# EXPLORATION OF GROUNDWATER POTENTIAL ZONES FOR SHIMLA DISTRICT USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

A

PROJECT REPORT

*Submitted in partial fulfillment of the requirements for the award of the degree*

*of*

**BACHELOR OF TECHNOLOGY**

**IN**

**CIVIL ENGINEERING**

*Under the supervision*

*of*

**Mr. AKASH BHARDWAJ**

**ASSISTANT PROFESSOR (GRADE II)**

*by*

**KARMA YOEZER (201603)**
**PHURPA DORJI (201604)**

*to*

**JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY**

**WAKNAGHAT, SOLAN–173234**

**HIMACHAL PRADESH, INDIA**

**MAY, 2024**

# DECLARATION

We hereby declare that the work presented in the Project report entitled "**EXPLORATION OF GROUNDWATER POTENTIAL ZONES FOR SHIMLA DISTRICT USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM**" submitted for partial fulfillment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of our work carried out under the supervision of **Mr. Akash Bhardwaj (Assistant Professor, Grade II).** This work has not been submitted elsewhere for the reward of any other degree/diploma. We are fully responsible for the contents of our project report.

Karma Yoezer (201603)

Department of Civil Engineering

Jaypee University of Information Technology

JUIT, Waknaghat

Phurpa Dorji (201604)

Department of Civil Engineering

Jaypee University of Information Technology

JUIT, Waknaghat

# CERTIFICATE

This is to certify that the work which is being presented in the project report titled "**EXPLORATION OF GROUNDWATER POTENTIAL ZONES FOR SHIMLA DISTRICT USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM**" in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology,** Waknaghat is an authentic record of work carried out by **Karma Yoezer (201603) and Phurpa Dorji (201604)** during a period from July 2023 to May 2024 under the supervision of **Mr. Akash Bhardwaj (Assistant Professor, Grade II),** Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

Date: ………………….

Prof. (Dr.) Ashish Kumar

Professor and Head of Department

Department of Civil Engineering

JUIT, Waknaghat, India

Mr. Akash Bhardwaj

Assistant Professor (Grade II)

Department of Civil Engineering

JUIT, Waknaghat, India

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# ABSTRACT

Exploration of groundwater can be done using various methods. However, over the years, exploration of groundwater using remote sensing and geographic information system has gained popularity because it is efficient in both cost and time. Mapping and evaluation of groundwater potential zones as well as identifying sites suitable for recharge are some features of groundwater study using remote sensing and geographic information system.

Construction of new wells requires prior information about the groundwater potentiality of the area if not; there are high possibilities that the ground may be dry. Likewise in Shimla district, many handpumps have been abandoned due to low yield and some borewells were found dry. In this research, we create groundwater potential zone map of Shimla district by using a combination of remotely sensed data, geographic information system and analytical hierarchical process technique.

In this study, thematic maps are created using remotely sensed data and Geographic information system software. A total of seven thematic layers were studied and weight is assigned to each class in all the thematic layers through analytic hierarchical process techniques and weighted overlay method. By integrating and doing pair wise comparison, a map of groundwater potential zones is created. The map shows Very High, High, Moderate, Low and Very Low zones of groundwater of Shimla District.

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# LIST OF ACRONYMS & ABBREVIATIONS

| | |
|---|---|
| AHP | Analytical Hierarchical Process |
| AOI | Area of Interest |
| ArcSDM | Spatial Data Modeller for ArcGIS and Spatial Analyst |
| AUC | Area under Curve |
| CGWB | Central Groundwater Board |
| CI | Consistency Index |
| CR | Consistency Ratio |
| DEM | Digital Elevation Model |
| DSMW | Digital Soil Map of the World |
| E&SE | East & Southeast |
| FAO | Food and Agriculture Organization |
| FPR | False Negative Rate |
| GIS | Geographic Information System |
| GSI | Geology Survey of India |
| GWPZ | Groundwater Potential Zone |
| IMD | Indian Meteorological Department |
| IRS LISS III | Indian Remote Sensing Linear Imaging Self Scanning III |
| ISRO | Indian Space Research Organization |
| K | Coefficient of Permeability |
| LPM | Liters per Minute |

| | |
|---|---|
| LULC | Land Use/Land Cover |
| N&NE | North & Northeast |
| NE&E | Northeast & East |
| NW & N | Northwest & North |
| n | number of factors considered (thematic layers) |
| QGIS | Quantum Geographic Information System |
| RCI | Random Consistency Index |
| ROC | Receiver Operating Characteristic |
| RS | Remote Sensing |
| SRTM | Shutter Radar Topography Mission |
| S&SW | South & Southwest |
| SE&S | Southeast & South |
| SW&W | Southwest & West |
| USGS | U.S. Geology Survey |
| TPR | True Positive Rate |
| W&NW | West & Northwest |
| $\lambda max$ | Principal Eigen Vector |

# CHAPTER 1

# INTRODUCTION

## 1.1 GENERAL

In this chapter, we discuss the importance of groundwater and the various methods used for its exploration. Most importantly, groundwater exploration using geographic information system and analytic hierarchical process is presented here.

## 1.2 NEED OF GROUNDWATER

Even though there is a lot of water on earth, only about 2.5% of it is freshwater and about 30% of freshwater exist in the form of groundwater. Due to rapid population growth and increased demand on water for various purposes, people living around the world suffer from a lack of fresh water that is suitable for drinking. Freshwater scarcity results from distinct hydrologic, geologic, geomorphic and demographic characteristics. The only freshwater supply is groundwater.

Because of the expanding population and urbanization of the region, there is an annual increase in the demand for groundwater. To meet the growing demand and to plan for the future development of water resources, it is critical to have a thorough understanding of the availability, distribution, and quality of groundwater.

The application of exploring groundwater potential includes:

1. The agricultural conduit

   Effective groundwater extraction system becomes critical as we tackle the problems of maximizing agricultural waste use. To make sure that agriculture is resilient in the face of unpredictable rainfall patterns and climatic uncertainty, it is essential to comprehend the hydro geological factors and optimize well location.
2. Urban hydrodynamic

   As towns and cities continue to grow, so does the need for water. The design and maintenance of well, pump and distribution netwroks becomes a complex puzzle, balancing the importance of water security against the sustainability of aquifers. Groundwater reduces the need and pressure on surface water sources.
3. Ecological Foundation

Sustainable urban planning and infrastructure development as well as water resource management practices must focus on preserving groundwater fed habitats for biodiversity and ecological equilibrium.

4. Water quality assurance

   We understand the importance of groundwater in maintaining water quality. Many deep aquifers contain clean water protected from contaminants that can contaminate surface water. Precision engineered groundwater wells act as conduits for providing clean drinking water to local communities. Not only do we need to extract groundwater effectively but we also need to protect its purity to ensure public health and wellbeing.

5. Sustainable management

   Risks of pollution, over extraction and inadequate recharging techniques threaten groundwater. So to balance the demands of the present and the future generation's access to clean groundwater is it must to find the potential of it.

## 1.3 METHOD OF GROUNDWATER EXPLORATION

There are two broad categories to explore groundwater namely surface method and geophysical method.

### 1.3.1 Surface methods

It is simple to use and apply surface approaches. The very minimum of resources such as top sheets, maps, reports, field measurements and data analysis in the lab are needed for these. Among the surface techniques for investigating groundwater are the following:

1. Esoteric method
2. Water witching
3. Remote sensing and the geographic information system

#### 1.3.1.1 Esoteric methods

The ancient approaches are known as esoteric ways. These are the oldest techniques for water divination that have been used for many millennia by ancient people. Another name for them is water-dowsing. It was once thought that certain essential currents may be induced above the surface by the flow of groundwater. A wet plant twig has a tendency to rotate when it is pushed above these zones. As dowsing materials, there have been timepieces, damp tree twigs, coconuts without the husk and other objects used

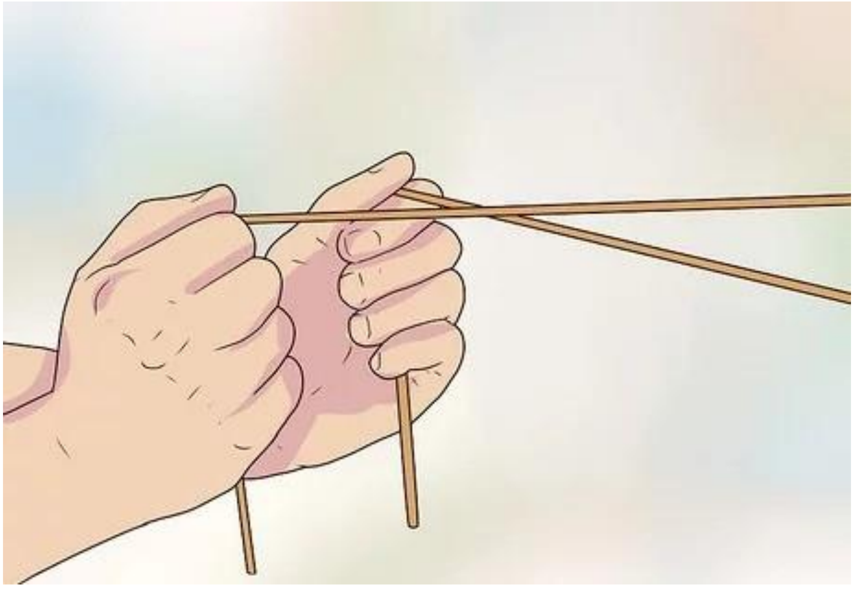

**Figure 1.1:** Water Dowsing

(Source: www.wikihow.com/Use-Dowsing-or-Divining-Rods)

#### 1.3.1.2 Water Witching

One old technique used by individuals to locate bore-wells is called "water witching." Water witching is the practice of finding a water source with a forked stick. Despite the lack of scientific support for this technique, water witches zealously perform their craft wherever people can be convinced of its potential benefits.

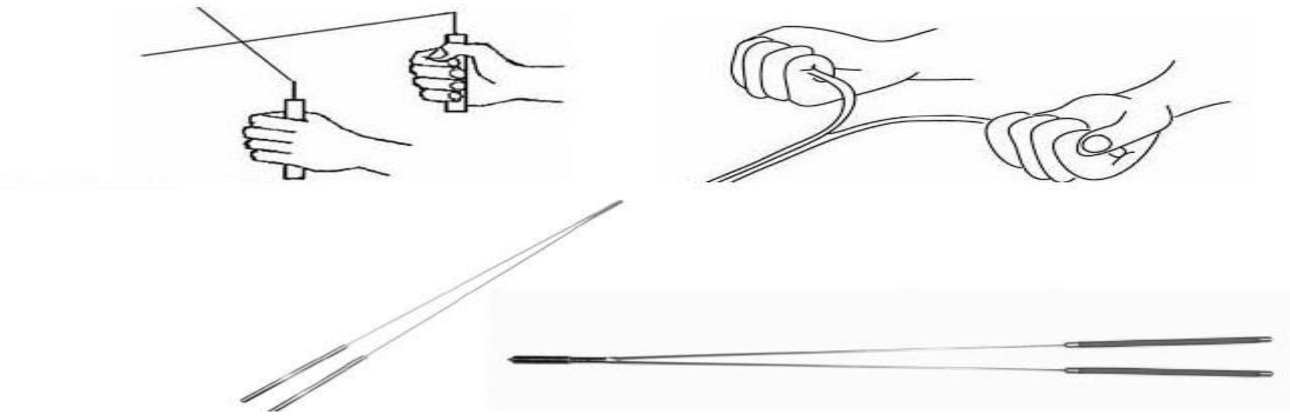

**Figure 1.2:** Water Witching

(Source: Water witching- waterdowsingindia.in)

### 1.3.1.3 Remote Sensing and the Geographical Information System

Remote sensing and geographic information system have become very useful tools for groundwater resource access, monitoring and conservation because of their rapid manipulation of data covering large area and inaccessible areas and their spatial, spectral and temporal availability. Furthermore, studies have demonstrated that remote sensing can assist in evaluating an area's total groundwater resources in addition to assisting in the identification of possible study zones. [3]

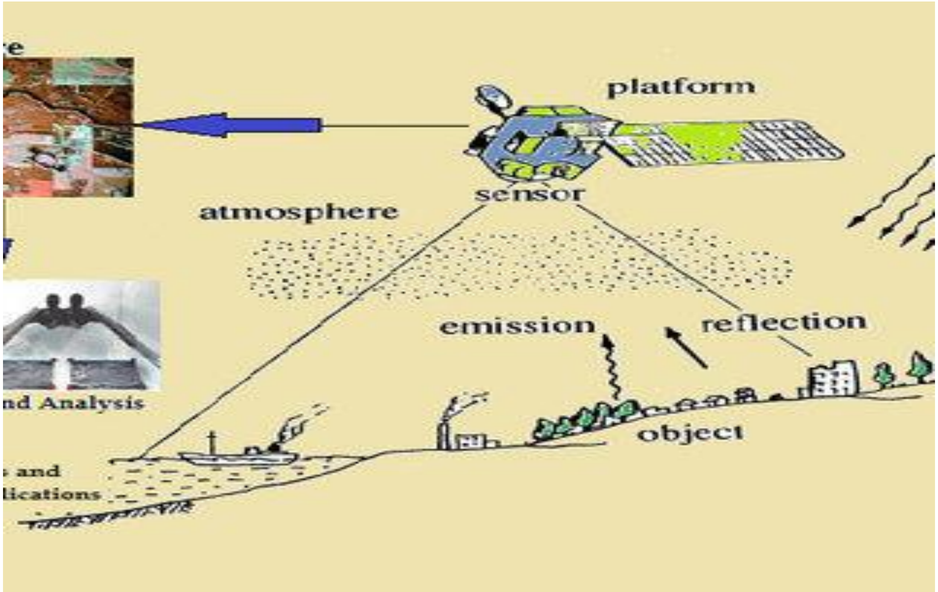


**Figure 1.3:** Capturing of satellite image

Image source: GIS Development India | Photogrammetry Services, LiDAR Survey

## 1.3.2 Geophysical methods

### 1.3.2.1 Gravity Method

The gravity method is a widely used geophysical approach for locating groundwater and mineral resources in sedimentary terrain. Using gravimeters, this technique detects changes in density on earth's surfaces, potentially illuminating underlying geologic structures. The gravity method is not widely utilized in groundwater prospecting because of its expensive cost and the infrequency of notable variations in specific gravity at the surface due to changes in the water content of subsurface strata. In some geological contexts, such as large buried valley, gravity changes can be utilized to infer the general architecture of an aquifer.

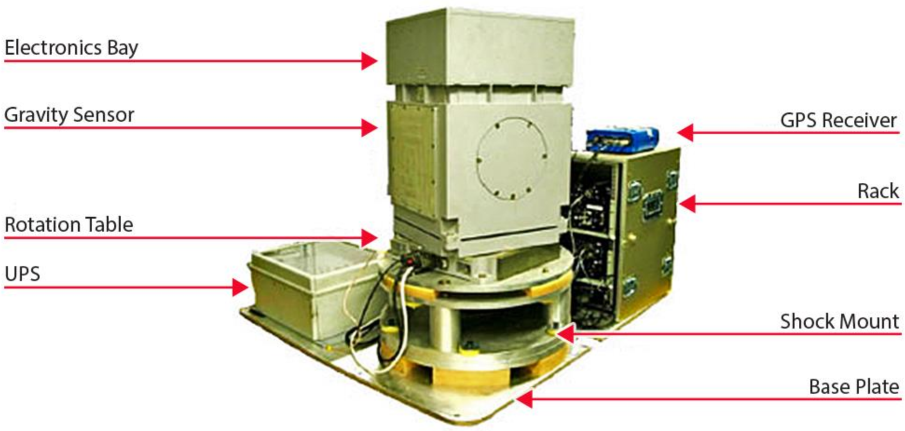


**Figure 1.4:** Gravimeter

(Image source: Canadian micro gravity)

### 1.3.2.2 Magnetic Method

The magnetic method makes it possible to calculate and chart the magnetic fields of the earth. Magnetometers are the instruments used to measure magnetic fields and variations. The technique is not very useful for investigating groundwater since magnetic differences are rarely linked to the occurrence of groundwater. This approach could be utilized to gain indirect data sources relevant to the groundwater investigations, like the presence of dikes defining aquifer boundaries or basaltic flow's boundaries.

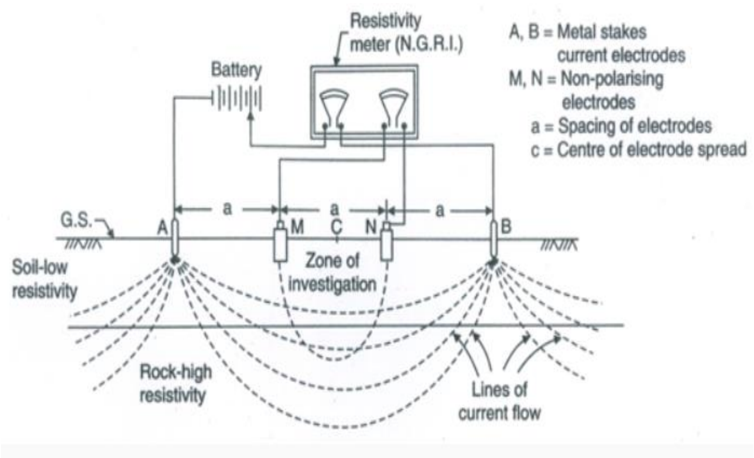


**Figure 1.5:** Schematic view of Wenner Electrode Arrangement

(Source: Raghunath, 2007)

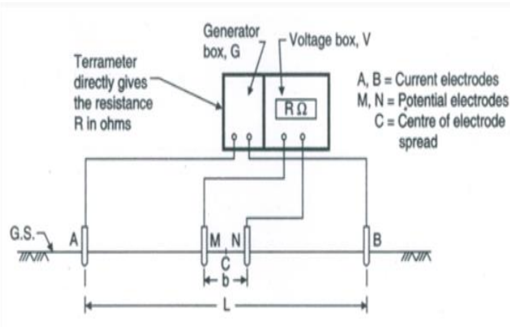


**Figure 1.6:** Schematic view of Schlumberger Electrode Arrangement

(Source: Raghunath, 2007)

### 1.3.2.3 Seismic Method

Seismic refraction and seismic reflections are the two categories of seismic techniques. By using a small explosive charge or a heavy instrument to create a small shock near the earth's surface, the seismic refraction method calculates the time it takes for the resulting shock wave to travel over specific distances. Similar to light rays, seismic waves can be reflected or refracted at any interface where there is a change in velocity. While seismic refraction methods which are important for groundwater studies only go to approximately 100 meters below the surface, seismic reflection methods can reveal information on geologic structure thousands of meters below the surface. The medium that a seismic wave passes through determines how long it will take to travel.

