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Enhancing water security: A geospatial AHP approach to identifying groundwater potential zones

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Abstract

Groundwater is crucial for both human activities and ecosystem health, but its availability and quality are threatened by over-exploitation, population growth, climate change, and human actions. Identifying and delineating potential groundwater zones is essential for sustainable management and utilization. This study employs the Analytical Hierarchy Process (AHP) and geospatial analysis to evaluate groundwater potential in Una district, Himachal Pradesh, India. It integrates thematic maps of geomorphology, lithology, soil, lineament, drainage, land use, slope, aspect, and rainfall using ArcGIS software, assigning scores and weights through AHP. The district is classified into five groundwater potential zones: Very Poor (1%, 17.85 km²), Poor (7%, 114.89 km²), Fair (30%, 453.76 km²), Good (36%, 548.06 km²), and Excellent (26%, 392.78 km²). The Central Ground Water Report (2021–2022) is consulted for validation, comparing designated zones with open well yield data. The study's findings provide valuable insights into Una district's groundwater potential, aiding policymakers, planners, and the farming community in implementing sustainable water resource management strategies.

Keywords: Geospatial analysis, groundwater potential zone, analytic hierarchy process, remote sensing

Introduction

Groundwater is crucial for meeting India's water needs, particularly in regions with limited surface water. However, concerns arise due to India being one of the world's largest consumers of groundwater, with an annual replenishable resource of 433 billion cubic meters (MOWR 2020) [33]. Its accessibility and safety make it the predominant water source, leading to increased reliance in residential, urban, farming, and industrial sectors (Takase and Fujihara, 2019) [49]. Groundwater, catering to approximately 65% of irrigation needs, is vital for agricultural productivity in India. Failure to implement timely measures may lead to a severe water crisis in many states (Jasrotia *et al.*, 2019) [24]. Challenges include over-exploitation, causing declining water tables and aquifer depletion. Excessive irrigation pumping, coupled with insufficient management, poses a threat to long-term sustainability. The mainstay of traditional methods used to identify, delineate, and map the groundwater potential zones is ground surveys using geophysical, geological, and hydrogeological tools, which are generally expensive and time-consuming (Sander *et al.*, 1996; Jha *et al.* 2007, Echogdali *et al.*, 2022) [44, 25, 15]. However, in a number of geoscience domains, geospatial technologies can generate and model valuable data fast and cheaply (Jha *et al.*, 2007; Adiat *et al.*, 2012) [25, 2]. To estimate groundwater potential under different conditions, researchers use a variety of techniques, including the Analytical Hierarchy Process (AHP), Artificial Neural Network (ANN), Electrical Resistivity (ER), Evidential Belief Function Model (EBFM), Multi-Influencing Factor (MIF), and probabilistic models like Frequency Ratio (FR) (Ahmed *et al.*, 2021; Anbarasu *et al.*, 2020; Roy *et al.*, 2020) [3, 7, 42]. Researchers have published a great deal on the use of GIS in groundwater monitoring and management, including GIS delineation (Nagarajan and Singh, 2009; Magesh *et al.*, 2012; Shukla, 2014; Oikonomidis *et al.*, 2015; Kumar *et al.*, 2016; Das *et al.*, 2017; Thapa *et al.*, 2017; Das and Pardeshi, 2018; Andualem and Demeke, 2019; Nithya *et al.*, 2019; Bhattacharya *et al.*, 2020; Ghosh *et al.*, 2020; Rajasekhar *et al.*, 2020) [34, 30, 46, 36, 29, 11, 50, 12, 8, 35, 10, 20, 40]. Groundwater research has evolved with the development of several GIS tools, such as the height above the closest drainage (Omid *et al.*, 2014) [36].

The Analytic Hierarchy Process (AHP) is a methodical approach to decision-making that uses a hierarchical breakdown to evaluate and prioritize certain criteria and options. Using a Saaty scale established in 1980, decision-makers use pairwise comparisons to give relative weights. Singh *et al.* (2018) [48] introduced the Groundwater prospective Index (GWPI), a quantitative technique that uses themed maps to determine prospective groundwater scores. Pairwise comparisons are performed using Saaty's scale, which has a range of 1 to 9. The weights of the criterion and alternatives are determined by calculating an eigenvector.

This research evaluates geological features, geomorphology, lineament density, drainage density, slope, soil, and hydrological parameters in order to identify groundwater potential zones in the target region using the Analytic Hierarchy Process (AHP). AHP will be used to weight thematic layers produced by GIS and remote sensing methods to create a thorough groundwater potential map. Comparison with well yield data and current groundwater reports will be used for validation. By identifying high, moderate, and low prospective zones for groundwater availability, the study hopes to provide important information for sustainable water supply plans and efficient resource management in the region.

Given the rising demand for freshwater resources, it is critical to accurately and efficiently define groundwater (GW) potential zones in areas where these difficulties exist in order to alleviate water shortages and meet the growing demands of society for water. Moreover, this strategy is essential for achieving the world's sustainable development goals.

