector	Ward_No	Width	Length	Construction Material	Ground_Height	Shape_Length	Shape_Area											
LULC	Bridges	Bridges	Code	ID	Class	Sub_Class	Sector	Ward_No	Width	Length	Construction Material	Ground_Height	Shape_Length	Shape_Area											
LULC	Bridges	Pedestrain Underpass	Code	ID	Class	Sub_Class	Sector	Ward_No	Width	Length	Construction Material	Ground_Height	Shape_Length	Shape_Area											
LULC	Water Bodies	Stream	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Water Bodies	Drainage	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Water Bodies	Lake	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Water Bodies	Dam	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Water Bodies	Water Body	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Water Bodies	Water Tanks (Underground)	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Water Bodies	Well	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Water Bodies	Water Body Dry	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													

LULC	Water Bodies	Jetty	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Water Bodies	Sluice Gate	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Residential	Landuse - Residential	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	House_No	Shape_Length	Shape_Area													
LULC	Commercial	Hotel/Lodge /Restaurant	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Commercial	Shopping centre /Mall	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Commercial	Multiplex/ Cinema	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Commercial	Function hall	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Commercial	Storage Godown	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Commercial	Petrol Pump	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Commercial	Hostel	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Commercial	Market (Daily/ Weekly)	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Commercial	Landuse - Commercial	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Commercial	Fish Market	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Commercial	Wood / Coal Depot	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Industrial	IT Parks	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												

LULC	Industrial	Industrial	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												
LULC	Educational	School	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Educational	College	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Educational	University	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Educational	Vocational Institute	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Educational	Anganwari	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Educational	Training Institute	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Educational	Hostel	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	BLDG_No	Shape_Length	Shape_Area												
LULC	Health Services	Govt.Hospital	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												
LULC	Health Services	Private Hospital	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												
LULC	Health Services	Clinic/Dispensary	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												
LULC	Health Services	Primary/ Community Helath Centre	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												
LULC	Health Services	Vetenary Hospital	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												
LULC	Central Govt. Property	Office	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												

LULC	Central Govt. Property	Quarter	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	State Govt Property	Office	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	State Govt Property	Quarter	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	State Govt Property	State Govt Property	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Railway Property	Railway Property	Code	ID	Class	Sub_Class	Sector	Ward_No	Railway_Line_Name	Width	Length	Ground_Height	Shape_Length	Shape_Area											
LULC	Railway Property	Railway Overhead Bridge	Code	ID	Class	Sub_Class	Sector	Ward_No	Railway_Line_Name	Width	Length	Ground_Height	Shape_Length	Shape_Area											
LULC	Railway Property	Railway Underpass	Code	ID	Class	Sub_Class	Sector	Ward_No	Railway_Line_Name	Width	Length	Ground_Height	Shape_Length	Shape_Area											
LULC	Railway Property	Railway Gate	Code	ID	Class	Sub_Class	Sector	Ward_No	Railway_Line_Name	Width	Length	Ground_Height	Shape_Length	Shape_Area											
LULC	Public & Semi - Public	Banks	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Police Station	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Jail	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Crematorium/ Burial Ground / Grave Yard	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Guest House	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												

LULC	Public & Semi - Public	Community Hall	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Dharmasala	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Tourist Facility Centre	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Auditorium	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Convention Centre	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Museum	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Public Library	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Art & Cultural Centre	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Disaster Management Centre	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Dhobi Ghat	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Crech/ Day Care	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Public/ Community Toilet	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Social Welfare Centre	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Fire Station	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												
LULC	Public & Semi - Public	Sampark Centre Area	Code	ID	Class	Sub_Class	Sector	Ward_No	Ground_Height	Name	BLDG_No	Shape_Length	Shape_Area												

LULC	Religious	Temple	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												
LULC	Religious	Mosque	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												
LULC	Religious	Idgah	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												
LULC	Religious	Church	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												
LULC	Religious	Gurudwara	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area	BLDG_No												
LULC	Recreational	Garden	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Recreational	Park	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Recreational	Playground - Basic	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Recreational	Club	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Recreational	Sports Centre	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Recreational	Gymnasium	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Recreational	Swimming Pool	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Recreational	Stadium	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Recreational	Golf Course	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													
LULC	Recreational	Playground - Handball Court	Code	ID	Class	Sub_Class	Sector	Ward_No	Name	Ground_Height	Shape_Length	Shape_Area													

Point	Storm water Drainage	Rectangular Manholes Type - 1	Code	ID	Class	Sub_Class	Sector	Ward_No	X	Y	RW_Sewage_WS	Top_Height	Ground_Height	Junction											
Point	Storm water Drainage	Rectangular Manholes Type - 2	Code	ID	Class	Sub_Class	Sector	Ward_No	X	Y	RW_Sewage_WS	Top_Height	Ground_Height	Junction											
Point	GNSS	Survey Station Points	Code	CLASS	SUB_CLASS	Point_ID	Easting	Northing	Elevation																
Point	GNSS	Surveyed GPS Reference Point	Code	CLASS	SUB_CLASS	Point_ID	Easting	Northing	Elevation																

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APPENDIX: RESEARCH CONTRIBUTIONS

Publication accepted:

1. Gopal Mohan and K.C. Tiwari, “**Potential of Rainwater Harvesting in Delveloping Water Resilience: Case of bangalore**” in (*International Journal of Research-Granthaalayah* (Accepted on 23rd may,2023).

Thank you for submitting your manuscript **"POTENTIAL OF RAINWATER HARVESTING IN DEVELOPING WATER RESILIENCE: CASE OF BANGALORE"** to **"International Journal of Research -GRANTHAALAYAH"**.

The editorial team and a group of expert reviewers have assessed your submission and feel that it has potential for publication, and so we would like to invite you to revise the paper and resubmit for further review.

We found Similarity index in your manuscript, please try to reduce it upto 15% and self plagiarism level must be less than 20% and also update references as per report.

You have 4 weeks (If you required more extensions for resubmission please informed us by email) to respond to this revise and resubmit request, after which point we will presume that you have withdrawn your submission from **"International Journal of Research -GRANTHAALAYAH"**.

Publication submitted, but acceptance yet to be received:

1. Gopal Mohan and K.C. Tiwari, “**Utilizing lidar Data for Indentification of potential Rainwater harvesting points in Chandigarh**” in *Water Security Journal* (Submitted on 22nd May 2023).