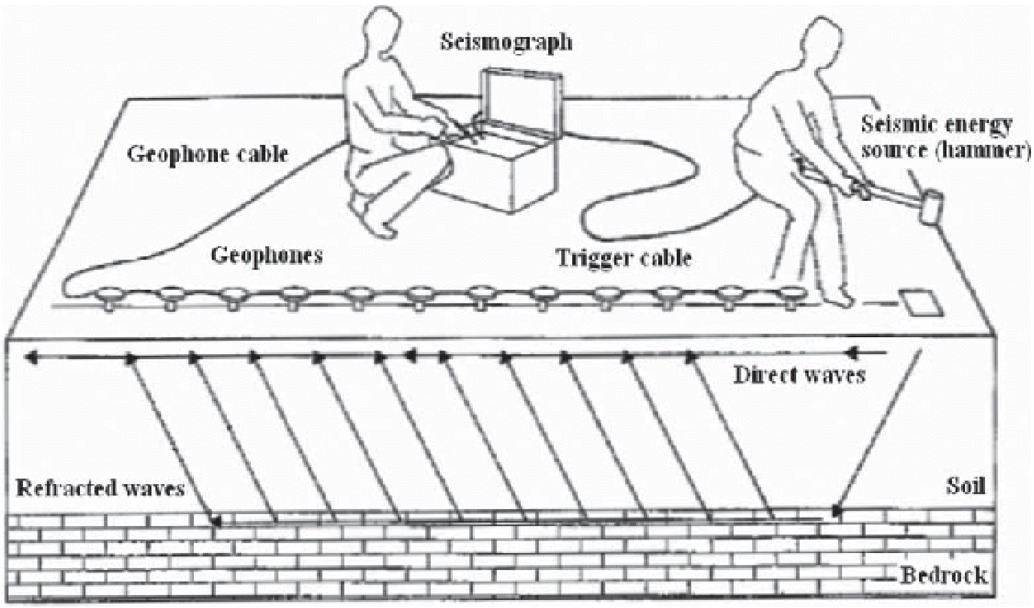


**Figure 1.7:** Seismic Method

Image source: Land Seismic refraction; GBG Group Australia

## 1.4 GEOGRAPHIC INFORMATION SYSTEM

The Geographic Information System, or GIS, is a geospatial technology breakthrough. In contrast to traditional GIS, GIS uses quantum computing to process enormous and complicated spatial data sets at previously unheard-of speeds. The utilization of quantum principles, namely superposition and entanglement, enables the execution of several calculations concurrently, hence greatly boosting the effectiveness of spatial analysis.

Because GIS processes complex spatial relationships quickly, it has enormous potential applications in urban planning, natural resource management, and climate modelling. Decision-making processes are revolutionized by quantum algorithms, which allow for faster terrain modelling, improved geospatial simulations, and improved route planning. With the development of quantum computing technologies, Quantum GIS has the potential to revolutionize geospatial analysis by providing fresh perspectives and answers to challenging spatial problems that were previously unachievable.

## 1.5 ANALYTIC HIERARCHICAL PROCESS

The analytical hierarchy process (AHP) is a method of decision-making compares the relative value of choices through pair wise comparisons in order to systematically analyze and rank them. To facilitate sound decision-making in challenging situations, it entails building matrices, figuring out weights, and synthesizing the findings. AHP helps choose the best option based on a hierarchical model of decision factors by offering a systematic and mathematical method for handling various criteria.

### 1.5.1 Application of AHP

Prof. Thomas L. Satty created the multi-criteria Analytical Hierarchical Process (AHP) in 1980. This is a method for using paired differences to obtain proportion scales. All of the theme layers are integrated with it. These theme layers are grouped together and assigned a weight based on how they respond to the presence of groundwater and professional judgment. A layer with great impact is shown by a parameter with a high weight, and vice versa. The geometric mean and normalized weight of parameters are determined using AHP's analysis of various datasets into a pairwise matrix [1]. Ground water potential zones are computed with the use of geometric mean and normalized weight of parameters.

## 1.6 ADVANTAGES OF GIS

In the times of geospatial technology, geographic information system (GIS) has great impact on management of many natural resources which also include finding groundwater potential zone in the area. GIS is far advance method as compared to other method as

1. Spatial context: GIS software allows hydro geologist to integrate various spatial data layers, providing a compressive visual representation of the subsurface. The spatial context helps in understanding the complex relationships influencing groundwater potential.

2. Data Integration: A comprehensive understanding of groundwater dynamics is made possible by GIS's ability to smoothly combine a variety of information, including satellite imagery and hydrological parameters. Mapping recharge zones, locating possible extraction locations, and evaluating the general health of aquifer systems all depend on this integration.

3. Modelling Capabilities: GIS makes it easier to model aquifer properties in three dimensions, which aids in forecasting groundwater flow patterns and simulating the effects of human activity. The precision of decisions made in groundwater exploration and management is improved by these modelling capabilities.

4. Remote Sensing: GIS uses technologies for remote sensing, which makes it possible to track surface water-groundwater interactions in real time. This expertise is crucial for understanding the connection between surface and groundwater, pinpointing recharge zones, and managing water resources responsibly.

5. Decision Support System: By offering a platform for examining land use, extraction rates, and groundwater quality in a spatial context, GIS functions as a potent decision support system. Making well-informed judgments for sustainable groundwater management is made easier by this.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 GENERAL

This chapter presents the critical observation and analysis of various research papers, articles, books and journals related to exploration of groundwater using remote sensing and geographic information system. Different papers are evaluated to understand how thematic layers of groundwater are created. It helped us to find different methods of analyzing thematic layers in order to create groundwater map. Most importantly, it guided us in learning how analytical hierarchical process technique works. In addition, it helped us to identify the research gap and the need to study groundwater in Shimla District.

Brief summary of few research paper and journals presented below.

**Arulbalaji, P., Padmalal, D., Sreelash, K. "GIS and AHP Techniques based Delineation of Groundwater Potential Zones: a case study from Southern Western Ghats, India", Scientific Reports 9, Article Number 2082 (2019).**

An analytical hierarchical process technique and a geographic information system were combined in this study to delineate groundwater. The research region is the Vamanapuram river basin in South India, a humid tropical river basin situated on the elevated continental border of the southern Western Ghats. Groundwater potential zones were defined using a total of twelve theme levels. Their study's findings were cross-validated with the local groundwater prospect in order to increase accuracy. Zones with extremely high groundwater potential are mostly found in the middle reaches of the river basin and in the lower watershed. Zones with low and extremely low groundwater potential are found in the river basin's migmatite complex structure.

**R. P. Mathews. "Groundwater information booklet, Shimla District, Himachal Pradesh", Central Groundwater Board (2013).**

This study was carried out by Central Groundwater Board in order to explore groundwater in Shimla District with the help of hydro-geology features of the area. In the district, numerous short-term studies have also been conducted to determine the best sites for ground water management and development. A groundwater information booklet was published based on dug well data. The study found out that the quality of groundwater is good but it is highly vulnerable to pollution and low yield in the near future. They also provided some other approaches as such, the promotion of rain water harvesting and revision of tradition water storage system. But a scheme for the management of groundwater was still lacking.

**Table 2.1:** Groundwater Information of Shimla District (Source: [2])

| Sl.No | Items | Statistics |
|---|---|---|
| 1. | Geographical Area (sq. km) | 5131 |
| 2. | Annual average rainfall in 5 years (mm) | 999.64mm |
| 3. | Major physiographic units | High hills and mountains, deep valley and gorges |
| 4. | Major drainages | Sutlej, Giri, Pabbar |
| 5. | Major soil type | Brown hill soil, alpine humus mountain skeletal soil |
| 6. | Groundwater structures | Springs, shallow bore wells |
| 7. | Quality of groundwater | Good |
| 8. | Presence of chemical constituents more than permissible limits | Nil |
| 9. | Predominant geological formations | Quaternary and Proterozoic rocks |
| 10. | Yield prospect | Generally low (1-5 lps) |
| 11. | Major groundwater problems and issues | A mountainous region with low-yielding rocks; springs and other natural sources are susceptible to pollution |

**Sener, E., Davraz, A., Ozcelik, M. "An integration of GIS and remote sensing in ground water investigations: A case study in Burdur, turkey", Hydrogeology Journal 13, 826-834 (2005).**

This case study investigated new water sources by using remote sensing and geographic information system. They conducted the study by considering 7 parameters which affects the groundwater. Spatial Analysis technique was to integrate thematic layers and delineate groundwater potential zones. Areas of Akdag limestone, alluvium unit, high drainage density and high rainfall have high potential of groundwater.

**J.T. Al-Bakri. "Application of GIS and remote sensing to groundwater exploration in Al Wala Basin in Jordan", Journal of Water Resource and Protection (2013).**

Digital Layers of lithology, topography, geology structure and drainage were prepared and analyzed to detect the most suitable site for groundwater exploration in a semi-arid basin in Jordan. Thematic maps were intersected with map of existing well using different GIS functions and spatial query. Area having Alluvial and wadi sediment has high potentials. Their findings recommended the use of GIS tools and remotely sensed data to identify promising sites of groundwater before carrying out further investuigation.

**Solomon, S., Queil, F. "Groundwater study using remote sensing and Geographic information systems (GIS) in the central highlands of Eritrea", Hydrogeology Journal 14(5): 729-741 (2006).**

Lineament, lithology, geomorphology and slope maps were created. The study starts with creation of Digital Elevation Model for mapping geomorphology and lineament. Lithology and lineament maps were created through the interpretation of remote sensing data. All the thematic layers were analyzed and integrated in GIS. Basaltic rocks, flat terrain with thick lineament, and structurally managed drainage channels with valley fill deposits are among the regions with exceptionally high groundwater potential [10].

**N.S. Magesh, N. Chandrasekar, Soundranayagam, J. P. "Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques" (2011)**

It has been shown that utilizing remote sensing, GIS, and MIF techniques to delineate the groundwater potential zones in Tamil Nadu's Theni district is an efficient way to save time, effort, and money. This allows swift decision-making to manage water resources sustainably. Topographic maps, satellite imagery, and traditional data were employed to prepare the lithology and lineament thematic layers, rainfall, soil, slope, density, drainage density, and land use. Through MIF, different thematic layers are given the appropriate weighting. As stated by the Theni district's groundwater potential zone map is divided into four distinct categories: excellent, good, poor, and very good wretched. The current study's findings can be used as recommendations.

**Singh, S. K., Kanga, S., Mishra, S. K.. "Delineation of Groundwater Potential Zone Using Geospatial Techniques for Shimla City, Himachal Pradesh (India)" (2017)**

Seven sets of criteria were chosen because they were thought to be influencing the area's groundwater potential. After giving each component the proper weight according to Saaty's scale and knowledge base, a map of the research area's groundwater potential was created. Using the models mentioned above, five places with extremely low Groundwater Potential: Poor, Moderate, Good, and Excellent Zones were identified. The findings showed that 7% of the region had 11% (moderate), 50% (low), and very good-good and 32% of zones with extremely poor groundwater potential employing knowledge-based approach, yet just 7% of the region had(excellent-good), 12% (middle), 47% (poor), and 34% zones with (very low) groundwater potential utilizing analytical method of the hierarchy process. The total outcome demonstrates that the groundwater barely changed at all.

**Solomon, S., Quiel, F. "Groundwater study using remote sensing and geographic information systems (GIS) in the central highlands of Eritrea" (2006)**

Remote sensing and GIS techniques are essential for studying hard rock aquifers with complex hydro geological fluctuations, particularly in places where there is a dearth of hydro geological data. Digital elevation models help with geomorphologic mapping, and optical satellite data is useful for lithological and lineament mapping. Insights into hydro geological conditions and validation of interpretations are provided by field research. GIS analyses show that landforms, rock type, and structures all affect the presence of groundwater. The study validates the importance of satellite-derived lineaments by establishing connections between well yield. For thorough groundwater research, remote sensing and GIS integration are crucial because they facilitate resource appraisal and exploration planning.

**J.S. Sharma & Singh, D. Government of India Ministry of Water Resources Central Ground Water Board "Ground Water Information Booklet Ground Water information booklet Shimla District, HIMACHAL PRADESH" (2013)**

The ground water is generally alkaline, according to the chemical quality data of samples taken from hand pumps, tube wells, and springs. All of the parameters assessed fall well within the Bureau of Indian Affairs' permitted range (BIS-1991), making the ground water suitable for both residential and irrigation use. Despite the fact that there have been no reports of groundwater contamination in the district Thus far, notwithstanding, the significant towns' rapid increases in both population and tourism, In particular, Shimla is extremely susceptible to pollution from small-scale municipal effluents and sectors. As a result, adequate Effluent Treatment Plants (ETPs) are required. Waste disposal systems in large cities and all industries, along with adequate oversight are extremely necessary.

**D. Himabindu, G. Ramadass. "Remote sensing and geophysical studies for groundwater exploration in Osmania University campus, Hyderabad, India: A case study" (2001)**

To identify regions with good groundwater prospects, an integrated survey including image analysis, geophysical, and hydrogeological research was conducted on the campus of Osmania University (OU). Three key findings emerged from the study: 1. Delineation of several NW-SE and NE-SW trending fractures in the southern side; 2. Identification of a major linear N-S exposure of granitic rocks running continuously for almost the entire length of the campus; and 3. Demarcation of potential groundwater-bearing zones.

**Kamal Khodaei Hamid Reza Nassery "Groundwater exploration using remote sensing and geographic information systems in a semi-arid area (Southwest of Urmeih, Northwest of Iran)" (2011)**

Based on the determined ground water favorability index for different sub zones, layers, weighting, and overlapping, a ground water potential index (GWPI) was created. The groundwater potential zoning was completed in accordance with the prepared GWPI map of the area. Out of the six unique subzones that were defined, two were deemed to have very good and high potential and were strongly recommended for further development and exploration. Target areas' geophysical studies validate the designated subzones. The study's findings support the conclusion that groundwater exploration information can be gleaned greatly from remote sensing data. Additionally, using geographic information systems to identify potential groundwater exploration target areas is a good way to save money and time.

**Dr. D K Chadha. Central Ground Water Board Ministry of Water Resources Government of India "Detailed Guidelines For Implementing The Ground Water Estimation Methodology" (2009)**

Micro-level studies are essential for sustainable groundwater management in severely classified or over-exploited sub-units of command and non-command areas. It is advised to take the following course of action: Watershed as the Assessment Unit: Given their hydrological importance, micro-level research in hard rock terrain should only consider watersheds as the groundwater assessment unit. Subdivision according to Hydrologic and Hydrogeological factors: To improve the accuracy of assessments, sub-units should be further split according to hydrologic (sub-watersheds), hydro geologic (recharge/discharge/transition zones), and geochemical factors. More Observation Wells: More observation wells are needed to provide a sufficient representation of each sub-area, and data on the water table must be continuously monitored from at least one well in each sub-area. Gathering of Hydrological Data: For various formations within a formation, hydrological and hydro geological data, particularly specific yield, should be gathered.

**Thomas L. Saaty "Decision making with the analytic hierarchy process"(2008)**

Organizing a decision-making process is inevitable when a group has to make decisions. This entails gathering all relevant information and discussing the opinions and beliefs of all parties involved. It is equivalent to formulating a strategy to ensure that all viewpoints are acknowledged and comprehended, facilitating collective decision-making. Working through differing viewpoints and ensuring that everyone's ideas and principles are taken into consideration when making a decision require this structured procedure.

**Razand, Y., Pourghasemi, H. R., Neisani, N. S., & Rahmati, O. "Application of analytical hierarchy process, frequency ratio, and certainty factor models for groundwater potential mapping using GIS"(2015)**

The groundwater potential maps in this study were created utilizing the AHP, FR, and CF methods with conditioning factors such as lithology, rainfall, aquifer thickness, water table level, and drainage density. When mapping groundwater potential, the FR model outperformed AHP (AUC=73.47%) and CF (AUC=65.08%) in terms of accuracy (AUC=77.55%). The findings, which were verified using ROC (Receiver Operating Characteristic) curves, confirm that the FR and AHP models are effective for planning thorough groundwater exploration and managing Iran's water resources. The produced groundwater potential map highlights important influencing elements for future planning, making it an invaluable tool for relevant authorities to use in their decision-making.

## 2.2 RESEARCH GAP

The groundwater investigation in Shimla District is mostly done using boreholes. Due to the over development of wells, a decrease in the groundwater yield has been observed. In the last decade, Himachal government constructed a number of shallow bore holes with hand pumps at various places. Due to lack of systematic approach finding favorable locations was very difficult and people landed up constructing wells and bore holes in area having low groundwater potentials.

Direct investigation of groundwater using borehole is less reliable and costly. No area or zones in the district has been identified as the zone of high potentials for groundwater.

## 2.3 RESEARCH OBJECTIVES

2.3.1 To create GIS database of various thematic layers for Shimla District.

2.3.2 Delineate the study area into five zones using AHP namely Very High, High, Moderate, Low and Very Low zones of groundwater.

2.3.3 To cross validate the GIS based Groundwater potential map with statistical data.

# CHAPTER 3

# METHODOLOGY

## 3.1 GENERAL

Remote sensing and GIS technique is a powerful tool to map groundwater potential zones before doing any detail investigation and survey. Groundwater exploration using RS data and GIS take less time and give more accurate result. It also covers a large area.