This study's use of AHP greatly improves the precision and dependability of the groundwater potential assessment in the large basin. This study's introduction of the synergy between GIS and AHP methodologies is a novel strategy for sustainable water resource management and decision-making. This approach offers a useful plan for meeting the region's growing water demands, which include those for industry, agriculture, and drinking. The study's conclusions add to the larger conversation on sustainable water management by providing a useful framework for well-informed decision-making in the face of changing issues with water resources.

Study Area

The Una district, which is situated in the southwest of the state and is bordered to the north by the Kangra district, the east by the Hamirpur district, the west by the Punjabi district of Hoshiarpur, and the south by the Bilaspur district, is where the research was carried out (Fig 1). Situated between latitudes 31°24' and 32°27' north and longitudes 75°46' and 76°24' east is where the district may be found. Its size is estimated to be 1540 square kilometers, and its population is roughly 521,173 as of the 2011 census.

This district is tucked away between the lower Himalayas and the Siwalik hills. Its terrain is varied, with terraces, piedmont zones, hills, and valleys. The district's land surface altitudes vary from 340 meters above mean sea level (AMSL) in the southeast to 1041 meters above amsl in the east. The bulk (80%) of the Una district is drained by the Soan or Swan River, which is a tributary of the Sutlej. The lower parts of the Soan River have a steady base flow, but it is an intermittent river. The Soan River splits the Una district in half and drains around 80% of the area. There are two different types of soil in the district: non-calcic brown soil and alluvial soil. Alluvial soil makes up the majority of the district; just around 25%.

The district's main supply of residential and agricultural water

comes from groundwater. There are many of springs, kulhs (water canals), tube wells, and water supply wells. Studying groundwater potential zones is best done in Himachal Pradesh's Una district because of its varied topography, climate, and natural resources.

Materials and Methods

Data Collection

Various sources were used for data gathering in order to obtain the relevant information for the investigation. The USGS Earth Explorer (United States Geological Survey) platform was used to collect digital elevation data from the satellite-borne sensor ASTER. This information was gathered expressly for slope mapping, allowing for a complete investigation of the topography and its inclination. Land-use data was gathered from Bhoonidhi, a platform supplied by National Remote Sensing Centre (NRSC), which was critical for understanding the distribution and patterns of land usage in the research area. The high-resolution satellite imagery provided by ResourceSat-2A LISS3 was used for land-use mapping (Table 1).

Data from the Geological Survey of India was used to gain understanding of the local geology. The Geological Survey of India website acts as a reference for geological mapping, providing important details on the geological features and formations in the area. Data from Land Use Planning and the National Bureau of Soil Survey were used to map the texture of the soil. The organization's website provided pertinent soil texture references, which allowed the research to gain a better understanding of the composition and characteristics of the soil in the study region. To map the drainage network, multiple sources were used. The Earth Explorer platform and Google Earth were utilized to access relevant data, such as the Global Digital Elevation Model (GDEM) and Survey of India (SOI) Toposheets, while the Survey of India website provided additional information. With the help of automatic drainage extraction methods especially in hydrology tools of ArcGIS. Then, Kernel density tool is used for deriving the drainage density. These sources were instrumental in mapping drainage density and understanding the flow patterns of watercourses in the study area. For lineament density mapping, the Geological Survey of India served as a valuable reference source. Lineament of the study area explored from satellite image by using automatic lineament extraction methods. Before extracting the lineament, the satellite data has been worked some preprocessing methods which were converted into a PCA in ERDAS 9.2 software. Then, the PCA image taken into PCI Geomatica software and the lineament was explored by using lineament extraction tool. Afterwards, ArcGIS software was used to produce the lineament density map using the retrieved lineament. The Kernel density tool is used for deriving the lineament density. The organization's portal provided essential data and information related to lineaments, which significant linear geological features indicative are of fault lines or fractures.

Finally, for geomorphological mapping, data from L.U.P. and N.B.S.S. was utilized. The organization's website provided relevant references and resources for understanding the various landforms and processes shaping the study area's geomorphology. The combination of these data sources, ranging from satellite imagery to geological references, facilitated a comprehensive and detailed collection of information necessary for the study's objectives.

Methodology

This study used geospatial techniques to identify possible groundwater zones in the Una district. The study's methodology included the collecting and compilation of eight thematic layers with ArcGIS software. To give weights to these layers, the analytical hierarchy approach was employed, and the weights were normalised to ensure uniformity (Table 2 and 3). The strata underwent a weighted overlay study, which produced the groundwater potential zone. A number of factors, including geomorphology, geology, lineament density, drainage density, slope, rainfall, land use and land cover, and soil, were weighted and combined to create the groundwater potential index. The results were cross-checked with data on groundwater variation and well yield collected before and after the monsoon. The method employed is shown in Figure 2.

$$GWPI = G_rG_w + Ge_rGe_w + L_rL_w + D_rD_w + Sl_rSl_w + R_rR_w + Lu_rLu_w + S_rS_w$$

The acronym for groundwater potential index is GWPI. L stands for lineament density, D for drainage density, Sl for slope, R for rainfall, Lu for land use and land cover, and S for soil. The letters G, Ge, and R stand for geomorphology, geology, and drainage, respectively. By dividing the total number of layers by the rankings (suffix r) and weights (suffix w) given to each layer, the groundwater potential index (GWPI) was determined.