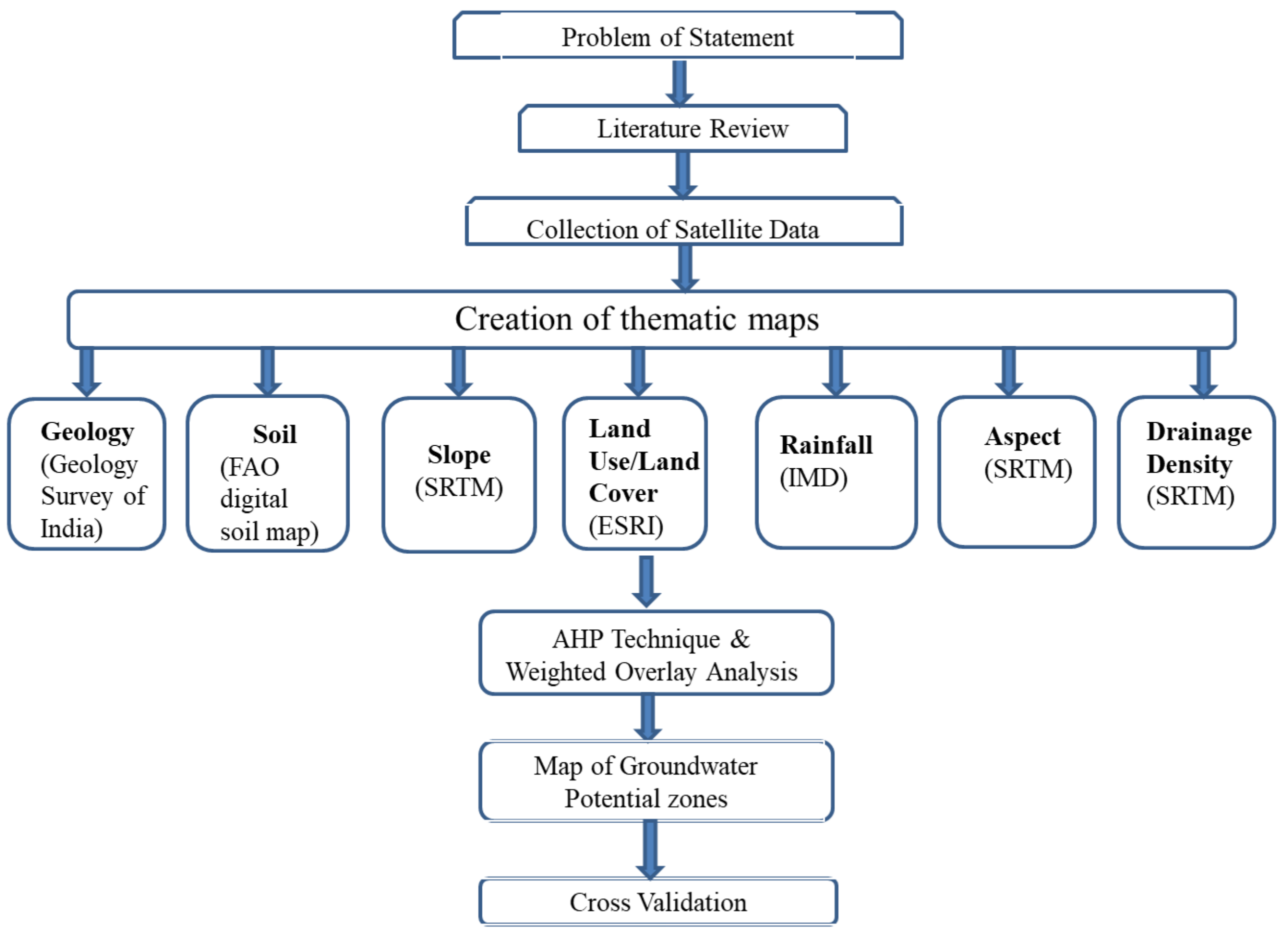


**Figure 3.1:** Research Framework

## 3.2 STUDY AREA

The Shimla District is the site of the current investigation. Himachal Pradesh's Shimla District is situated in the southeast. Its total size is 5131 square kilometers. The district, which is included in Survey of India degree-sheets Nos. 53A, 53E, 53F, and 53I, is located between north latitude 30º43'00" and 30º45'48" and east longitude 76º59'22" and 78º18'40". With a population of 9.10 lakh in 2022, the district is the most populous in Himachal Pradesh, despite the fact that much of its terrain is severely undulating and hilly. It serves as the state's administrative capital. In the district, there is an average of 999.64 mm of rainfall annually, of which 75% falls between June and September during the monsoon season. Snowfall and other precipitation also happen during the winter [2].

Most of the inhabitants depend upon agriculture for their livelihood and groundwater serves as a valuable source of freshwater for both domestic and irrigation purposes. As per the study carried out by CGWB in March 2013, the quality of groundwater is good and no contamination has been found. But due to rapid population growth and industrialization, a decline in the groundwater level has been observed.  In order to decrease the pressure on groundwater usage, rainwater harvesting has been promoted in the district. Figure 3.2 shows the map of AOI.

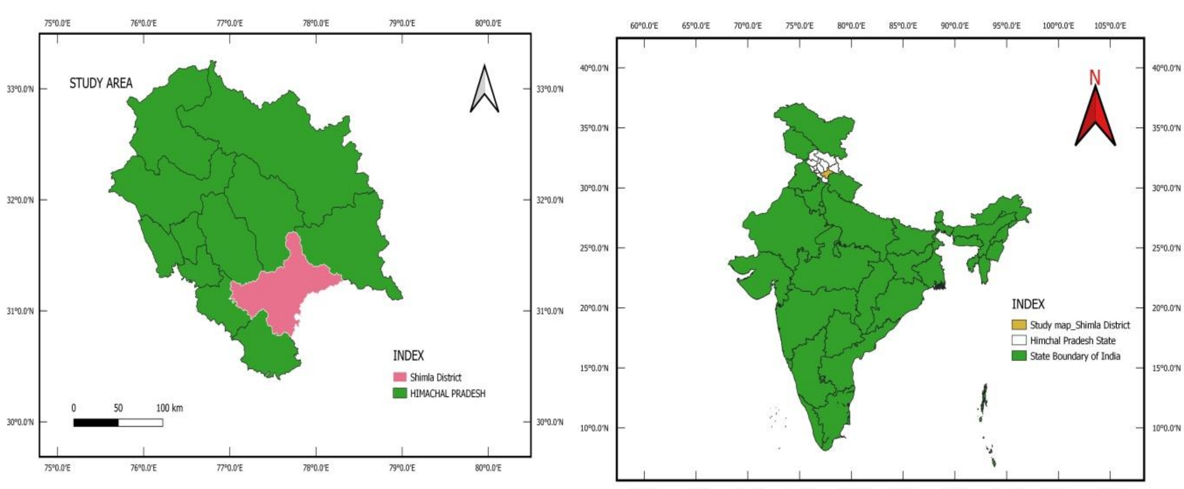


**Figure 3.2:** Area of Interest: Shimla District

## 3.3 MATERIALS AND METHODS

### 3.3.1 Remotely Sensed Data

Remote sensing is a technique to detect and monitor the various features on the earth surface by measuring its reflected and emitted radiation with the help of cameras on satellite and airplanes. The satellite data serves as the input to create thematic layers.

In order to create rainfall map, we have extracted satellite images in shape file from Indian Meteorological Department, IMD. IMD is the main agency of Indian government which looks after the weather forecast. It keeps a record of precipitation occurring at all places in India in hours, daily, monthly and yearly. IMD comes under the Ministry of Earth Sciences and headquarter is located at Mausam Bhavan, Lodhi Road, New Delhi. In our study we are using 2022 annual rainfall.

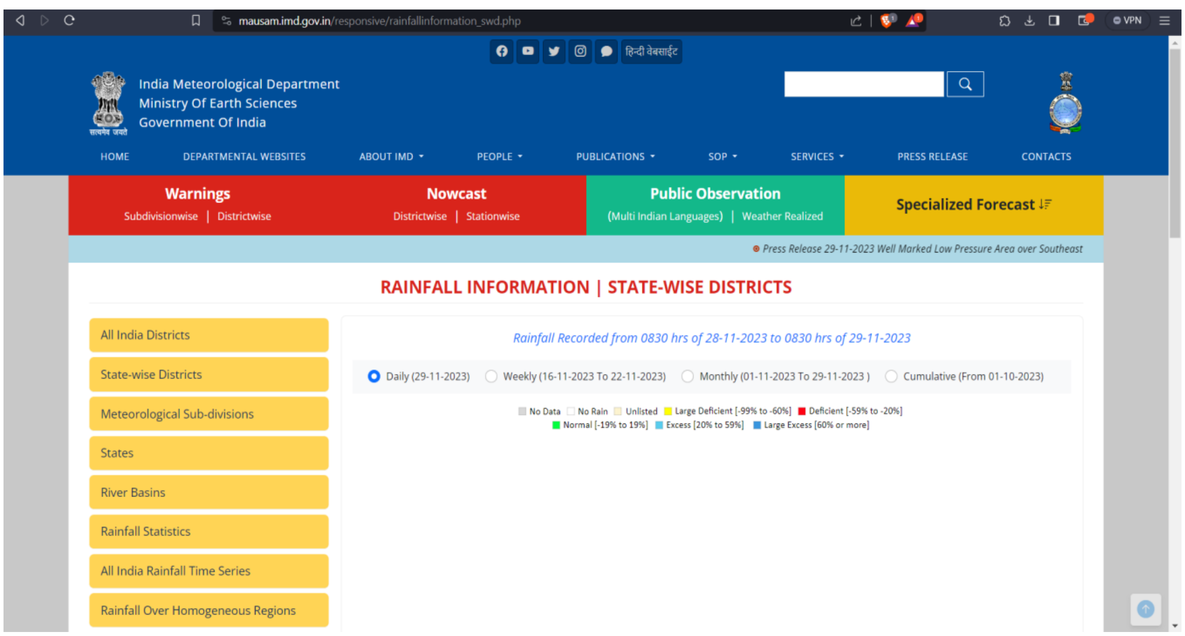


**Figure 3.3:** Website of Indian Meteorological Department

Geology shape file of Shimla district was downloaded from Bhukosh GSI website. Bhukosh GSI is a geoportal of Geology Survey of India which provides free satellite images of different rocks. It contains earth related information if India such as lithology, soil C horizon, soil regolith, lineament, curvature, river system etc. Lithologic classification is done in GIS software.

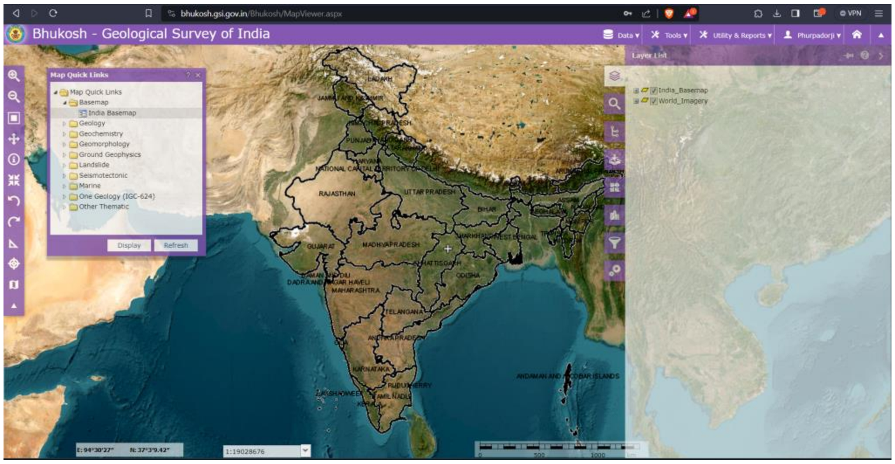


**Figure 3.4:** Website of Bhukosh, GSI

The following figure shows Open Topography which is a raster file portal that provides DEM, slope, aspect and curvature raster data globally. SRTM GL_1 data is downloaded from Open Topography.

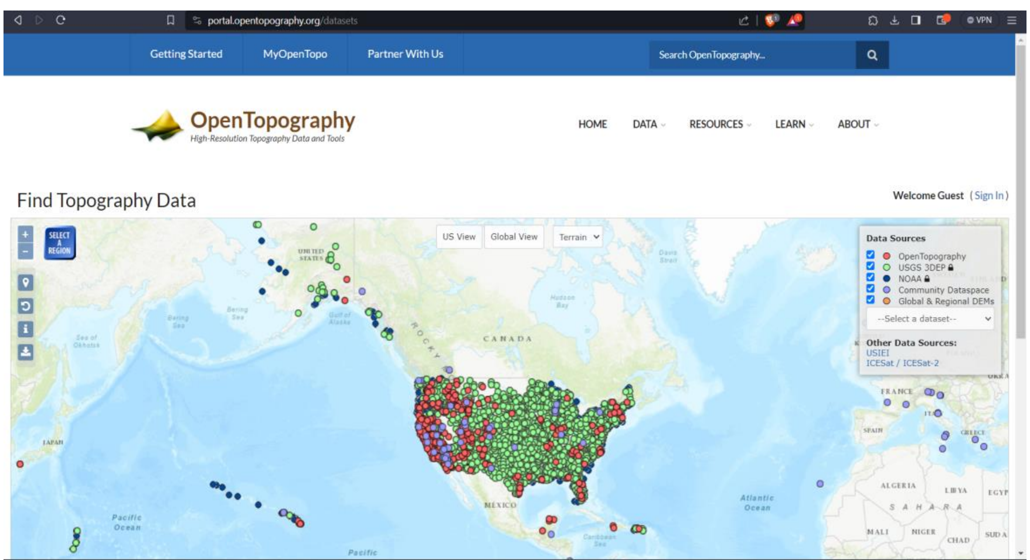


**Figure 3.5:** Open Topography Website

We are using FAO digital soil map of the world for creating soil types in Shimla. The soil data of DSMW is classified by integrating the field and laboratory methods of soil testing with the spatial and non-spatial soil inference system.

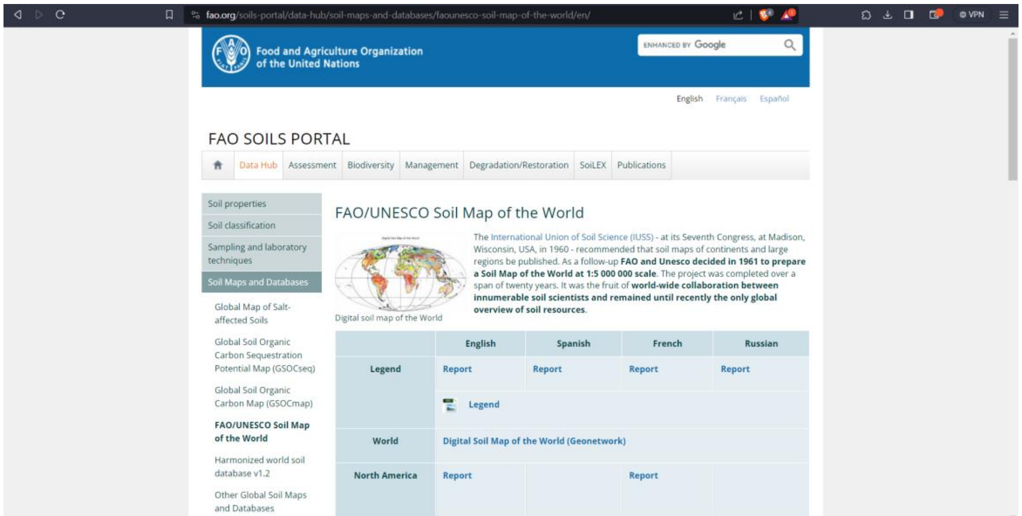


**Figure 3.6:** FAO Soils Portal

The LULC data was downloaded from Esri Land cover- Arcgis Living Atlas of the world. This United States of America based portal provides free annual high resolution land use land cover. You can download land cover of any AOI of any time period from it.

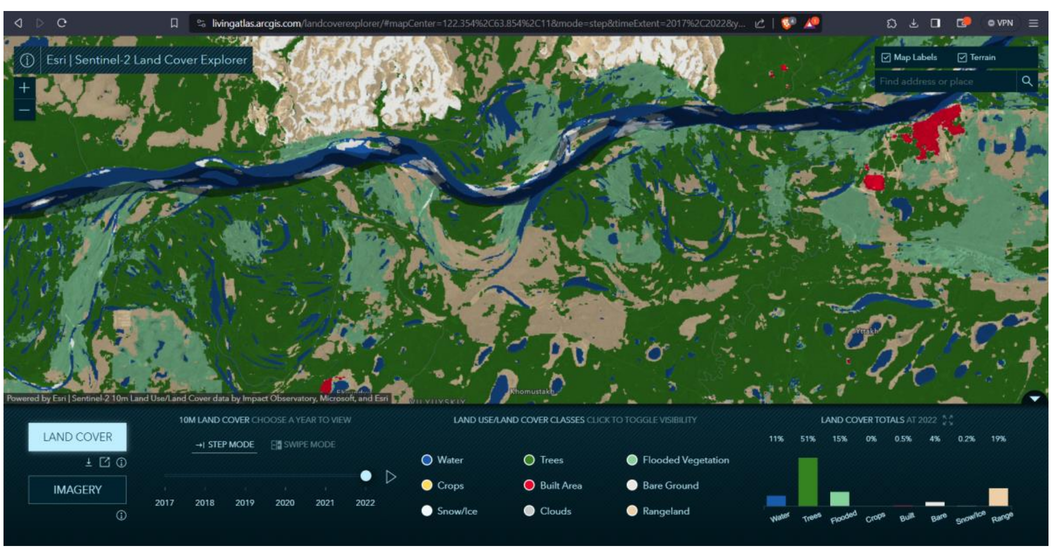


**Figure 3.7:** Esri Land Cover Portal

### 3.3.2 ArcMap Software

ArcMap is geographic information system software that allows users to analyze and edit GIS datasets. ArcMap interface support both vector file and raster file. In our research ArcMap version 10.8.2 is used. The satellite data of all seven thematic layers are edited and analyze here. Thematic layers can be exported as .pdf and .jpeg file. AHP technique for preparing of groundwater potential map is performed in it. The following figure shows the interface of a ArcMap software.

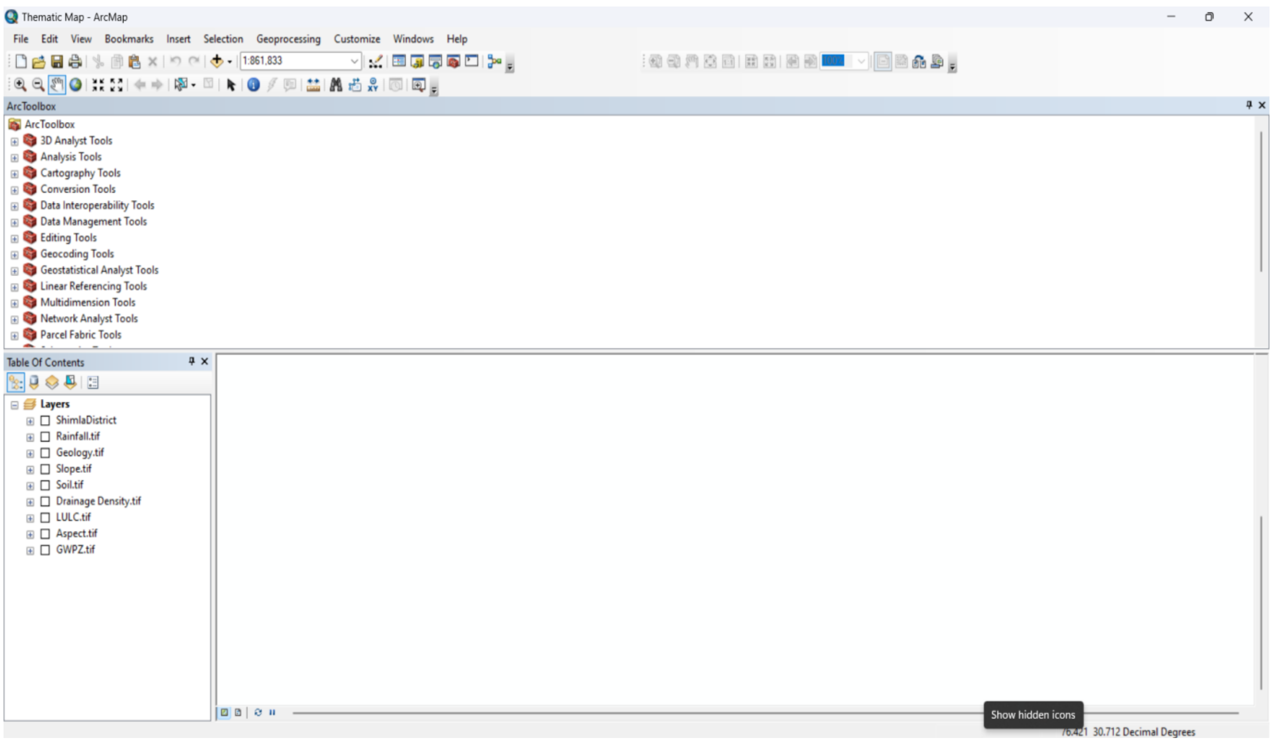


**Figure 3.8:** ArcMap 10.8.2 Software

### 3.3.3 Analytic Hierarchical Process

L. Saaty created the analytic hierarchical process in the 1970s. The AHP is a multi-criteria decision analysis technique used to calculate the priority of each criterion to the overall goal. AHP method was developed by L.Saaty in the 1970s. AHP compares the importance of all the criteria by making pair wise comparison. A priority score is obtained.