Results and Discussion

Geomorphology

The study of geomorphology involves the exploration of physical features and processes on Earth's surface. It deals with the formation, evolution, and classification of landforms, including mountains, valleys, rivers, and coastlines. Field observations, remote sensing, and numerical modeling are some of the techniques used by geomorphologists to study landforms. A variety of factors shape landforms, such as tectonic activity, climate, and erosion, which, in turn, influence natural processes, such as soil formation, water cycle, and habitat diversity. Therefore, geomorphology is important in a variety of applications, such as natural hazard assessment, land use planning, and environmental management. Geomorphology can help with groundwater potential zoning by providing details about the hydraulic qualities and subsurface structure. For instance, the distribution and kind of sedimentary deposits can impact the permeability and porosity of the subsurface, while the form and orientation of mountains and valleys can alter the direction and pace of groundwater flow. Dissected hills, alluvial plains, flood plains, valleys, and reservoirs characterise the research area (Fig 3). Various weights were assigned to these groups according to how important they were for groundwater recharge. Because of its great capacity for recharging, the alluvial flat took on the most weight; on the other hand, because they are mainly responsible for runoff, hills that are severely and moderately dissected took on the least weight (Table 4). Therefore, adding geomorphological data to the AHP method can improve the precision and reliability of groundwater potential zoning. The usefulness of geomorphological data has been demonstrated by several research that have utilized it to identify groundwater potential zones. For instance, Rajashekhra *et al.* (2018) [40] identified possible groundwater recharge zones in a semi-arid area of India using hydrogeological and geomorphological data. The study found that because of their high permeability and water-holding capacity, valley fills and alluvial fans offer excellent potential for recharging.

Geology

The features of the local geology have a major impact on the existence and distribution of groundwater, encompassing both surface and subsurface geology. Geology, as a scientific discipline, delves into the examination of the Earth's physical structure, composition, and historical development. This field involves the study of rocks, minerals, fossils, and various materials, contributing to an enhanced comprehension of the intricate processes that have shaped the Earth's surface over extended periods, spanning millions of years. The Geology map is important in understanding the subsurface structure and qualities that affect groundwater occurrence, transport, and storage in the context of potential groundwater zoning. The composition and structure of rocks and sediments, for example, can influence their permeability and porosity, which determine groundwater's ability to flow and be stored in the subsurface. Similarly, the presence of faults, fractures, and other geological features can influence groundwater movement direction and pace. Geological data can be used to create maps and models that depict the geographical distribution of various rocks and sediments, as well as their composition, thickness, and hydrological characteristics. Afterwards, by applying the AHP technique, this data may be utilized to assess the relative significance of geological components in locating prospective groundwater zones. For example, Allafta *et al.* (2021) [6] identified potential zones for groundwater recharge in the Shatt al-Arab basin using geological and hydrogeological data. The study found that because of their high permeability and storage capacity, fractured limestone formations and unconsolidated sediments had the greatest potential for recharging.

Lineament density

An understanding of the existence of water leakage through joints, fractures, and faults is provided by lineament analysis. Lines in the subsurface, which are major geological features, influence groundwater circulation and storage. By mapping and evaluating lineament density to identify probable groundwater replenishment and extraction zones, the research area can be better understood. The density of lineaments may be determined using a variety of technologies, including as satellite photography, field mapping, and remote sensing methods like LiDAR (light detection and Ranging) and RADAR (radiation detection and Ranging). Lineament density maps show linear characteristics in space and their density values as a function of length per unit area. Most of the lineament has been found in different angles in the North-East direction, as opposed to the North-West and South-West directions (Fig. 5). The arrangement of lineaments is important because it indicates regions with more fractures, longer fracture lengths, and broader fracture widths. According to Edet *et al.*'s 1998 [16] research, these lineaments serve as conduits that promote improved fracture connection and aquifer replenishment. The lineament density was divided into five groups using a categorization scheme, ranging from low to very high. Areas with high to extremely high lineament densities have significant potential for aquifer replenishment, storage, and leakage. Areas falling within the high and very high lineament density classifications constitute 16% of the total area under study. However, it is noteworthy that these specific classifications do not exert a significant impact on the overall study. Approximately 23% of the study area is made up of the moderate group, while 61% of the study area is made up of the very low and the low groups together. Lineament density is a significant element in defining groundwater potential zoning, according to several research (Varade *et al.* 2018; Satapathy and Syed 2015) [51, 45]. Because of cracks and joints, areas with high lineament density have a

higher potential for groundwater recharge.

Drainage density

According to Ganapuram *et al.* (2009) ^[17], one of the most important factors influencing the availability and pollution of groundwater is the drainage network's density. The whole length of streams or channels in a particular region is measured as drainage density, which is commonly stated as kilometers of channel length per unit area, such as square kilometers. It is a crucial variable in the study of geomorphology and hydrology since it tells us about the drainage network's capacity to transfer water. An area's lithology influences the drainage network and offers important insights into the rate of infiltration. Drainage density is a key factor in identifying possible groundwater zones since it is inversely correlated with permeability.