Two steps of AHP:

1. Comparative study of one criterion with another criterion through pair wise comparison.
2. Study of a criterion in itself by taking into consideration the various properties affecting the overall goal.

AHP technique of any problem consist of three parts namely; problem statement, evaluation and choice.

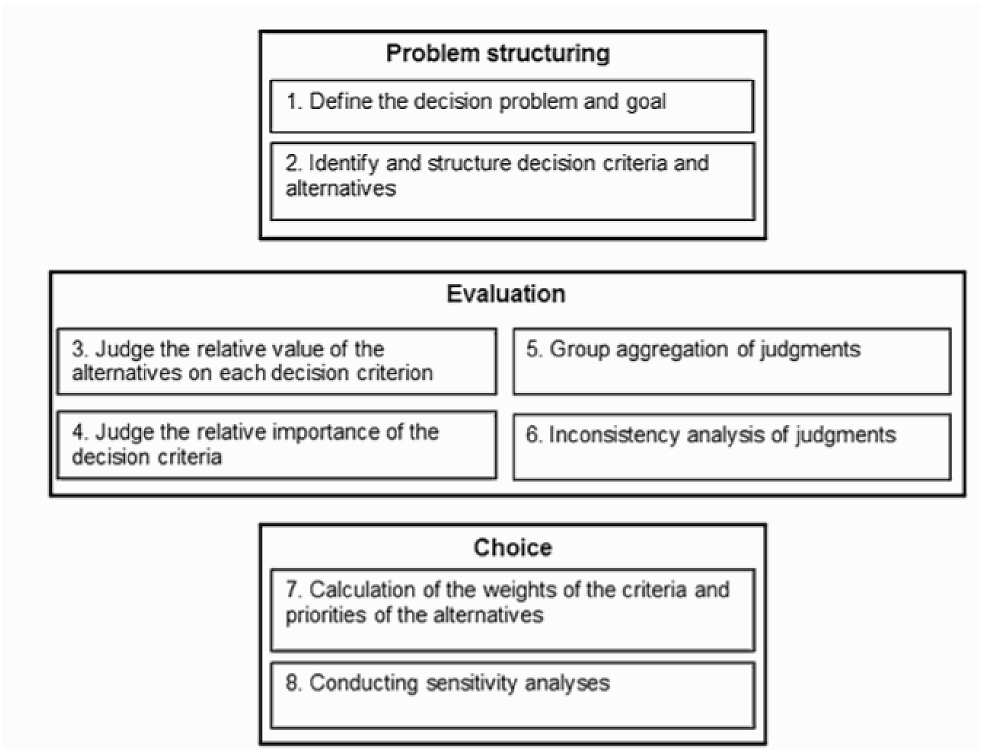


**Figure 3.9:** AHP Technique Framework

The AHP method calculation can be done manually but as the number of criteria increases, it becomes tedious to do and there is high chance of involving human error. So for that purpose AHP calculations are done in AHP excel sheet.

AHP technique helps to integrate all thematic layers. For mapping potential zones for groundwater, the sub categories in each thematic of layer are assigned weights according to their influence for occurrence of groundwater. A parameter with low weightage indicates less impact and vice- versa. A pair-wise comparison of all the thematic layers is performed to calculate priority vector and normalized weight.

### 3.3.4 Saaty Scale

In 1970s, L. Saaty introduced Saaty Scale in order to compare and determine the priority of one factor to another factor. It is scale of number from 1 to 9 used in multi criteria decision making. Table below shows the numbers in Saaty Scale. A pairwise comparison of all the thematic layers is done by it.

**Table 3.1:** Values of Saaty Scale

| Scale | Level of importance | Explanation |
|---|---|---|
| 1 | Equal | Two factors are equally important |
| 2 | Weak or slight | Intermediate value between 1&3 |
| 3 | Moderate | Judgement and experience slightly favor one factor over another |
| 4 | Moderate plus | Intermediate value between 3&5 |
| 5 | Strong | Judgement and experience strongly favor one factor over another |
| 6 | Strong plus | Intermediate value between 5&7 |
| 7 | Very strong | Clear preference for one component over another, which is manifested in practice |
| 8 | Very, very strong | Intermediate value between 7&9 |
| 9 | Extreme importance | The strongest kind of confirmation comes from evidence that one aspect is preferred over another |

### 3.3.5 Consistency Index in AHP

Consistency ratio (CR) is a value that shows how far our analysis is going away from the consistent matrix. A consistent matrix has CR value equal to zero. CR is less than 0.05 for a 3x3 matrix, 0.09 for 4x4 matrices. If CR value is equal to or less than 0.1 for large matrix, then it is said to be consistent.

It is calculated using

$$CR = \frac{CI}{RCI} \quad (1)$$

$$CI = \frac{\lambda max - n}{n-1} \quad (2)$$

Where;

CI = consistency index.

RCI = Random consistency index value whose value is obtained from the Saaty's standard.

λmax = principal Eigen vector. It is obtained by from summation of products between each element of priority vector with corresponding sum of the column of pairwise comparison matrix.

n = number of factors considered (thematic layers).

**Table 3.2:** Random Consistency Indices for different n values

| **n** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **RCI** | 0 | 0 | 0.58 | 0.89 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 |

### 3.3.6 Weighted Overlay Analysis Method

Weighted overlay method is a method of integrating multiple raster layers by using one common value scale for each raster, weighting the respective raster based on importance and create a new integrated raster.

The new integrated raster produced from weighted overlay is the groundwater potential map which shows five different zones of groundwater potentials namely very high, high, moderate, low and very low.

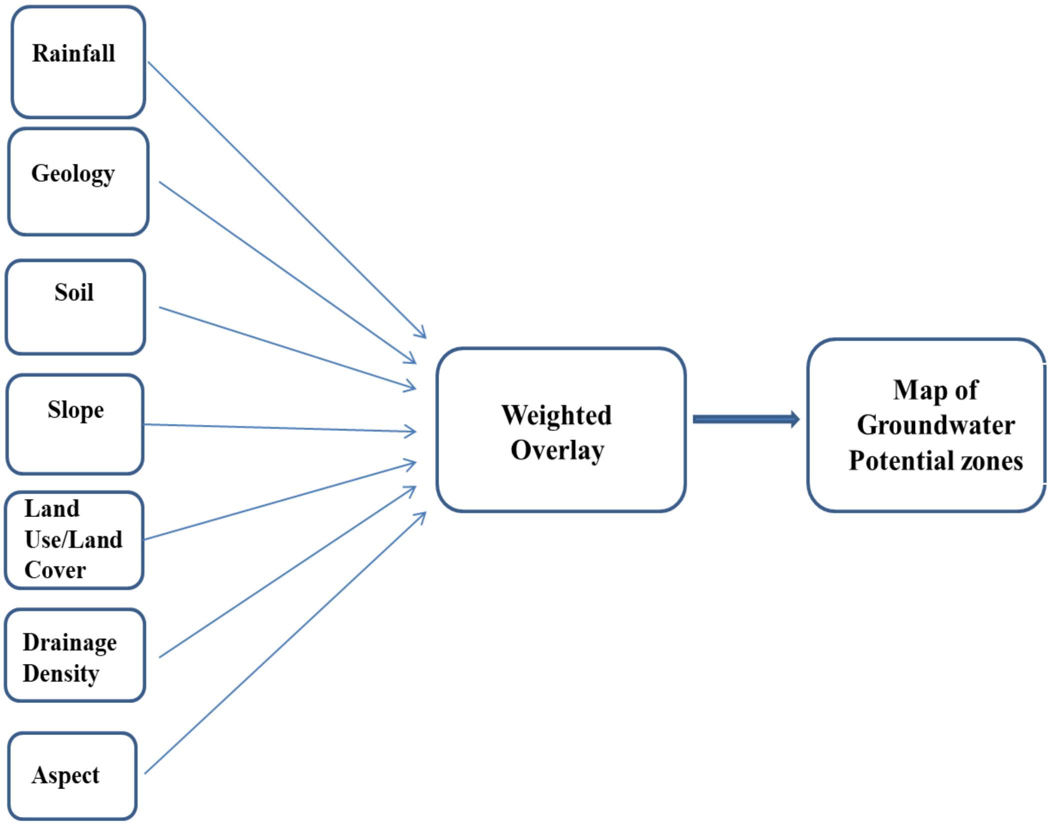


**Figure 3.10:** Weighted Overlay Analysis Framework

The following equation will be used in the weighted overlay analysis method in GIS to produce the groundwater potential zone map.

$$GWPZ = \sum_{i}^{n} Xa * Yb \qquad (1)$$

Where;

GWPZ = Groundwater potential zone

X= weight of the thematic layers

Y= rank of the thematic layers' sub class

a = (1, 2, 3…..X) thematic map

b = (1, 2, 3…..Y) thematic map classes

## 3.4 METHOD FOR VALIDATION OF RESULT

### 3.4.1 ROC-AUC Tool

In order to check the accuracy of the GIS based groundwater map, ROC-AUC tool is used. It stands for Area under the Receiver Operating Characteristic Curve. It is a data science and machine learning simulation and modeling technique.

ROC graph shows the performance of the classifier and AUC quantify the performance. For both, value is between 0 – 1. It indicates the degree to which the model can differentiate between the classes. The better the model is in differentiating between classes, the higher the AUC value. ROC curve is plotted with TPR on y-axis against FPR on x-axis.

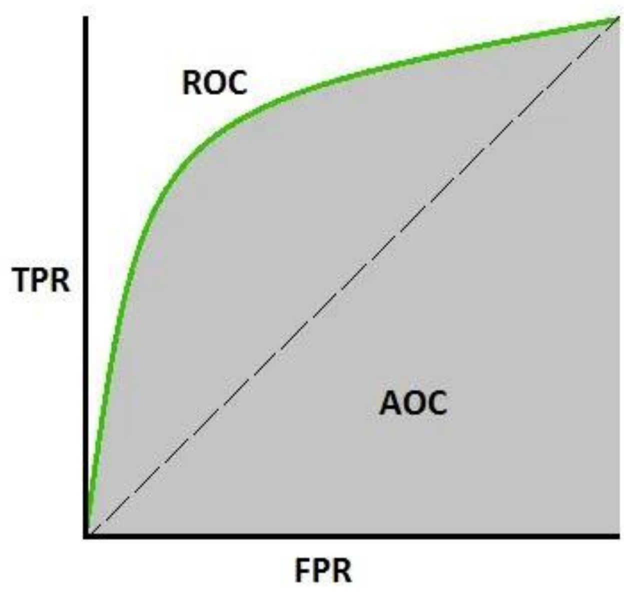


**Figure 3.11:** ROC-AUC Curve

Where;

TPR = fraction of positive samples correctly classified. It answers the question when the actual classification is admitted i.e. positive, how often does the classifier predict positive.

FPR = fraction of negative samples incorrectly classified. It answers the question when the actual classification is not admitted i.e. negative, how often does the classifier incorrectly predict positive.

ArcSDM tool is used to generate AUC-ROC Curve in ArcGIS software. The framework of the technique is explained below. Cell size of both the hand pump raster and GWPZ raster is 12.5, 12.5 and projected coordinate system is WGS_1984_UTM_Zone_43N.

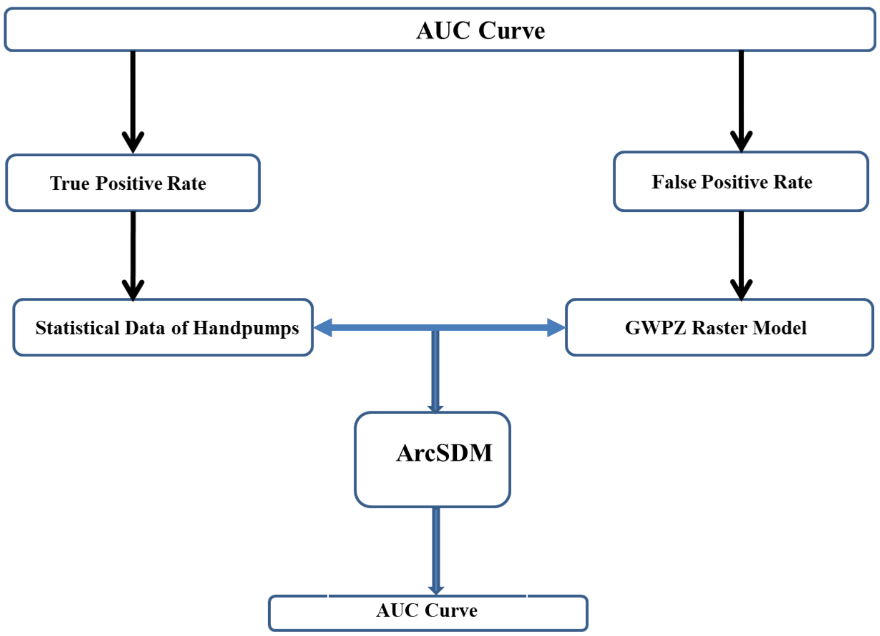


**Figure 3.12:** ROC-AUC Framework

The following table of AUC scale that shows the test quality corresponding to different values of AUC.

**Table 3.3:** AUC Value

| Sl.No | AUC Value | Test Quality |
|---|---|---|
| 1. | 0.9 – 1.0 | Excellent |
| 2. | 0.8 – 0.9 | Very Good |
| 3. | 0.7 – 0.8 | Good |
| 4. | 0.6 – 0.7 | Satisfactory |
| 5. | 0.5 – 0.6 | Unsatisfactory |

# CHAPTER 4

# CREATION OF LAYERS AND AHP ANALYSIS

## 4.1 GENERAL

In this section, we will demonstrate and discuss how we create thematic layers in ArcMap. We will also discuss how AHP technique and weighted overlay method are employed.

The thematic layers are the datasets of the factors that affect groundwater for a given area of interest. The flow and evolution of groundwater are mainly controlled by material factors. These material factors are like geology, soil, and slope and drainage density. On the other hand, replenishment and recharge is influenced by land cover and rainfall. In our work we have considered seven factors as mentioned below.

1. Rainfall: serve as a major source of groundwater.
2. Soil: controls the infiltration rate.
3. Slope: governs the water flow energy.
4. Geology: controls infiltration rate and storage of groundwater.
5. Land use/Land cover: impacts replenishment and recharge process.
6. Drainage density: controls the rate of infiltration and runoff
7. Aspect: influence the ground surface temperature and rate of evapotranspiration.

## 4.2 SOURCE

All the thematic layers that are created in our study have a cell size of 12.5m x 12.5m. The projection coordinate system used is WGS_1984_UTM_Zone_43N. The pixel type is unsigned integer and the pixel depth is 16 Bit.

## 4.3 DIGITAL ELEVATION MODEL

A digital elevation model is a three-dimensional representation of the earth's surface that is devoid of all surface characteristics, such as buildings, trees, and other man-made things. In short it is known as DEM. DEMs show the height of the points from the horizontal ground surface. DEMs are one of the products of Light detection and ranging data. Raster DEM file of Shimla district was downloaded from Open Topography portal. SRTM_GL1 DEM is used. It has a global resolution of 30m.The Digital Elevation model is used to plotting topographic maps of elevation, slope and aspect for our AOI. The drainage density map is also delineated from DEM file.

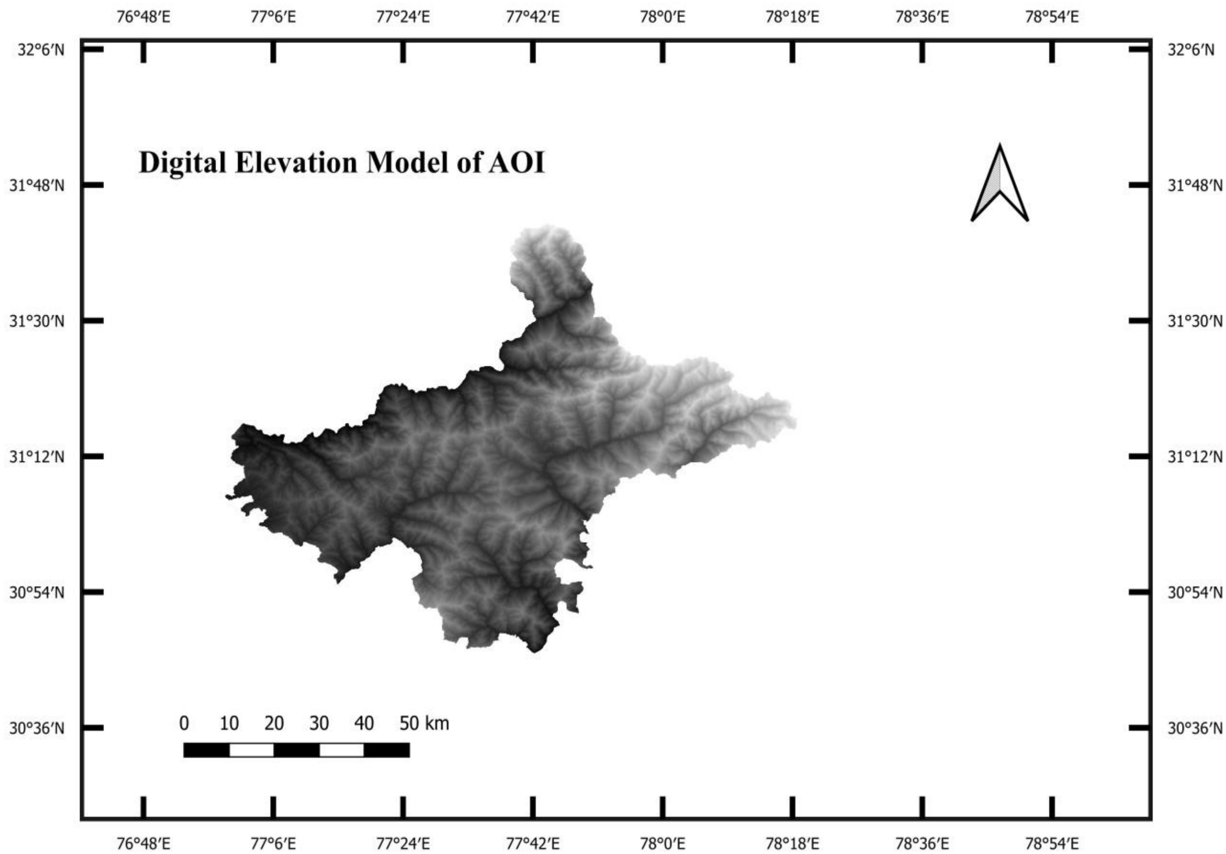


**Figure 4.1:** Digital Elevation Model of Shimla District

## 4.4 ELEVATION MAP

Elevation means the height of different geographical features of the earth. It is like DEM but its representation is two-dimensional. The elevation is ranging from one point to another because Shimla district has undulating hills and mountainous terrain. The elevation ranges from 567 meters to 5605 meters.