An important measure of erosion and deposition in landscapes, drainage density sheds light on hydrological features such as surface water runoff and recharge of groundwater. A drainage density map (Fig. 6) was generated using ArcGIS and a 30-meter DEM. An important factor in determining whether places have a high potential for groundwater recharge is low drainage density. On the other hand, limited groundwater recharge capacity is indicated by high drainage density, which is given a lower weight. This categorization scheme provides a succinct but thorough evaluation of the hydrological features of the area. There are other tributaries and seasonal streams in addition to the main stream of the Swan River. Based on the research area's drainage density (km/km²), five categories were identified. Very low (>2.0) makes up 11% of the entire area; low (1.5-2.0) is 22% of the area; moderate (1.0-1.5) is 31% of the area; high (0.5-1.0) is 25% of the area; and very high (<0.5) is 11% of the total area (Fig.6). Because well-developed drainage networks enhance surface water penetration and recharge, high drainage density values imply a low ground-water potential zone due to their beneficial effects on runoff. Conversely, low values reflect a high ground-water potential zone. (Pinto and others, 2017).

Slope

A terrain surface's steepness is gauged by its slope percentage, which is represented as a percentage or degree of inclination. It influences the flow and storage of surface and groundwater as well as the erosion and deposition of soil and sediments, making it a crucial element in the study of geomorphology and hydrology. To get a slope's percentage, divide its vertical rise by its horizontal distance. Then, multiply the result by 100 to get the slope percentage. For instance, a slope with a 10% slope percentage would have a 10 meter vertical climb over a 100 meter horizontal distance.

Slope percentage is a relevant metric for determining prospective zones for groundwater recharging and extraction. Gentle slopes may offer a better potential for groundwater recharge since water can more easily permeate and percolate through the soil. (Satapathy and Syed, 2015) ^[45]. Because of the increased risk of surface runoff and erosion, regions with steep slopes may have limited capacity for groundwater recharge. To create the slope map, a digital elevation model is utilized. Roughly 12% of the territory is below 40°–50°, while 71% of the region is below 200° slope. Given that the majority of the research region has a lower slope percentage, it has a better potential for groundwater (Fig. 7).

Rainfall

As the main source of recharge for groundwater systems, rainfall is an important consideration in groundwater potential zoning

studies. A rainfall map was created by importing rainfall data as point data into ArcGIS. Since it has been shown to produce acceptable results, the inverse distance weighted (IDW) approach was used for mapping (Al-Areeq *et al.*, 2021; Achilleos *et al.*, 2011) ^[4, 1]. The rainfall map is categorized into five subclasses (Jenks) using the natural break classification technique, as shown in Figure 8., i.e., very low (106.42-116.70 mm), low (116.71-126.97 mm), moderate (126.98-137.24 mm), high (137.25-147.51 mm), and very high (147.52-157.78 mm). The research area's westernmost section had the highest rainfall intensity (147.52-157.78 mm), and rainfall usually decreases from west to east (Fig. 8). Locations with more rainfall have a higher weight value (Alharbi *et al.*, 2023) ^[5], which covers around 154.9 km² (10.06 percent) of the area, indicating excellent groundwater potential. Regions with high yearly rainfall or seasonal monsoon patterns are thought to have a higher potential for groundwater recharge since there is more water available for infiltration and percolation into the earth. Arid locations with little annual rainfall, on the other hand, may have limited capacity for groundwater recharging due to a lack of precipitation.

Rainfall has been employed as a crucial component in groundwater potential zoning in several studies. Kukuric *et al.* (2021) ^[28] investigated rainfall and other characteristics in a Croatian region to locate possible zones of groundwater recharge. The investigation found that locations with annual rainfall greater than 1000 mm had a better potential for groundwater recharge because there was more water available for infiltration and recharge.

LULC

Classifying land use is a crucial technique that provides vital information about things like infiltration, soil moisture, surface water dynamics, and groundwater needs (Ibrahim-Bathis *et al.*, 2016 and Yeh *et al.*, 2016) ^[23, 52]. The evaluation of current land use/cover (LU/LC) is very helpful in figuring out whether regions are suitable for potential groundwater resources. Based on geography and geology, the land in the research region is mainly divided into three categories: plain, piedmont, and hilly. The eastern and northern sections of the region are covered with rocky terrain and steep hills that make up the region's rugged scenery. The piedmont region, which is central to the district, is characterized by gently sloping hills and gentle slopes.

The plain region is located in the district's south and is distinguished by flat and gradually sloping terrain. Land usage in the Una district is grouped into six categories: forest land, agricultural land, barren land, water bodies, built-up area, and others. Forest land contributes for around 41.67 percent of total land area, while agroforestry and agriculture land accounted 25.47 percent and 16.43 percent, respectively. Barren terrain and water bodies represents for approximately 4.5 percent, while settlements cover 7.43 percent of the total area (Fig. 9). This classification plays a significant role in governing various hydrological processes, including evapotranspiration, runoff, and replenishing groundwater systems, as emphasized by Chaudhary and Kumar in 2018. For example, forest land and agricultural land may contribute to groundwater recharge through vegetation uptake and infiltration, while water bodies may act as recharge areas for groundwater (Ghanim *et al.*, 2023) ^[18]. On the other hand, barren land and settlements may contribute to groundwater depletion through land use practices such as urbanization and extraction of groundwater (Goyal *et al.*, 2013) ^[21]. Therefore, analyzing land use and land classification can help to locate regions with a high potential for recharging of

groundwater and availability, as well as areas where groundwater depletion may be a concern (District Statistical Handbook of Una District, 2017-18) ^[14].