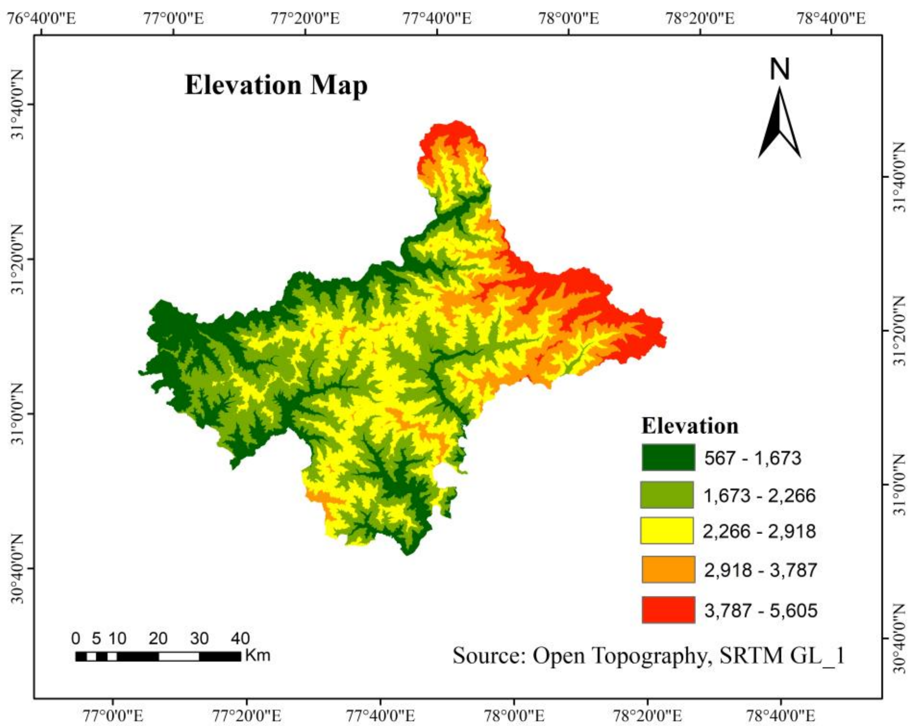


**Figure 4.2:** Elevation Map

## 4.5 RAINFALL MAP

Rainfall is very important for groundwater because it is the major source of water. The annual rainfall map was created using IMD data for the year 2022. The resolution of the data was 0.25 degree x 0.25 degree. Inverse Distance Weighted interpolation (IDW) method was used. IDW works on the principle that weight is an inverse function of distance and the influence of a variable decreases as the distance from the sample location decreases.

### 4.5.1 Steps for creating Rainfall Map

1. Open rainfall data downloaded from IMD which is a raster file.
2. Export data using Data tool.
3. Raster processing and composite band.
4. Local and cell statistic. Use “sum” as overlay.
5. Using conversion tool, convert raster to point.
6. Add Shimla District shape file.
7. Interpolation by IDW technique.

8. Clip the layer using Shimla District (AOI) as clip feature.
9. Edit the layer by changing cell size and projection coordinate system.

The rainfall layer has been classified into five categories namely area receiving Very low (1646-2093), Low (2093-2485), Moderate (2485-2815), High (2815-3097) and Very High (3097-3399). While performing AHP technique the ratings and rankings are given based on intensity of the rainfall. As the intensity of the rain increases, it drives more infiltration and possibility of groundwater potential also increases. Those areas receiving high rainfall get higher ratings and low values are given to areas receiving low rainfall.

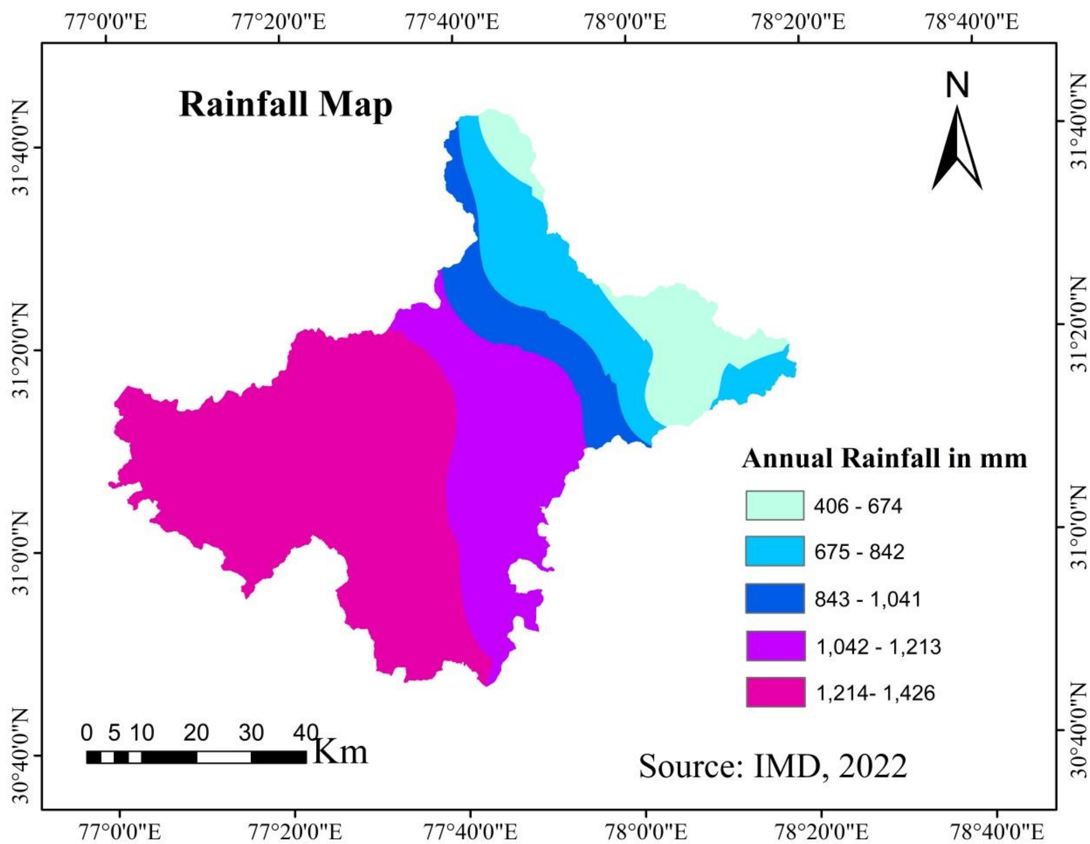


**Figure 4.3:** Rainfall Map

Most part of the Shimla district receives heavy rainfall in the month of July and lowest rain comes in the November. The rainfall is more than 100mm between June to September. Table 4.1 shows that the highest percentage of area is receiving very high rainfall and it covers 2418.245 sq.km which equals to 47.13% of total area.

**Table 4.1:** Area coverage of different Annual Rainfall in 2022

| Sl.No | Intensity of Annual Rainfall (mm) | Area( sq.km) | Percentage of Area (%) |
|---|---|---|---|
| 1. | Very Low (406-674) | 504.621 | 9.83 |
| 2. | Low (675-842) | 685.836 | 13.37 |
| 3. | Moderate (843-1041) | 398.796 | 7.77 |
| 4. | High (1042-1213) | 1123.724 | 21.90 |
| 5. | Very High (1214-1426) | 2418.245 | 47.13 |

## 4.6 GEOLOGY MAP

Geology plays an important role in the movement of groundwater and it controls the infiltration rate. Different rocks have different faults and fractures, porosity, permeability and water holding capacity. The geology datasets were downloaded from Bhukosh GSI geoportal.

### 4.6.1 Steps for creating Geology Map

1. Open Bhukosh GSI dataset in ArcMap.
2. Add AOI shape file.
3. Extraction by Mask
4. Change cell size to 12.5 using “Resample” tool under Data Management.
5. Change Projection Coordinate System to UTM Zone_43N using “Project and transformation”.
6. Convert vector to raster using “Polygon to raster” from Conversion tool.

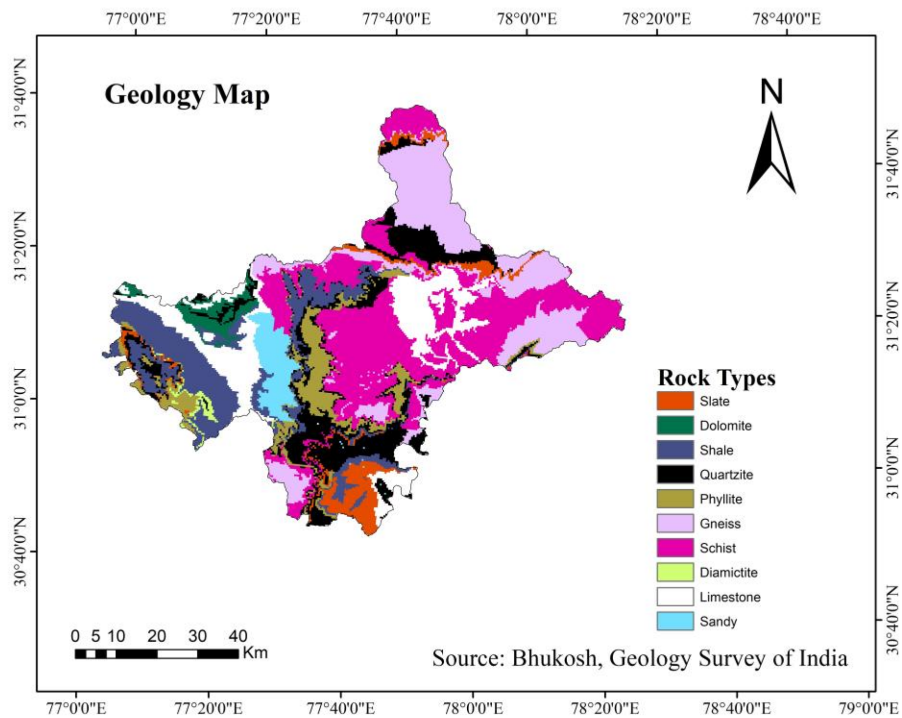


**Figure 4.4:** Geology Map

Many of the rocks are formed during the precambrain and Paleozoic eons of rocks age. The geology is classified based on the Lithologic features and there are ten major rock types.

1. Slate: it is a metamorphic rock formed through metamorphism from clay or volcanic ash. It usually occurs in grey, green or bluish purple in color and it can be split easily. It has fine, homogenous and foliated texture. Slate occurs in the southern part of Shimla.
2. Dolomite: it is a carbonate sedimentary rock. It is made of 60% Calcium carbonate and 40% magnesium carbonate. It can contain other minerals in small quantity such as zinc, lead etc.
3. Shale: a clastic sedimentary rock formed from mud. It is split into compressed layers and has less void and low permeability. It is predominantly found in the western part of Shimla district.
4. Quartzite: they are the metamorphic rocks which are formed from quartz rich sandstone through metamorphism. The predominant color shade is white and grey. It has a good permeability.

5. Phyllite: they have fine grained texture. It is a metamorphic rock formed from mudstone and shales at high temperature and high pressure. It is characterized by low permeability and low water holding capacity.
6. Gneiss: a foliated metamorphic rock formed through the process of metamorphism of granite and sedimentary rocks. The northern part of our study area contains gneiss. The permeability depends upon the mineral composition of layers. It has medium to coarse grain size.
7. Schist: medium grade metamorphic rocks. They are formed from mudstone, shale and some igneous rocks when subjected to high pressure and temperature. Schist has a plane of weakness and gets split along this plane. Schist is found in the central part of the area.
8. Diamictite: a poorly sorted sedimentary rock matrix comprising of pebble and angular fragment rocks. The dominant part of the matrix is mud. Its composition contains poorly sorted conglomerate containing upto about 25% of clasts whose size is greater than 2mm. the Diamictite matrix is supported by an argillaceous matrix. They are found in the south western part of the study area and cover a very small area.
9. Limestone: the primary composition of limestone is calcium carbonate (CaCO3) or calcite. Some other minerals such as silica, clay and organic materials are found in small amount. Marine and fresh sediments that are originally composed of remains of marine organic matter harden over time to become limestone. Geologically, limestone is classifies as sedimentary rocks. It is highly permeable and has a good water holding capacity.
10. Sandy: it is a sedimentary rock which is composed of sand sized minerals and rock grains. The sand and rock grains are predominantly made of mineral quartz or fieldspar which are formed from bigger rocks through weathering process. It has a coarse texture and has many voids in between the grains. Sandy and sandstone are highly porous rocks and support faster infiltration.

Sedimentary rocks have high porosity and good water holding capacity whereas; the igneous rock has the least. The porosity and water holding capacity of metamorphic rocks is less as compared to sedimentary rocks but more than igneous rocks. In AHP technique, ranks are given as per the grain size and water holding capacity of the rocks. Sedimentary rocks such as sandy, limestone and dolomite are ranked higher. Shale, slate and Phyllite get low rank. Metamorphic rocks like gneiss, schist, Diamictite and quartzite are given intermediate values.

**Table 4.2:** Area coverage of different Geology

| Sl.No | Lithologic Name | Area (sq.km) | Percentage of Area (%) |
|---|---|---|---|
| 1. | Slate | 252.065 | 4.91 |
| 2. | Dolomite | 111.195 | 2.17 |
| 3. | Shale | 661.224 | 12.89 |
| 4. | Quartzite | 698.604 | 13.62 |
| 5. | Phyllite | 342.025 | 6.67 |
| 6. | Gneiss | 878.473 | 17.12 |
| 7. | Schist | 1369.448 | 26.69 |
| 8. | Diamictite | 32.108 | 0.63 |
| 9. | Limestone | 607.777 | 11.85 |
| 10. | Sandy | 177.143 | 3.45 |

Most part of the study area has metamorphic rocks. Schist covers 26.69% of the total area which is the highest. Diamictite rocks are the least found lithology. It covers 32.108 sq.km of area, which is equal to 0.63%.

## 4.7 SOIL MAP

Soil is a very important variable that affects the infiltration rate, runoff and recharge of groundwater. The permeability, void ratio, geologic characteristic and hydraulic characteristic of the soils influence the potentiality of groundwater. The soil shape files were downloaded from FAO digital soil map of the world and analyzed using ArcMap software.

### 4.7.1 Steps for creating Soil Map

1. Open FAO DSMW dataset in ArcMap.
2. Add AOI shape file.
3. Extraction by Mask

4. Change cell size to 12.5 using “Resample” tool under Data Management.
5. Change Projection Coordinate System to UTM Zone_43N using “Project and transformation”.
6. Convert vector to raster using “Polygon to raster” from Conversion tool.

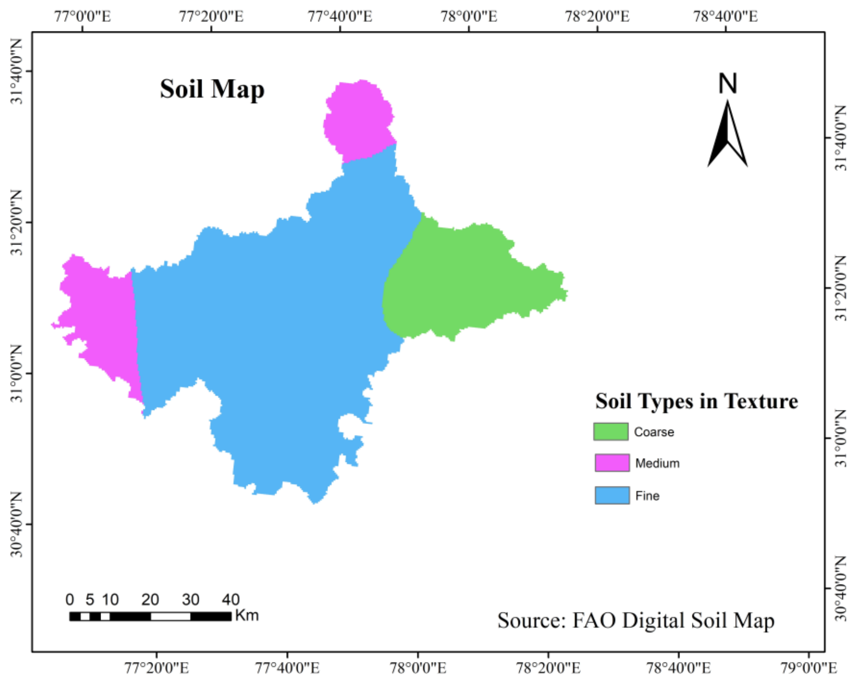


**Figure 4.5:** Soil Map

In Shimla district, most of the soils are mountainous soils of lithosols, cambisols and glacial soils. These soils contain minerals like organic carbon, sodium, nitrogen, potassium, magnesium, manganese, calcium, zinc, iron, phosphorous and other organic materials. The cambisols are usually fertile and is extensively used for farming and growing crops. The soil map was prepared based on texture and classified into three groups.

1. Coarse: Sand, sandy loams and loamy sands that have more than 65% sand and with less than 18% clay.
2. Medium: Loams, loams, sandy clay loams and sandy loams. Clay loams with less than 65% sand and less than 35% clay as well as silty clay loams, silt and silt loams. (If atleast 18% clay is present, the sand proportion can reach as high as 82 percent).
3. Fine: clay, silty clays, sandy clays, clay loams with more than 35% clay present.

Table below shows the coefficient of permeability (K)

**Table 4.3:** Coefficient of Permeability of Soils [23]

| Soil Texture | K factor(cm/sec) |
|---|---|
| Sand | 0.0014 |
| Loamy sand | 0.0060 |
| Sandy loam | 0.0171 |
| Silty sandy Loam | 0.0513 |
| Sandy clay loam | 0.0263 |
| Loam | 0.0395 |
| Silt loam | 0.0513 |
| Clay loam | 0.0402 |
| Silty clay loam | 0.0428 |
| Silty clay | 0.0349 |
| Clay | 0.000014 |

The dominant soil texture found in the study area is fine textured soil. It covers a total area of 3435.635sq.km and equals to 69.10%.

**Table 4.4:** Area coverage of different Soils

| Sl.No | Type of Soil Texture | Area (sq.km) | Percentage of Area (%) |
|---|---|---|---|
| 1. | Coarse | 886.990 | 17.29 |
| 2. | Medium | 698.860 | 13.62 |
| 3. | Fine | 3545.635 | 69.10 |

## 4.8 SLOPE MAP

Slope indicates the steepness of a terrain from the ground surface. It is expressed in degrees from the horizontal surface. A horizontal surface has a zero degree slope and is termed as Flat. Slope datasets were downloaded from Open Topography portal. SRTM GL1 data was used. It has a resolution of 30m.