Soil

The amount of water that may permeate underground formations depends on the kind of soil, which ultimately affects groundwater replenishment. ArcGIS software was used to gather and analyse data in order to construct the soil thematic map that was used in this investigation. The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) or another reliable soil database was consulted for the collection of soil data. Soil type, texture, and other pertinent soil parameters were among the information gathered. This information was then processed and analysed to produce a soil thematic map, which depicts the spatial distribution of various soil types and their properties within the research area.

To create the soil thematic map, various techniques were employed, such as image classification, spatial interpolation, and attribute data analysis. Image classification techniques were used to categorize the soil types based on their spectral signatures in satellite imagery or other remotely sensed data. Spatial interpolation methods, such as kriging or inverse distance weighting, were applied to estimate soil properties at unsampled locations. Attribute data analysis involved analyzing the soil dataset to identify patterns, relationships, and trends in soil characteristics. The final soil thematic map provides valuable details on the variety and distribution of soil types in the research area. Two main soil groups observed in the study area Orithic luvisols covering 63.8% and Eutric gleysols 36.71% of the total area (Fig.10). Luvisols are light-colored soils with a high concentration of clay in the B-horizon. Clays with a high cation exchange capacity are found in these soils. As a result, they have a significant groundwater potential.

Ground water potential

A renewable resource, groundwater supply has significantly decreased in recent decades as a result of imbalanced development and human activity. To guarantee sustainable development and planning in any region, a thorough grasp of groundwater potential is necessary. Having this knowledge is essential for putting groundwater recharge strategies into practice. The majority of the area in this particular area has good or excellent groundwater potential. This means that there is a high likelihood of finding groundwater in these areas, and that the groundwater is likely to be of good quality (Fig 11). The areas with very poor or poor groundwater potential are relatively small, and are likely to have lower quality groundwater.

In making the evaluation, a number of variables were taken into account, such as soil properties, rainfall, lineament density, geology, geomorphology, slope, and land use (LU). In the Himachal Pradesh district of Una, a map of groundwater potential zones was created using the weighted overlay approach. Appropriate weighting factors were allocated to every category of the criteria taken into consideration (Table 4). Five different possible groundwater types were discovered in the research region, together with their respective areas in square kilometers and percentages of the overall area (Table 5). At 17.85 square kilometers, or 1% of the entire area, the zone with the lowest groundwater potential is the smallest. The region with limited groundwater potential is much smaller, making up just 114.89 sq. km, or 7% of the whole. With 453.76 square kilometers (30% of the entire area), the fair potential for groundwater zone is the biggest. The excellent possibility of groundwater zone is the greatest, covering 548.06 square kilometers (36% of the total area). The good groundwater potential zone encompasses 392.78 square kilometers, or nearly 26% of the total area. Groundwater potential is particularly high on the alluvial plain and active floodplain, where it is classed as good to outstanding. In contrast, the groundwater potential in heavily dissected hills and valleys is rated as fair. Lowland regions, the piedmont region, and steep slopes have good to exceptional potential groundwater zones. Surprisingly, the existence of lineaments in the research region had no effect on groundwater potential. The varying degrees of groundwater potential reflect the study area's diverse geological characteristics, complicated geomorphology, and variable land use patterns. This highlights the complex interaction of variables controlling groundwater distribution, emphasizing the importance of an in-depth knowledge of the local environment in order to successfully manage and use the resources of groundwater.

Validation

For the past five years, possible groundwater zones were cross-verified using well yields and Central Groundwater Board pre- and post-monsoon water level data. 30 observation wells were chosen from the research area, and their levels were interpolated in meters below ground level (mbgl). The well level varies between 1.12 and 15.97 metres (mbgl). Table 6 shows the well's specifications. Figure 12 displays the interpolated well level in the research region throughout different seasons. The graph illustrates that the methodology's output has a high correlation with real-time data. Furthermore, measurements of pre- and post-monsoon groundwater levels were utilized to determine the degree of recharge in the selected locations.

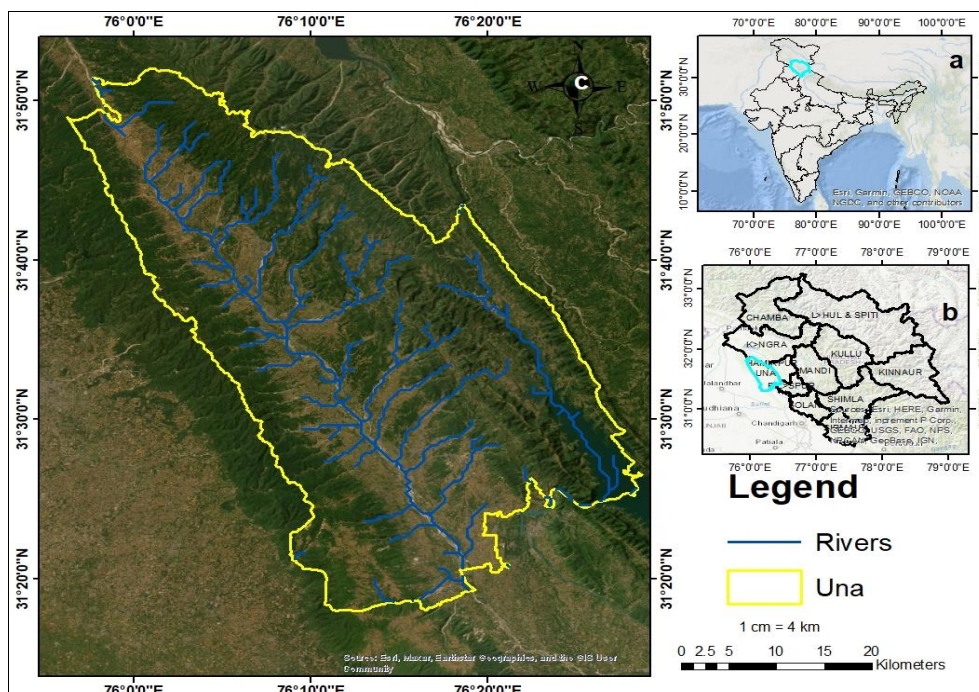


Fig 1: Location of the study area. (a) India, (b) Himachal Pradesh, (c) Una district. Map coordinates are in UTM zone 43.

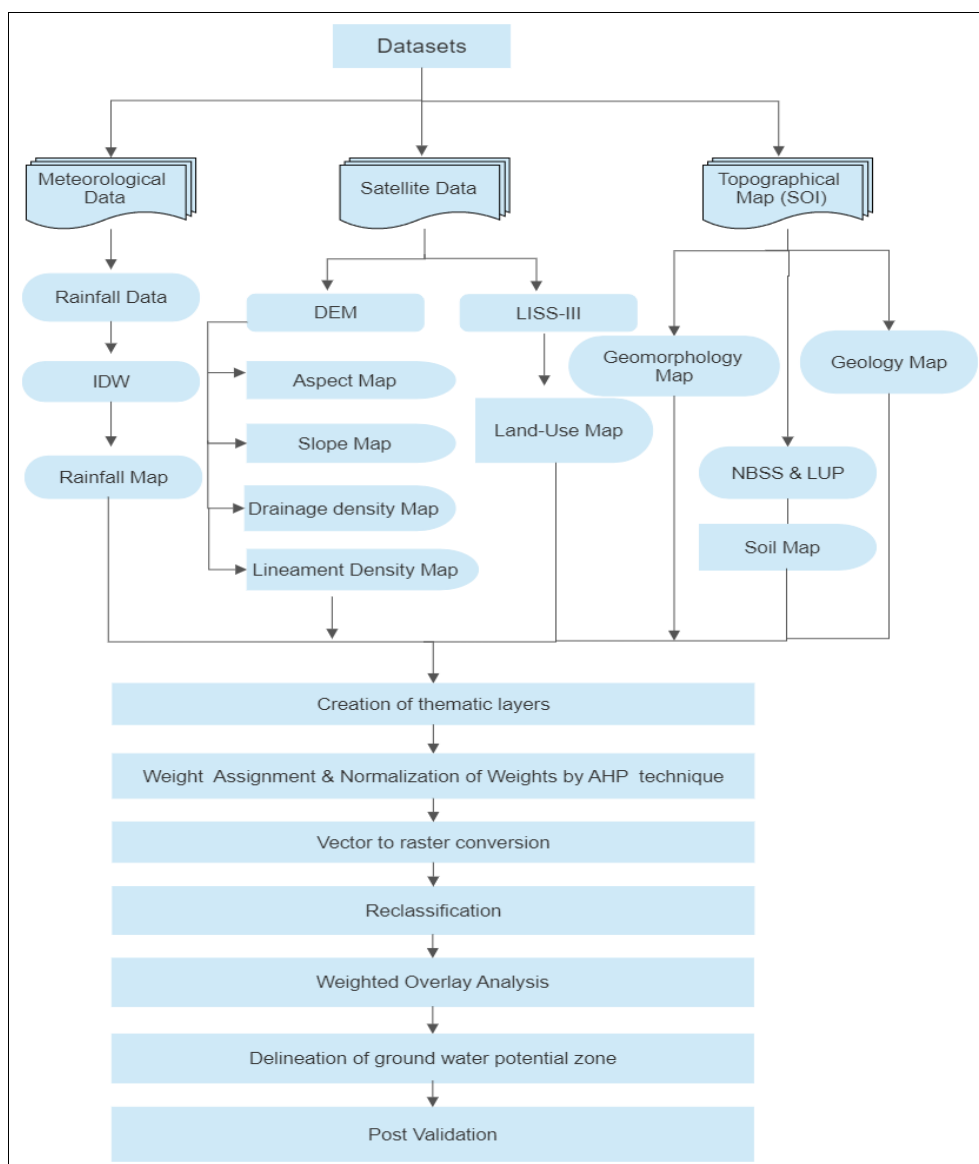


Fig 2: A flowchart methodology utilised to delineate the ground water potential zone.