### 4.8.1 Steps for creating Slope Map

1. Add SRTM GL1 slope datasets.
2. Add your AOI shape file.
3. Extraction by mask.

4. Convert float to integer.
5. Reclassify.
6. Change cell size to 12.5 using "Resample" tool under Data Management.
7. Change Projection Coordinate System to UTM Zone_43N using "Project and transformation".

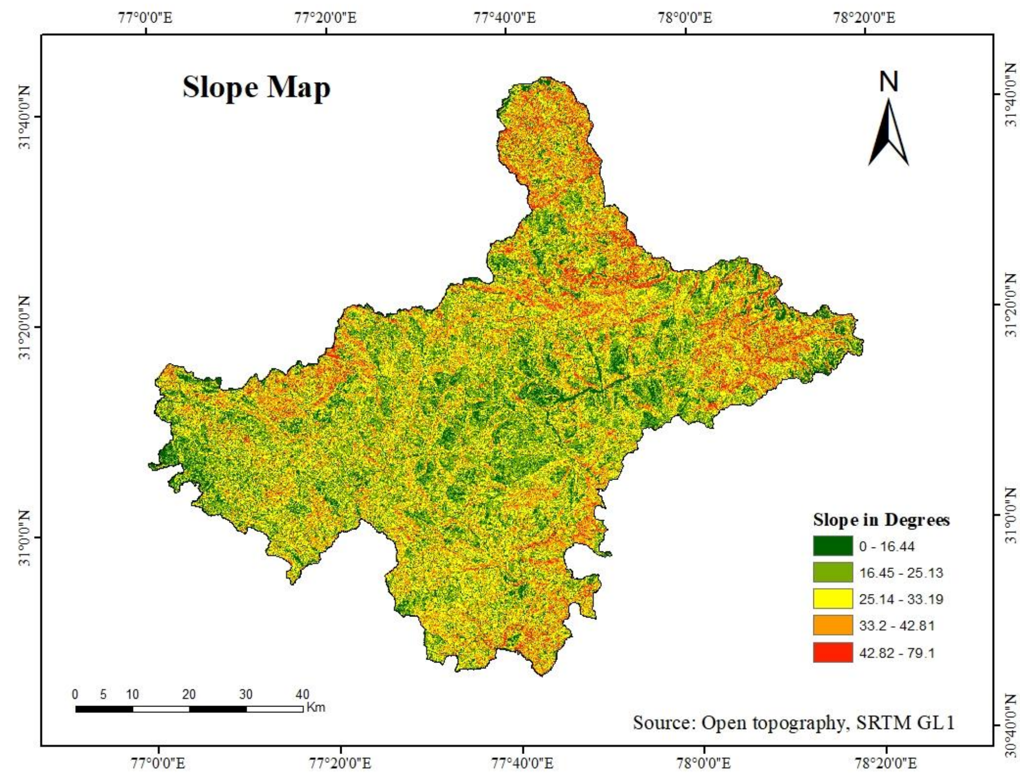


**Figure 4.6:** Slope Map

The slope is categorized into five subclasses as Flat (0-16.44), Gentle (16.45-23.13), Moderate (23.14-33.19), Steep (33.20-42.81) and Very Steep (42.8279.10) degrees. Slope controls the rate of infiltration and rate of surface runoff. Recharge of water in flat and gentle slopes are more because they produce less surface runoff and more infiltration during rainfall. There is more residence time for water to infiltrate. High rankings are given to such slopes. Steep slopes are associated with less residence time for infiltration as the water easily runs off to low slope areas. Low weightages are assigned to very steep and steep slopes.

Most part of the area has gentle to moderate slopes with area of 1628.159sq.km and 1647.787sq.km respectively. Very steep slope covers the least area (4.72%).

**Table 4.5:** Area coverage of different Slopes

| Sl.No | Slope Classes ( degrees) | Area (sq.km) | Percentage of Area (%) |
|---|---|---|---|
| 1. | Flat (0-16.44) | 769.270 | 14.99 |
| 2. | Gentle (16.45-25.13) | 1628.159 | 31.73 |
| 3. | Moderate (23.14-33.19) | 1647.787 | 32.11 |
| 4. | Steep (33.20-42.81) | 844.125 | 16.45 |
| 5. | Very Steep (42.8279.10) | 241.928 | 4.72 |

## 4.9 ASPECT MAP

Aspect shows the direction of the terrain face. Aspects are shown both in degrees and in eight cardinal directions. It is measured from the north in clockwise direction. Aspect datasets were downloaded from Open Topography portal. SRTM GL1 data was used. It has a resolution of 30m.

### 4.9.1 Steps for creating Aspect Map

1. Add SRTM GL1 aspect datasets.
2. Add your AOI shape file.
3. Extraction by mask.
4. Convert float to integer.
5. Reclassify.
6. Change cell size to 12.5 using "Resample" tool under Data Management.
7. Change Projection Coordinate System to UTM Zone_43N using "Project and transformation".

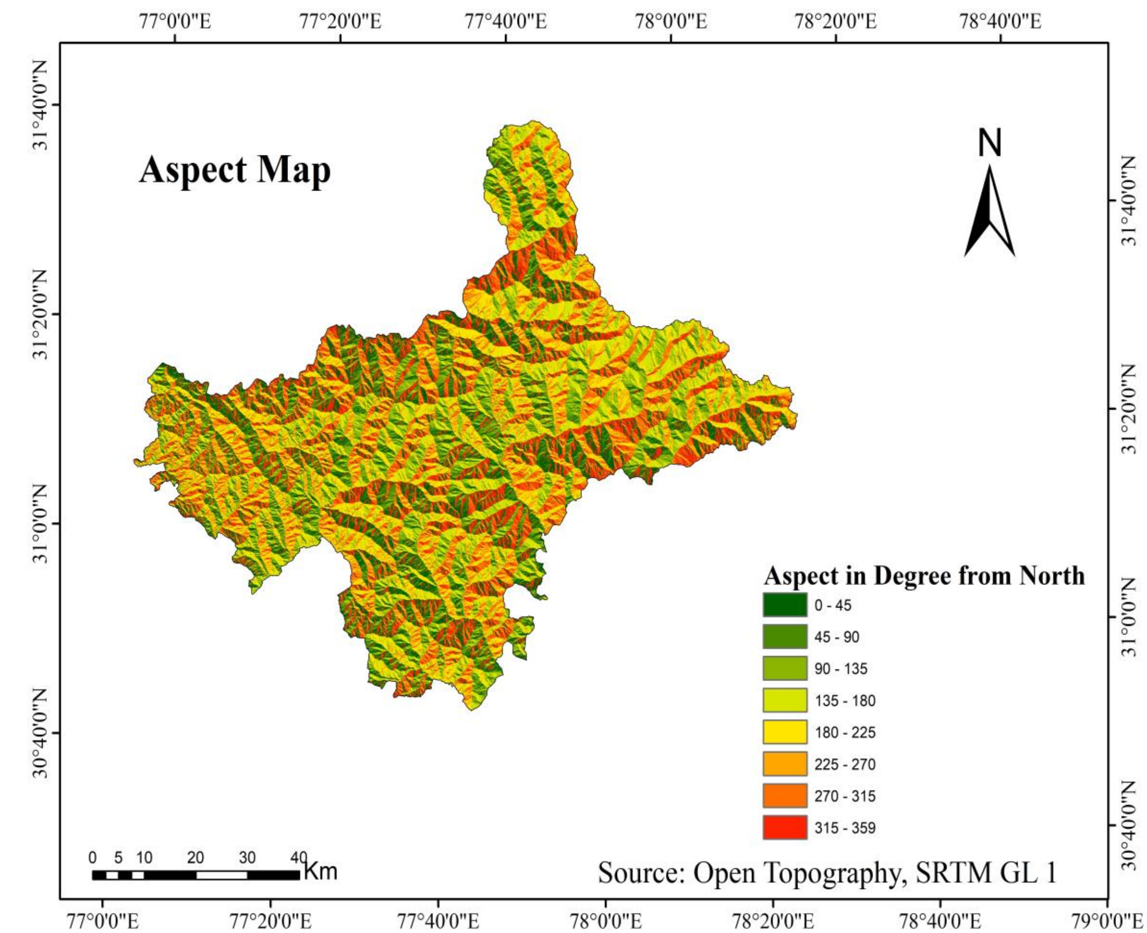


**Figure 4.7:** Aspect Map

Aspect influences the temperature and the rate of evapotranspiration. In a day, terrains facing the eight different cardinal directions do not receive equal intensity of sunlight. Aspect map was classified into eight groups of cardinal directions. The areas having (N&NE) and (NW&N) aspects receive less sunlight in a day. Higher ranks are assigned to them. The areas having (SE&S) and (S&SW) aspects receive more sunlight in a day. Lower ranks are assigned to them. Remaining aspects receive moderate sunlight and intermediate weightages are assigned to them.

**Table 4.6:** Area coverage of different Aspects

| Sl.No | Aspect (degree) | Area (sq.km) | Percentage of Area (%) |
|---|---|---|---|
| 1. | N&NE (0-45) | 762.006 | 14.85 |
| 2. | NE&E (45-90) | 517.279 | 10.08 |
| 3. | E&SE (90-135) | 561.605 | 10.94 |
| 4. | SE&S (135-180) | 715.722 | 13.95 |
| 5. | S&SW (180-225) | 742.852 | 14.48 |
| 6. | SW&W (225-270) | 578.821 | 11.28 |
| 7. | W&NW (270-315) | 546.456 | 10.65 |
| 8. | NW&N (315-359) | 706.448 | 13.77 |

## 4.10 DRAINAGE DENSITY MAP

Drainage area is the area from which all the drainage water passes into one stream or water course. Drainage density is calculated by divided total channel length by catchment area. In Shimla district the major drainages are Sutlej basin, Yamuna basin and Pabbar basin. The DEM data from Open Topography was used to prepare drainage density map. It provides a resolution of 30m.

### 4.10.1 Steps for creating Drainage Density Map

1. Add DEM file in ArcMap.
2. Select "Hydrology" under Spatial Analyst Tool.
3. Fill. Input is DEM and output is DEM Fill 1.
4. Flow Direction. Input is DEM Fill 1. Output is FlowDir_Fill 1.

5. Flow Accumulation. Input is FlowDir_Fill 1 and output is FlowAcc_Flow 1.
6. Select “Con” from Conditional tool. (Input: FlowAcc_Flow 1, Input true raster: DEM). Output is Conc_FlowAcc_1.
7. Select “Stream Order” from Hydrology tool. (Input: Conc_FlowAcc_1, Input flow direction raster: FlowDir_Fill 1). Output: StreamO_Conc_1.
8. Stream to Feature. (Input stream raster: StreamO_Conc_1, input flow direction: FlowDir_Fill 1). Output is StreamT_stream01.
9. Under properties then symbology choose “value field”.
10. Add all values.
11. Select Density tool.
12. Line Density. Input: StreamT_stream01.
13. Under Environmentals, choose AOI for processing extent and raster analysis.

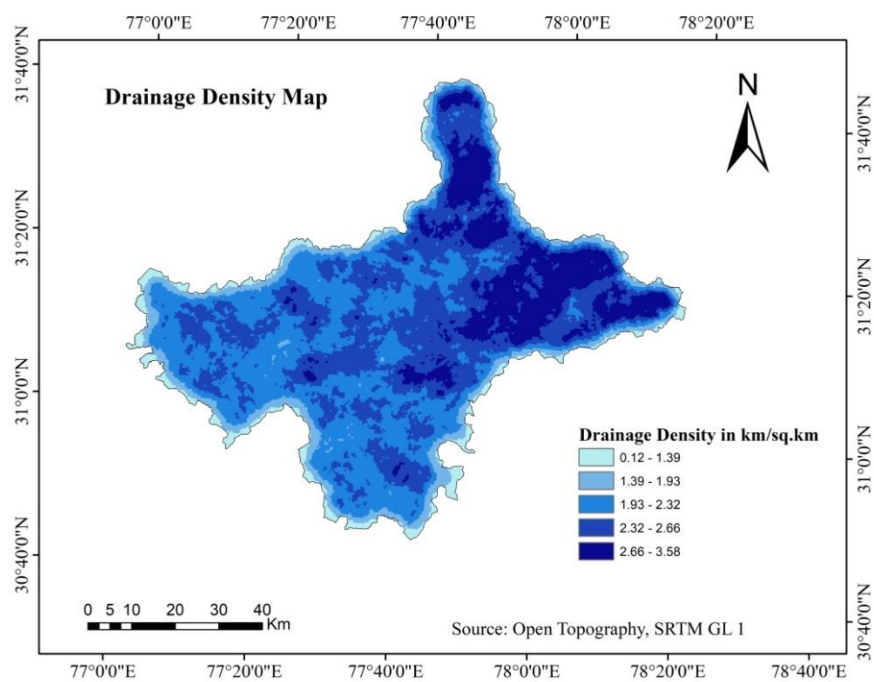


**Figure 4.8:** Drainage Density Map

Drainage density is inversely proportion with permeability. Higher permeability result in low drainage density and vice versa. Drainage density is an important parameter in determining groundwater potential because it affects the rate of infiltration and surface runoff. Low drainage density is characterized by less surface runoff and more infiltration. It favors the groundwater development and recharge. High drainage density represents more surface runoff and less infiltration and do not support groundwater. The drainage density map was classified into five categories as Very Low, Low, Moderate, High and Very High. For AHP technique, higher ranks are assigned for low density and lower ranks were given to high density.

Most of the study area has moderate to high drainage density because the slope is also mostly moderate to steep slopes. Shimla region is mountainous and there is less infiltration and percolation of water.

**Table 4.7:** Area coverage of different Drainage Density

| Sl.No | Drainage Density ($km/km^2$) | Area (sq.km) | Percentage of Area (%) |
|---|---|---|---|
| 1. | Very Low (0.12-1.39) | 253.641 | 4.94 |
| 2. | Low (1.39-1.93) | 495.098 | 9.65 |
| 3. | Moderate (1.93-2.32) | 1788.957 | 34.86 |
| 4. | High(2.32-2.66) | 1779.034 | 34.67 |
| 5. | Very High (2.66-3.58) | 815.278 | 15.89 |

## 4.11 LAND USE/ LAND COVER MAP

Land use land cover (LULC) shows the natural aspects of the earth and how the land is utilized for human activities like agriculture and for building infrastructures. Unsupervised classification of ESRI Land covers dataset for the year 2022 was used. The resolution of satellite dataset was 10m.

### 4.11.1 Steps for creating LULC Map

1. Add Esri land cover datasets in ArcMap.
2. Add your AOI shape file.
3. Extraction by mask.
4. Reclassify.
5. Change cell size to 12.5 using "Resample" tool under Data Management.
6. Change Projection Coordinate System to UTM Zone_43N using "Project and transformation".
7. Convert vector to raster using "polygon to raster" using conversion tool.

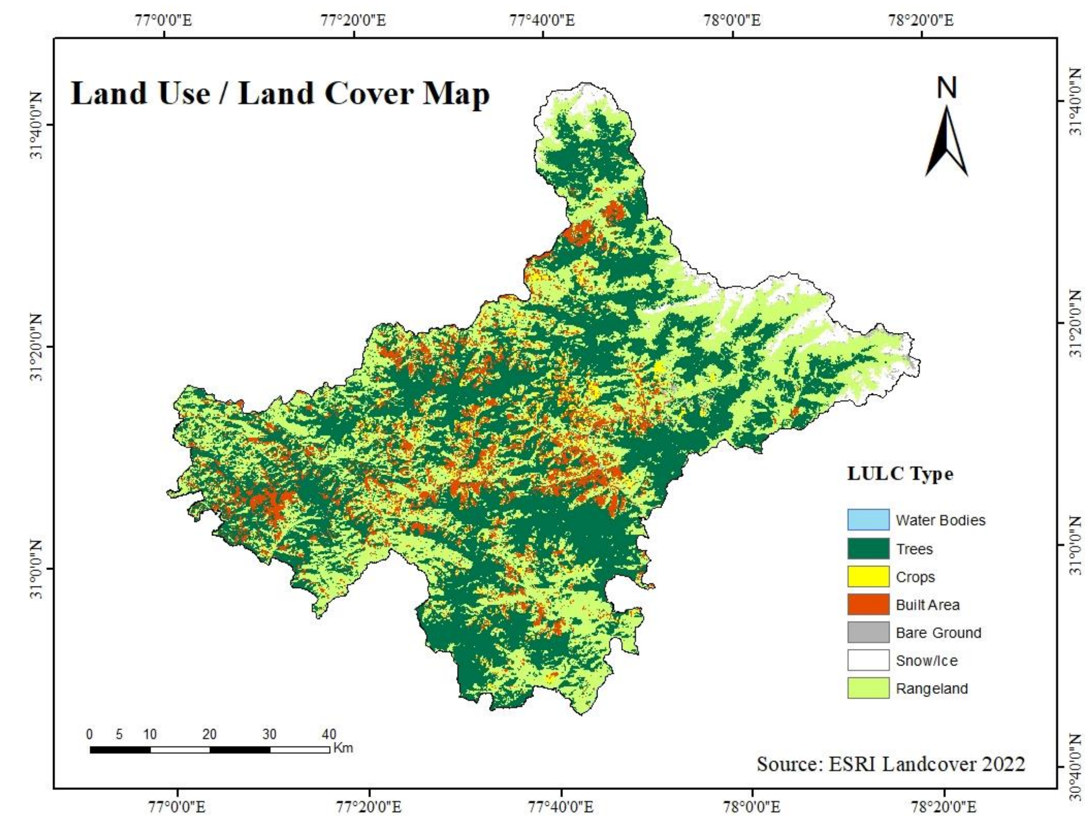


**Figure 4.9:** LULC Map

The land use land cover of the study area was reclassified into seven categories as shown below.

1. Water bodies: includes rivers, ocean, streams, ponds, lake, flooded salt plains and other areas where permanent water exist through the year. It does not include docks, sporadic and ephemeral water.
2. Trees: groups of trees taller than 15feet. Includes plantation, wooded vegetation, dense tall vegetation, swamp and mangroves where the vegetation is too thick to the satellite to detect water underneath.
3. Crops: areas where people practice farming and grow crops. It may also include fallow plots of structured land.
4. Built Area: Man-made features. It includes all the structures created by human activities such as roads, railways, all kinds of building, parking etc.
5. Bare ground: areas of rock or soil where there is no growth of vegetation for most time of the year. For example, desert, sand dunes, dry salt flats, gravel pits, dried bed of lake, mines, quarries and exposed rock surface. The cloud coverage during the time of image capturing by satellite.
6. Snow/Ice: only for mountainous region where there is snow and ice for most part of the year. Includes snow field, ice and glaciers.
7. Rangeland: open spaces with little to no taller plants and uniform grass cover; natural cereals and grasses without any human plotting. Height of taller vegetation must be less than 15 feet. For example; natural meadows and filed with no to sparse growing trees, open savanna with no or few trees, lawn, garden, parks, grazingland, and golf course. Bushes, grassland and shrub areas are also classified as rangeland.