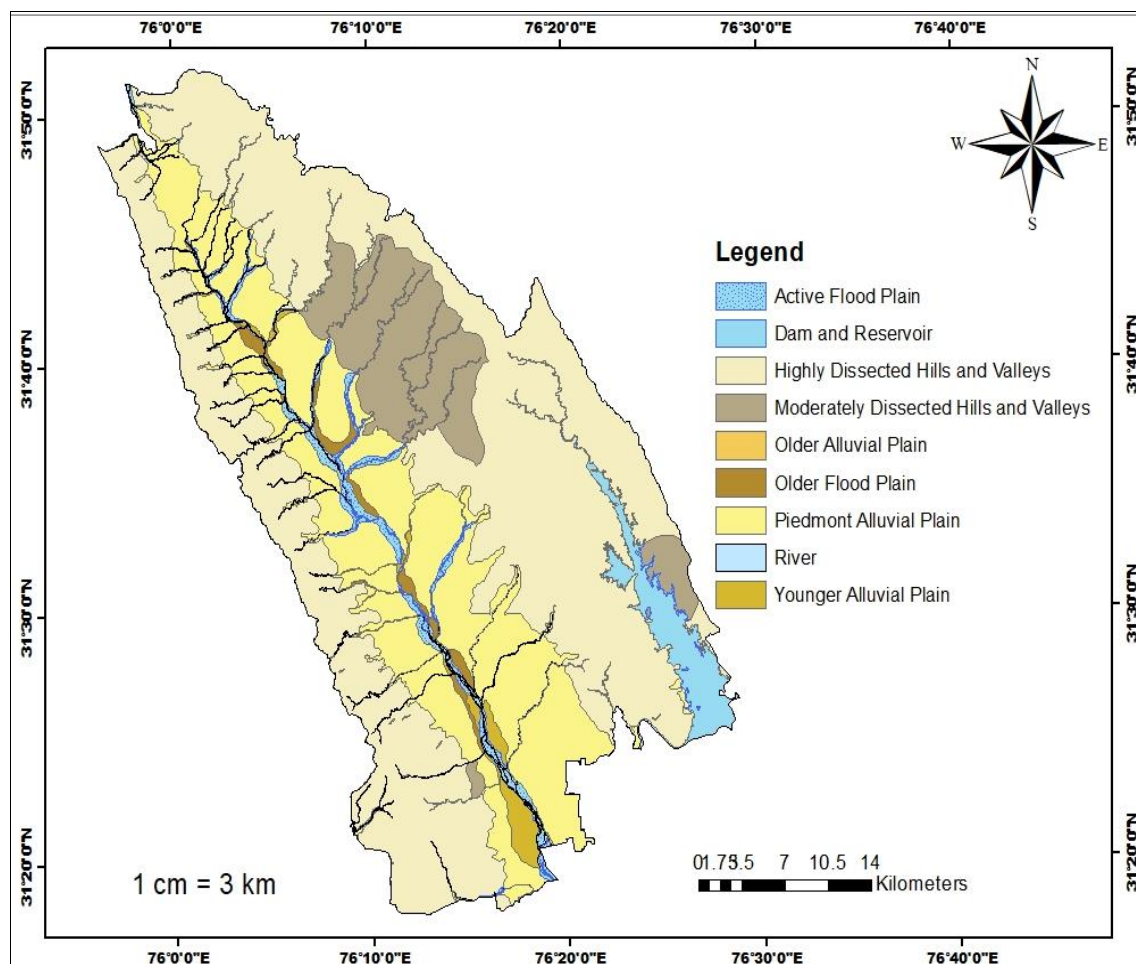


Fig 3: Geomorphology map of the district Una.