The ground surface's ability to hold water and the pace of infiltration are both significantly influenced by the LULC. Moisture content of the soil is also affected by LULC. Utilization and extent of groundwater requirement depends open the LULC. Replenishment and recharge process differs from one LULC to another LULC. Crop fields has greater void ratio which helps in easy infiltration and faster recharge can take place. Built up areas have low recharge for groundwater and are assigned with low weightages in AHP process. Conversion of natural land covers like water bodies, forest, grassland, snow and ice to man-made land covers and built up areas may reduce the rate of infiltration. While performing AHP technique higher weights are assigned to water bodies, crop areas and trees. The roots of the trees and grass help to improve the water holding capacity and also drive the water beneath the ground surface.

**Table 4.8:** Area coverage of different LULC

| Sl.No | LULC Type | Area (sq.km) | Percentage of Area (%) |
|---|---|---|---|
| 1. | Water bodies | 11.192 | 0.22 |
| 2. | Trees | 2380.540 | 46.35 |
| 3. | Crops | 73.682 | 1.43 |
| 4. | Built Area | 494.670 | 9.63 |
| 5. | Bare Ground | 26.250 | 0.51 |
| 6. | Snow/Ice | 202.850 | 3.95 |
| 7. | Rangeland | 1947.133 | 37.91 |

Trees and rangeland covers significant part of Shimla District. Bare grounds in the study area consist of exposed soil and rock surfaces.

## 4.12 ANALYTIC HEIRARCHICAL PROCESS

1. Pair wise comparison.

**Table 4.9:** Pairwise Comparison

| A | B | More important? (A or B) | Level of Importance (1-9) |
|---|---|---|---|
| Rainfall | Geology | A | 5 |
| | Slope | A | 3 |
| | Soil | A | 5 |
| | Drainage Density | A | 5 |
| | LULC | A | 3 |
| | Aspect | A | 7 |
| Geology | Slope | A | 1 |
| | Soil | A | 1 |
| | Drainage Density | A | 3 |
| | LULC | A | 1 |
| | Aspect | A | 5 |
| Slope | Soil | A | 1 |
| | Drainage Density | A | 3 |
| | LULC | A | 3 |
| | Aspect | A | 5 |
| Soil | Drainage Density | A | 3 |
| | LULC | A | 1 |
| | Aspect | A | 5 |
| Drainage Density | LULC | A | 1 |
| | Aspect | A | 5 |
| LULC | Aspect | A | 6 |

2. Pairwise comparison matrix.

**Table 4.10:** Pairwise Comparison Matrix

| **Thematic Layers** | **Rainfall** | **Geology** | **Slope** | **Soil** | **Drainage Density** | **LULC** | **Aspect** |
|---|---|---|---|---|---|---|---|
| **Rainfall** | 1 | 5 | 3 | 5 | 5 | 3 | 7 |
| **Geology** | 1/5 | 1 | 1 | 1 | 3 | 1 | 5 |
| **Slope** | 1/3 | 1 | 1 | 1 | 3 | 3 | 5 |
| **Soil** | 1/5 | 1 | 1 | 1 | 3 | 1 | 5 |
| **Drainage Density** | 1/5 | 1/3 | 1/3 | 1/3 | 1 | 1 | 5 |
| **LULC** | 1/3 | 1 | 1/3 | 1 | 1 | 1 | 6 |
| **Aspect** | 1/7 | 1/5 | 1/5 | 1/5 | 1/5 | 1/6 | 1 |

3. Sum of each column.

**Table 4.11:** Column Sum of Pairwise Comparison Matrix

| **Thematic Layers** | Rainfall | Geology | Slope | Soil | Drainage Density | LULC | Aspect |
|---|---|---|---|---|---|---|---|
| Rainfall | 1 | 5 | 3 | 5 | 5 | 3 | 7 |
| Geology | 1/5 | 1 | 1 | 1 | 3 | 1 | 5 |
| Slope | 1/3 | 1 | 1 | 1 | 3 | 3 | 5 |
| Soil | 1/5 | 1 | 1 | 1 | 3 | 1 | 5 |
| Drainage Density | 1/5 | 1/3 | 1/3 | 1/3 | 1 | 1 | 5 |
| LULC | 1/3 | 1 | 1/3 | 1 | 1 | 1 | 6 |
| Aspect | 1/7 | 1/5 | 1/5 | 1/5 | 1/5 | 1/6 | 1 |
| **SUM** | **253/105** | **143/15** | **103/15** | **143/15** | **81/5** | **61/6** | **34** |

4. Divide each element by the corresponding column sum. The value in each column must add up to 1.

**Table 4.12:** Normalized Pairwise Comparison

| **Thematic Layers** | Rainfall | Geology | Slope | Soil | Drainage Density | LULC | Aspect |
|---|---|---|---|---|---|---|---|
| Rainfall | 105/253 | 75/143 | 45/103 | 75/143 | 25/81 | 18/61 | 7/34 |
| Geology | 21/253 | 15/143 | 15/103 | 15/143 | 15/81 | 6/61 | 5/34 |
| Slope | 35/253 | 15/143 | 15/103 | 15/143 | 15/81 | 18/61 | 5/34 |
| Soil | 21/253 | 15/143 | 15/103 | 15/143 | 15/81 | 6/61 | 5/34 |
| Drainage Density | 21/253 | 5/143 | 5/103 | 5/143 | 5/81 | 6/61 | 5/34 |
| LULC | 35/253 | 15/143 | 5/103 | 15/143 | 5/81 | 6/61 | 6/34 |
| Aspect | 15/253 | 3/143 | 3/103 | 3/143 | 1/81 | 1/61 | 1/34 |

5. Average the value of each row. The rating produced is called the normalized principal Eigen vector or priority vector.

**Table 4.13:** Normalized Pairwise Comparison and Priority Vector

| **Thematic Layers** | Rainfall | Geology | Slope | Soil | Drainage Density | LULC | Aspect | **Priority Vector (%)** |
|---|---|---|---|---|---|---|---|---|
| Rainfall | 105/253 | 75/143 | 45/103 | 75/143 | 25/81 | 18/61 | 7/34 | **38.72** |
| Geology | 21/253 | 15/143 | 15/103 | 15/143 | 15/81 | 6/61 | 5/34 | **12.41** |
| Slope | 35/253 | 15/143 | 15/103 | 15/143 | 15/81 | 18/61 | 5/34 | **16.05** |
| Soil | 21/253 | 15/143 | 15/103 | 15/143 | 15/81 | 6/61 | 5/34 | **12.41** |
| Drainage Density | 21/253 | 5/143 | 5/103 | 5/143 | 5/81 | 6/61 | 5/34 | **7.26** |
| LULC | 35/253 | 15/143 | 5/103 | 15/143 | 5/81 | 6/61 | 6/34 | **10.47** |
| Aspect | 15/253 | 3/143 | 3/103 | 3/143 | 1/81 | 1/61 | 1/34 | **2.68** |

6. Check for CR.

$$CR = \frac{CI}{RCI} \quad , RCI = 1.32 \text{ for } n = 7$$

$$CI = \frac{\lambda max - n}{n-1}$$

$$\lambda max = \left( \frac{253*0.3842}{105} + \frac{143*0.1241}{15} + \frac{103*0.1605}{15} + \frac{143*0.1241}{15} + \frac{81*0.0726}{5} + \frac{61*0.1047}{6} + \frac{34*0.0268}{1} \right)$$

$$= 0.9329 + 1.1830 + 1.1021 + 1.1830 + 1.1761 + 1.0644 + 0.9112$$

$$= 7.5527$$

$$CI = \frac{\lambda max - n}{n-1}$$

$$= \frac{7.5527-7}{7-1}$$

$$= 0.9211$$

$$CR = \frac{0.9211}{1.32}$$

$$= 0.069$$

The consistency of the pairwise comparison matrix is ensured by the CR value being smaller than 0.1.

7. Ranks of the sub classes of all the thematic layers.

**Table 4.14:** Ranks of the sub classes of all the thematic layers

| Sl.No | Thematic Layer | Subclasses | Rank (1-9) |
|---|---|---|---|
| 1. | Rainfall | Very Low (1646-2093) | 3 |
| | | Low (2093-2485) | 4 |
| | | Moderate (2485-2815) | 5 |
| | | High (2815-3097) | 6 |
| | | Very High (3097-3399) | 7 |
| 2. | Geology | Slate | 2 |
| | | Dolomite | 7 |
| | | Shale | 1 |
| | | Quartzite | 7 |
| | | Phyllite | 3 |
| | | Gneiss | 5 |
| | | Schist | 4 |
| | | Diamictite | 6 |
| | | Limestone | 8 |
| | | Sandy | 9 |
| 3. | Slope | Flat (0-16.44) | 8 |
| | | Gentle (16.45-25.13) | 6 |
| | | Moderate (23.14-33.19) | 5 |
| | | Steep (33.20-42.81) | 4 |
| | | Very Steep (42.8279.10) | 2 |
| 4. | Soil | Coarse | 7 |
| | | Medium | 5 |
| | | Fine | 3 |

| | | | |
|---|---|---|---|
| 5. | Drainage Density | Very Low (0.12-1.39) | 7 |
| | | Low (1.39-1.93) | 6 |
| | | Moderate (1.93-2.32) | 4 |
| | | High(2.32-2.66) | 3 |
| | | Very High (2.66-3.58) | 2 |
| 6. | LULC | Water bodies | 9 |
| | | Trees | 8 |
| | | Crops | 7 |
| | | Built Area | 2 |
| | | Bare Ground | 4 |
| | | Snow/Ice | 6 |
| | | Rangeland | 6 |
| 7. | Aspect | N&NE (0-45) | 6 |
| | | NE&E (45-90) | 5 |
| | | E&SE (90-135) | 3 |
| | | SE&S (135-180) | 2 |
| | | S&SW (180-225) | 2 |
| | | SW&W (225-270) | 3 |
| | | W&NW (270-315) | 5 |
| | | NW&N (315-359) | 6 |

# CHAPTER 5

# RESULT AND DISCUSSION

## 5.1 GENERAL

In this chapter, we will discuss the result of weighted overlay analysis performed for Shimla district in ArcMap software. We will also interpret the different groundwater potential zones. Cross validation with hand pump map and accuracy of the GIS based GWPZ map will also be presented. The future scope is discussed here in this section.

## 5.2 GROUNDWATER POTENTIAL ZONES OF SHIMLA DISTRICT

Weighted overlay analysis was performed to delineate the groundwater potential zones of the study area. The groundwater map was classified into five categories as zones of Very high, High, Moderate, Low and Very Low potentials.

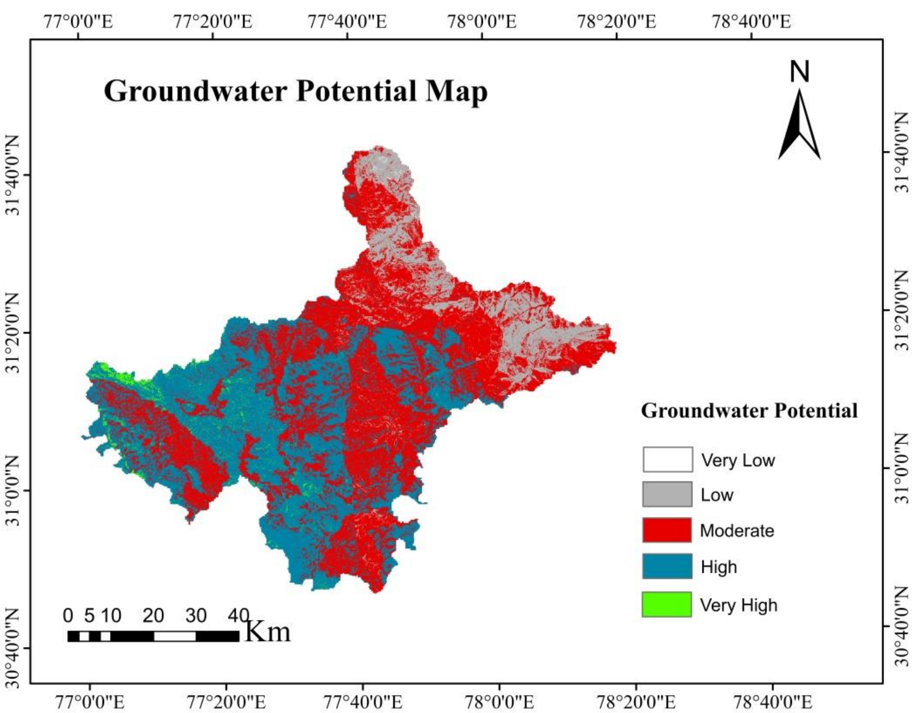


**Figure 5.1:** Groundwater potential map of Shimla District

**Table 5.1:** Area coverage of different groundwater potential zones

| Sl.No | Different Potential Zones | Area (sq.km) | Percentage of area (%) |
|---|---|---|---|
| 1. | Very Low | 2.743 | 0.05 |
| 2. | Low | 625.043 | 12.31 |
| 3. | Moderate | 2396.712 | 47.22 |
| 4. | High | 1981.503 | 39.04 |
| 5. | Very High | 69.970 | 1.38 |

Most part of the area has moderate groundwater potentials. Very high potential zones are located in the western part. Low to very low potentials occur in the north eastern part of the district. The thematic description of the GWPZ is presented below.

**Table 5.2:** Thematic Description of different GWPZ of Shimla District

| Sl.No | GWPZ | Thematic Description | Places |
|---|---|---|---|
| 1. | Very High & High | • Very high to High rainfall<br>• Fine to medium texture soil<br>• Flat to gentle slope<br>• Rangeland & trees<br>• Very Low to low drainage density<br>• Dolomite, limestone, sandstone | Seoni, Shimla rural area, Chopal. Kochi, Kotkhai |
| 2. | Moderate | • Low to moderate rainfall<br>• Fine texture soil<br>• Rangeland, trees and built area<br>• Schist, limestone, shale and Phyllite<br>• Gentle to steep slope<br>• Moderate drainage density | Theog, Tikar, Rohru, Shimla Municipal |

| | | | |
|---|---|---|---|
| 3. | Low & Very Low | • Low to very low rainfall<br>• Rangeland, snow and ice<br>• Steep slopes<br>• Gneiss, quartzite, slate and schist<br>• High drainage density | Upper Rampur |

## 5.3 ACCURACY OF THE MODEL

In order to check the accuracy of the GIS based GWPZ map, hand pump data of Shimla District is used. A total of 91 handpumps having a yield of 12LPM for 40 strokes per minute are analyzed. These hand pumps are used to draw groundwater mainly for domestic purposes.

**Table 5.3:** Location and Characteristics of Handpumps in Shimla District

| Station. No | Village/Place Name | Depth | Longitude | Latitude |
|---|---|---|---|---|
| 1 | Deorighat | 78.94 | 77.5948 | 31.1746 |
| 2 | Fruit Market Rohru | 78.94 | 77.7388 | 31.1958 |
| 3 | Kazail | 75.9 | 77.1298 | 31.1484 |
| 4 | Nirath | 75.9 | 77.5418 | 31.3692 |
| 5 | Bharara Jamrashli | 85.04 | 77.7249 | 31.1915 |
| 6 | Dayamoli | 78.94 | 77.7393 | 31.2328 |
| 7 | Gushangu Kainchy | 97.23 | 78.0675 | 31.197 |
| 8 | Snawgi | 85.04 | 77.3463 | 31.3205 |
| 9 | Halyana | 78.94 | 77.5063 | 31.3373 |
| 10 | Nehri Kralti | 85.04 | 77.5012 | 31.2924 |
| 11 | Jabu Jubbar | 85.04 | 77.5025 | 31.2952 |
| 12 | Kotgarh | 88.08 | 77.4774 | 31.3083 |
| 13 | Charota | 78.94 | 77.4999 | 31.3535 |
| 14 | Gharal Nallah | 82 | 77.4677 | 31.335 |
| 15 | Ghandal | 78.94 | 77.0411 | 31.1589 |
| 16 | Daj | 78.94 | 77.5527 | 31.3714 |
| 17 | Rampur Bus Stand | 72.84 | 77.6485 | 31.4543 |
| 18 | Rachoij | 72.84 | 77.6469 | 31.4524 |
| 19 | Ganeog | 79.24 | 77.091 | 31.1687 |

| | | | | |
|---|---|---|---|---|
| 20 | Bashol | 82 | 77.0541 | 31.1536 |
| 21 | Pajawat | 82.3 | 77.06 | 31.1331 |
| 22 | Kalani | 82 | 77.0334 | 31.1629 |
| 23 | Manlog | 90.83 | 77.4455 | 31.1418 |
| 24 | Bagain | 75.89 | 77.4338 | 31.1021 |
| 25 | Sainj | 94.18 | 77.3875 | 31.0751 |
| 26 | Charau | 78.94 | 77.1633 | 31.0388 |
| 27 | Sakrah | 91.14 | 77.1814 | 31.0775 |
| 28 | Kupri Ground | 85.04 | 77.7065 | 31.198 |
| 29 | Pauri Dhar | 78.94 | 77.7354 | 31.1918 |
| 30 | Suni College Ground | 72.84 | 77.1172 | 31.246 |
| 31 | Sialmooh | 75.9 | 77.0199 | 31.1176 |
| 32 | Shageen | 91.14 | 77.12 | 31.0743 |
| 33 | Yan | 82 | 77.1659 | 31.0107 |
| 34 | Gaya II | 75.9 | 77.1494 | 31.014 |
| 35 | Nishulla | 95.09 | 77.3194 | 31.0744 |
| 36 | Deora | 95.7 | 77.376 | 31.0844 |
| 37 | Madrot | 85.04 | 77.3776 | 31.0894 |
| 38 | Kundli Chalog | 85.04 | 77.3525 | 31.1297 |
| 39 | Bambi | 85.04 | 77.4164 | 31.0841 |
| 40 | Shalla | 78.94 | 77.4112 | 31.0609 |
| 41 | Siro | 90.83 | 77.4038 | 31.1731 |
| 42 | Shalog Kainchy | 88.08 | 77.4123 | 31.1709 |
| 43 | Satog | 72.84 | 77.3087 | 31.0113 |
| 44 | Jagratti | 91.13 | 77.2827 | 30.9552 |
| 45 | Dhainch | 82 | 77.1109 | 31.0755 |
| 46 | Palchon | 82 | 77.0538 | 31.1023 |
| 47 | Sari | 91.13 | 77.075 | 31.0471 |
| 48 | Kanori | 91.13 | 77.0346 | 31.1863 |
| 49 | Ghandal Temple | 85.04 | 77.0521 | 31.1647 |
| 50 | Sr. Sec. School Baichary | 72.84 | 77.0875 | 31.108 |
| 51 | Lower Junga | 85.04 | 77.1865 | 31.0235 |
| 52 | Chelli | 82 | 77.184 | 31.0661 |
| 53 | Kater | 75.9 | 77.0847 | 31.1156 |
| 54 | Balog | 78.94 | 77.0939 | 31.0939 |
| 55 | Navodya School | 78.94 | 77.3351 | 31.1242 |
| 56 | Sheel (Dharech) | 75.9 | 77.3323 | 31.0229 |

| | | | | |
|---|---|---|---|---|
| 57 | Dumehar | 78.94 | 77.273 | 30.9717 |
| 58 | Upper Dakolan | 63.7 | 77.6275 | 31.4246 |
| 59 | Bhaiyal | 82 | 77.121 | 31.0883 |
| 60 | Janol | 85.04 | 77.1144 | 31.1377 |
| 61 | Goshala | 85.04 | 77.1283 | 31.0956 |
| 62 | Kanda | 91.13 | 77.0854 | 31.124 |
| 63 | Sharda | 85.04 | 77.1168 | 31.1451 |
| 64 | Cheyon | 75.9 | 77.0848 | 31.1719 |
| 65 | Upper Androl | 72.84 | 77.0931 | 31.1739 |
| 66 | Suni Nr. College | 85.04 | 77.1202 | 31.2462 |
| 67 | Didoghatti | 85.04 | 77.101 | 31.1605 |
| 68 | Sallu | 88.08 | 77.107 | 31.1269 |
| 69 | Dido | 75.9 | 77.1134 | 31.1644 |
| 70 | Sheel 1 (Old Junga) | 69.8 | 77.1979 | 31.0251 |
| 71 | Kheel Ser 2 | 88.08 | 77.2766 | 30.9636 |
| 72 | Kutasni 2 | 63.7 | 77.0842 | 31.107 |
| 73 | Suni PWD Gand Hut | 72.84 | 77.1219 | 31.2442 |
| 74 | Lower Try | 54.77 | 77.288 | 30.9546 |
| 75 | Dhari | 66.75 | 77.1188 | 31.0616 |
| 76 | Paoghat (Kohbag) | 90.83 | 77.1673 | 31.1027 |
| 77 | Bhad 1 | 78.94 | 77.1704 | 31.028 |
| 78 | Bhad 2 | 85.04 | 77.1698 | 31.0745 |
| 79 | Deola Kainchi | 78.94 | 77.2889 | 31.2673 |
| 80 | Badash | 85.04 | 77.1745 | 31.1158 |
| 81 | Jais Talai | 75.89 | 77.3766 | 31.1006 |
| 82 | Lower Chamech | 71.32 | 77.3668 | 31.0897 |
| 83 | Dussehra Ground Suni | 60.65 | 77.1221 | 31.2458 |
| 84 | Manan | 72.84 | 77.4305 | 31.1963 |
| 85 | Lellu Village | 66.75 | 77.3921 | 31.0804 |
| 86 | Jubbar | 72.84 | 77.3598 | 31.1208 |
| 87 | Keet | 85.04 | 77.3428 | 31.1451 |
| 88 | Kalauni | 72.84 | 77.0387 | 31.193 |
| 89 | Pandoa | 72.84 | 77.3082 | 31.2749 |
| 90 | Kol Dam Colony 1 | 72.85 | 77.1221 | 31.2458 |
| 91 | Kol Dam Colony 2 | 51.5 | 77.1218 | 31.2468 |

### 5.3.1 True Positive Rate

It consists of 91 projected hand pumps each having a yield of 12 LPM for 40 strokes per minute.

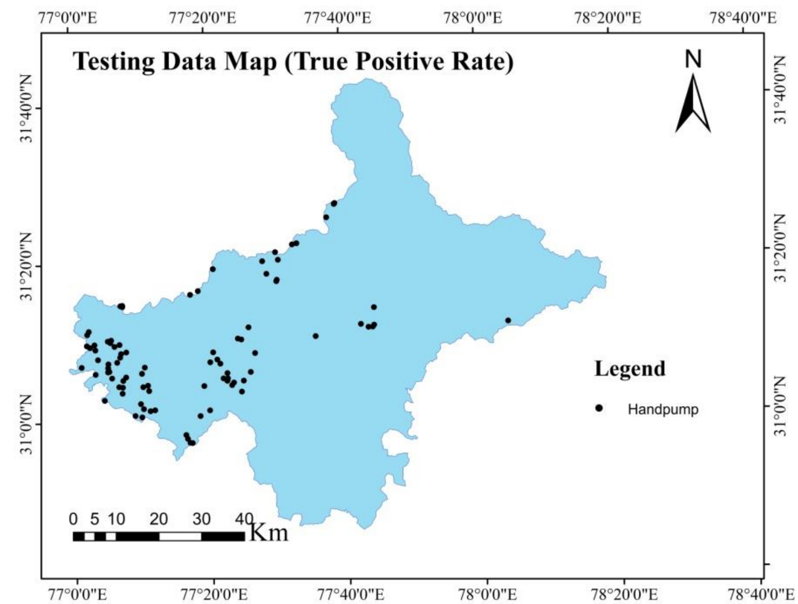


**Figure 5.2:** Testing Data (True Positive rate)

### 5.3.2 False Positive Rate

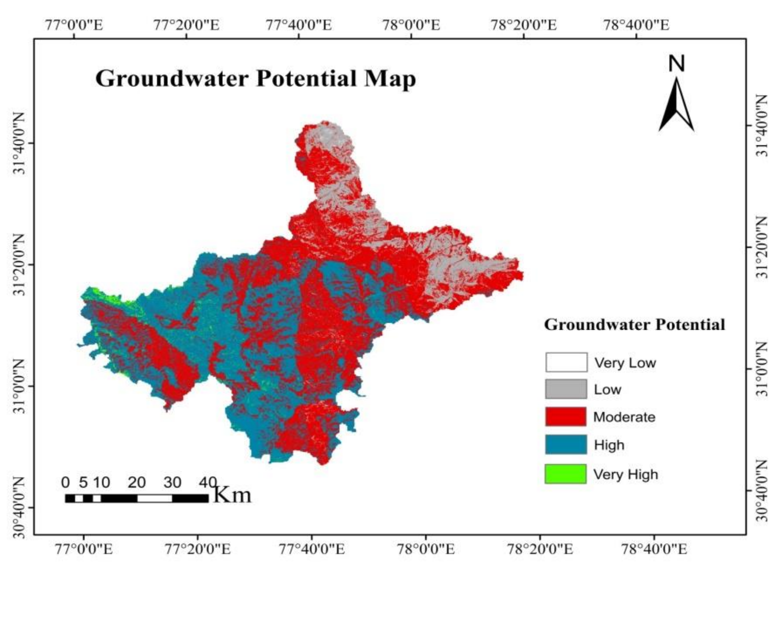


**Figure 5.3:** GWPZ Map (False Positive rate)

### 5.3.3 AUC Curve

Accuracy is 69%.

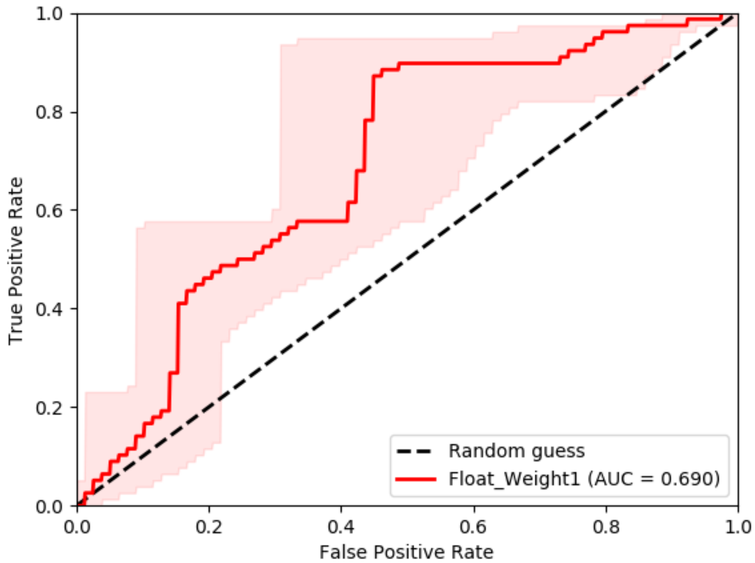


**Figure 5.4:** AUC Curve

## 5.4 CROSS VALIDATION

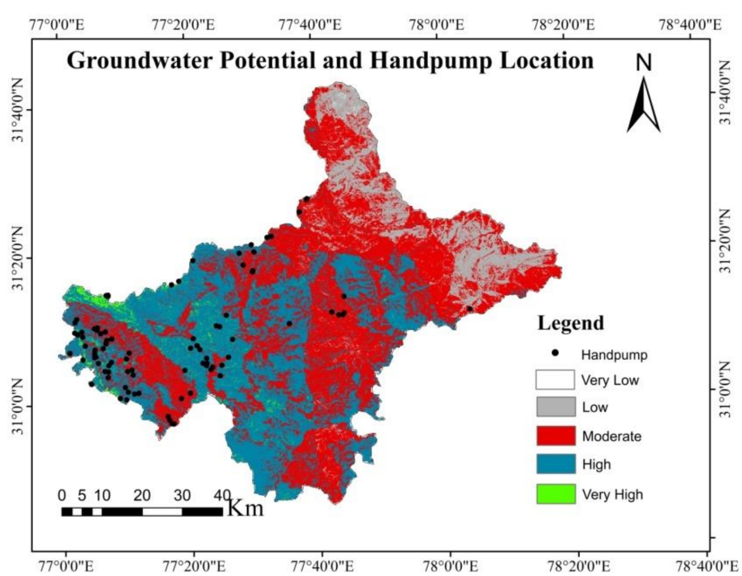


**Figure 5.5:** Integrated hand pump and GWPZ Maps

From Figure 5.5, the existed handpumps are located in moderate to high potential zones of groundwater. Overall, the locations of the existing handpumps are agreeing with the groundwater potential map.

## 5.5 FUTURE SCOPE

a) In order to enhance the accuracy of the model, high resolution satellite data needs to be used.
b) Although AHP is a hypothetical technique and it lies on the judgement of the expertise and literature available, its efficiency can be improved by keeping consistency ratio as close to zero as possible.
c) There is a scope to analyze and study groundwater potential using same thematic layers by applying other methods. Such methods include Frequency Ratio and Certainty Factor Models.
d) The same thematic layers can be used for studying other operations using AHP such as watershed management and detection of landslide susceptibility zones of an area.

# CHAPTER 4

# CONCLUSION

Through this project we are able to learn how to apply GIS technique and analytical hierarchical process to delineate different zones of groundwater potential in our study area. In general, exploration of groundwater can be done in two ways namely geophysical method and surface method. Some of the methods require more data, huge investment and it is time consuming. With the advancement in technology, groundwater exploration using remote sensing and GIS technique has been growing rapidly due to its effectiveness in time and resources incurred. Also, it can cover a large area under study.

The present work is carried in Shimla district. Shimla district is located in the southeast of Himachal Pradesh. Most of the study area is hilly and mountainous region with highly dissected and undulating terrain. As per CGWB (2013) the groundwater quality was found as good and no contamination can be found. Since most of the locals here are farmers, ground water serves as a valuable source of water for irrigation and domestic uses. In recent years, yield of the wells and bowries decreased due to over utilization of groundwater and a number of wells are abundant as of now. There is the need to address such issues to safeguard groundwater resources for future generations and manage them sustainably.

A combination of GIS technique and AHP method is used to delineate ground water potential zones. A total of 7 thematic layers of rainfall, soil, geology, slope, drainage density, LULC and aspect are used to create groundwater map. These thematic layers are the parameters which control the flow and replenishment of groundwater. Weightages are assigned to classes of all the 7 thematic layers using Saaty scale, which are determined by the AHP technique based on the class's attributes and water potential capacity.

As a final output we created a map which shows different zones of groundwater potential. The groundwater map was classified as very high, high, moderate, low and very low zones of groundwater potential. The area coverage of these classes is 69.97 $km^2$, 1981.503 $km^2$, 2396.712 $km^2$, 625.043 $km^2$ and 2.743 $km^2$ respectively. Most part of the area has moderate and high groundwater potentials which occupy the central Shimla region. Very high potential zones are located in the south western part and covers 1.38% of the total aerial spread. As northern part of the district is mountainous covered by snow and ice, low to very low potentials occurs in this part of the district which together makes up about 13% aerial coverage. The Shimla town and municipal area falls under low to moderate zones of groundwater.

The hand pump data of Shimla district were used to check the accuracy and validate the established groundwater potential zones map. A total of 91 hand pumps having 12 LPM yield for 40 strokes per minute were used in ROC AUC model. The accuracy of the model comes to 69%. An integrated comparison of hand pump map and established groundwater potential map showed that the existing hand pumps are located in moderate and high potential zones of the area.

Groundwater map would be recommended to use for further investigation of ground water. The map will help to guide the decision makers to target very high and high zones of groundwater potentials for constructing bore holes and wells. The current study offers guidance to decision makers on how to effectively plan and manage groundwater for domestic and agricultural uses. Since agricultural land makes up majority of Shimla region, this research will contribute to the development of the area's agricultural productivity and irrigation infrastructure

As the presence of groundwater is not visible from earth surface, construction of wells require prior information regarding the groundwater prospect of that location. It is critical to apply fast, cost effective and long term standardized strategy like GIS based study which covers a large area and identifies optimal groundwater potential zones. Since the thematic layers were prepared using less resolution data, future studies should focus on using high resolution to improve the accuracy. Moreover, greater the number of thematic layers used; more efficient will be the analysis

# REFERENCES


[1] Arulbalaji, P., Padmalal, D., Sreelash, K. "GIS and AHP Techniques Based Delineation of Groundwater Potential Zones: a case study from Southern Western Ghats, India", Scientific Reports 9, Article Number **2082** (2019).

[2] R. P. Mathews. "Groundwater information booklet, Shimla District, Himachal Pradesh", Central Groundwater Board (2013).

[3] N.B. Narasimha Prasad. "Geophysical Investigation for groundwater exploration in Lakshadweep Islands- A case study" (2011).

[4] Khodaei, K., Nassery, H.R. "Groundwater exploration using remote sensing and geographic information systems in a semi-arid area (Southwest of Urmeih, Northwest of Iran)", Arabian Journal of geosciences **6(4)** (2011).

[5] J.T. Al-Bakri. "Application of GIS and remote sensing to groundwater exploration in Al Wala Basin in Jordan", Journal of Water Resource and Protection (2013).

[6] Himabindu, D., Ramadass, G. "Remote sensing and geophysical studies for groundwater exploration in Osmania University campus, Hyderbad, India: A case study", ResearchGate, Mausam **53(1)**:87-93 (2002).

[7] Sener, E., Davraz, A., Ozcelik, M. "An integration of GIS and remote sensing in ground water investigations: A case study in Burdur, turkey", Hydrogeology Journal **(13),** 826-834 (2005).

[8] Fitts, C. R. Groundwater science (Elsevier, 2002).

[9] Theophilus A. Adagunodo, Margaret K. Akinloye, Lukman A. Sunmonu, Ahzegbobor P. Aizebeokhai, Kehinde D. Oyeyemi, Felicia. Abodunrin. "Groundwater Exploration in Aaba Residential Area of Akure, Nigeria", Front. Earth Sci. (2018).

[10] Solomon, S., Queil, F. "Groundwater study using remote sensing and Geographic information systems (GIS) in the central highlands of Eritrea", Hydrogeology Journal **14(5)**: 729-741 (2006).

[11] S. Vidhya Lakshmi, Y. Vinay Kumar Reddy. "Identification of groundwater potential zones using GIS and remote sensing", International Journal of Pure and Applied Mathematics, 119**(17)** (2018).

[12] Narkhede, S. "Understanding ROC-AUC Curve", (2018).

[13] Saaty, T. L. “Decision making for leaders: the analytic hierarchy process for decisions in a complex world”, (RWS publications, 1990).

[14] Pourtaghi, Z. S. & Pourghasemi, H. R. “GIS-based groundwater spring potential assessment and mapping in the Birjand Township, southern Khorasan Province, Iran”, Hydrogeo Journal. **(22)**, 643–662 (2014).

[15] Chenini, I. & Mammou, A. Ben. “Groundwater recharge study in arid region: an approach using GIS techniques and numerical modeling”, Comput. Geosci, **(36)**, 801–817 (2010).

[16] Singh, L. K., Jha, M. K. & Chowdary, V. M. “Assessing the accuracy of GIS-based Multi-Criteria Decision Analysis approaches for mapping groundwater potential”, Ecol. Indic. **(91)**, 24–37 (2018).

[17] Yeh, H.-F., Cheng, Y.-S., Lin, H.-I. & Lee, C.-H. “Mapping groundwater recharge potential zone using a GIS approach in Hualian River, Taiwan. Sustain”, Environ. Res. **(26)**, 33–43 (2016).

[18] Sahoo, S., K. Jha, M., Kumar, N., V.M, Chowdary. "Evaluation of GIS-based multicriteria decision analysis and probabilistic modeling for exploring groundwater prospects", Environmental Earth Sciences, (2015).

[19] Pinto, Domingos, Sangam Shrestha, Mukand S. Babel, and Sarawut Ninsawat. "Delineation of groundwater potential zones in the Comoro watershed, Timor Leste using GIS, remote sensing and analytic hierarchy process (AHP) technique" , Applied Water Science, (2015).

[20] M. Dashti Barmaki, M. Rezaei, S. Madadi. "Use of fractal dimensions analysis in geographic information system and remotesensing techniques to identify groundwater prospective zones in the Anar-Dashtegol anticline, Iran”, Carbonates and Evaporates (2019).

[21] Abdelouhed, F., Ahmed, A., Abdellah, A., Yassine, B., Mohammed, I. "Using GIS and remote sensing for the mapping of potential groundwater zones in fractured environments in the CHAOUIA-Morocco area”, Remote Sensing Applications: Society and Environment, (2021).

[22] S. Deepa, S. Venkateswaran, R. Ayyandurai, R. Kannan, M. Vijay Prabhu. "Groundwater recharge potential zones mapping in upper Manimuktha Sub basin Vellar river Tamil Nadu India using GIS and remote sensing techniques", Modeling Earth Systems and Environment, (2016).

[23] Nasui, D., Zisu, I. “Using universal soil loss equation for soil erosion assessment in agricultural land from Lugoj hills”, Geographica Timisiensis, vol. XXIV, nr.2, 2015 (13-23).

[24] Tanveer Dar, Nachiketa Rai, Aadil Bhat. "Delineation of potential groundwater recharge zones using analytical hierarchy process (AHP)”, Geology, Ecology, and Landscapes, (2020).

[25] Gebremedhin Godif, B.R. Manjunatha. "Delineation of groundwater potential zones using remotely sensed data and GIS-based analytical hierarchy process: Insights from the Geba river basin in Tigray, Northern Ethiopia”, Journal of Hydrology: Regional Studies, (2023).

[26] Pankaj Kumar, Srikantha Herath, Ram Avtar, Kazuhiko Takeuchi. "Mapping of groundwater potential zones in Killinochi area, Sri Lanka, using GIS and remote sensing techniques", Sustainable Water Resources Management, (2016).

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