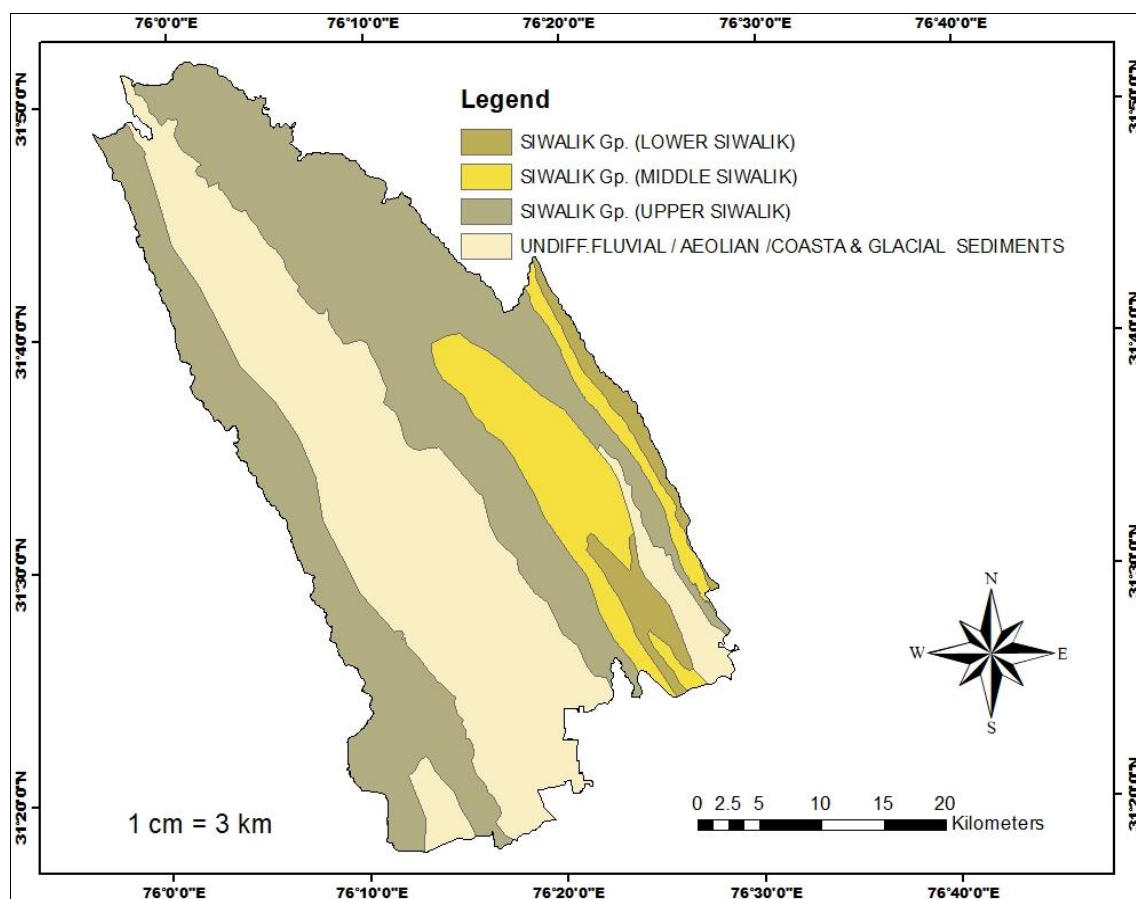


Fig 4: Geological setting of the district Una.

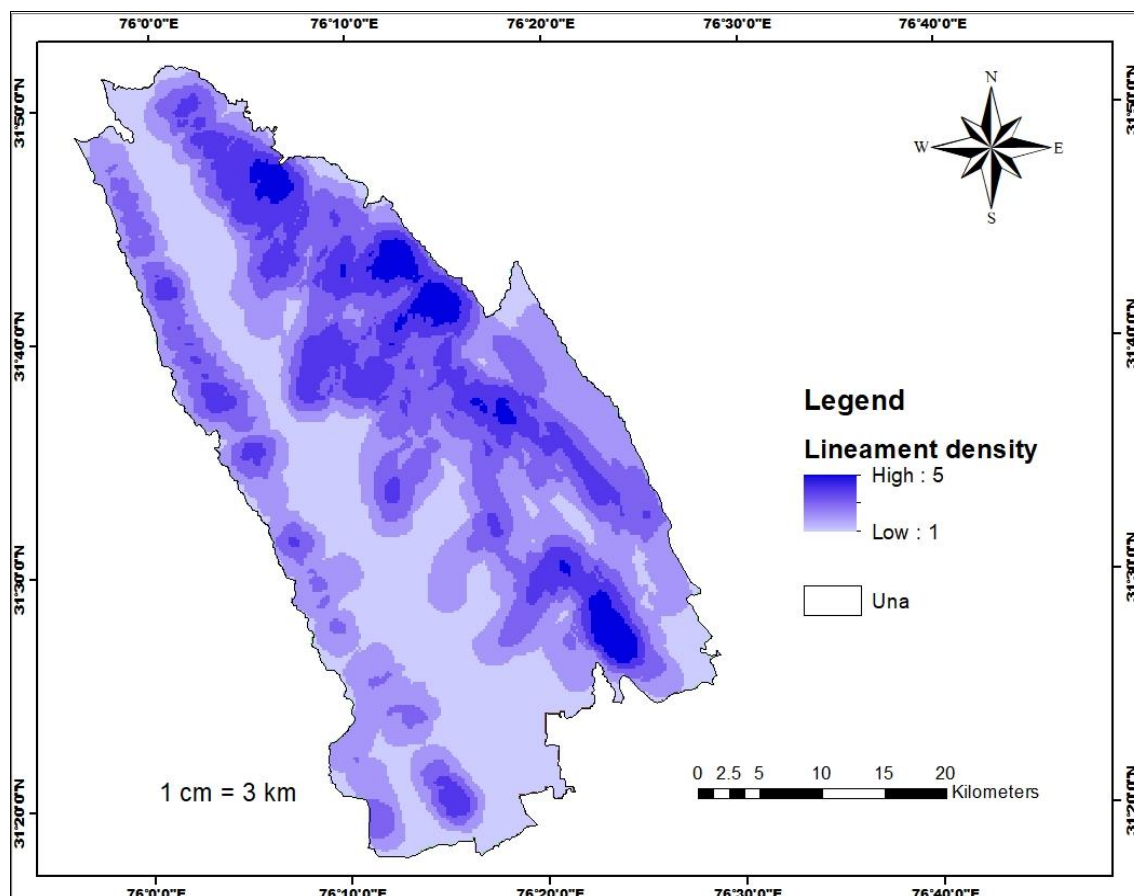


Fig 5: Lineament density map of the district Una.

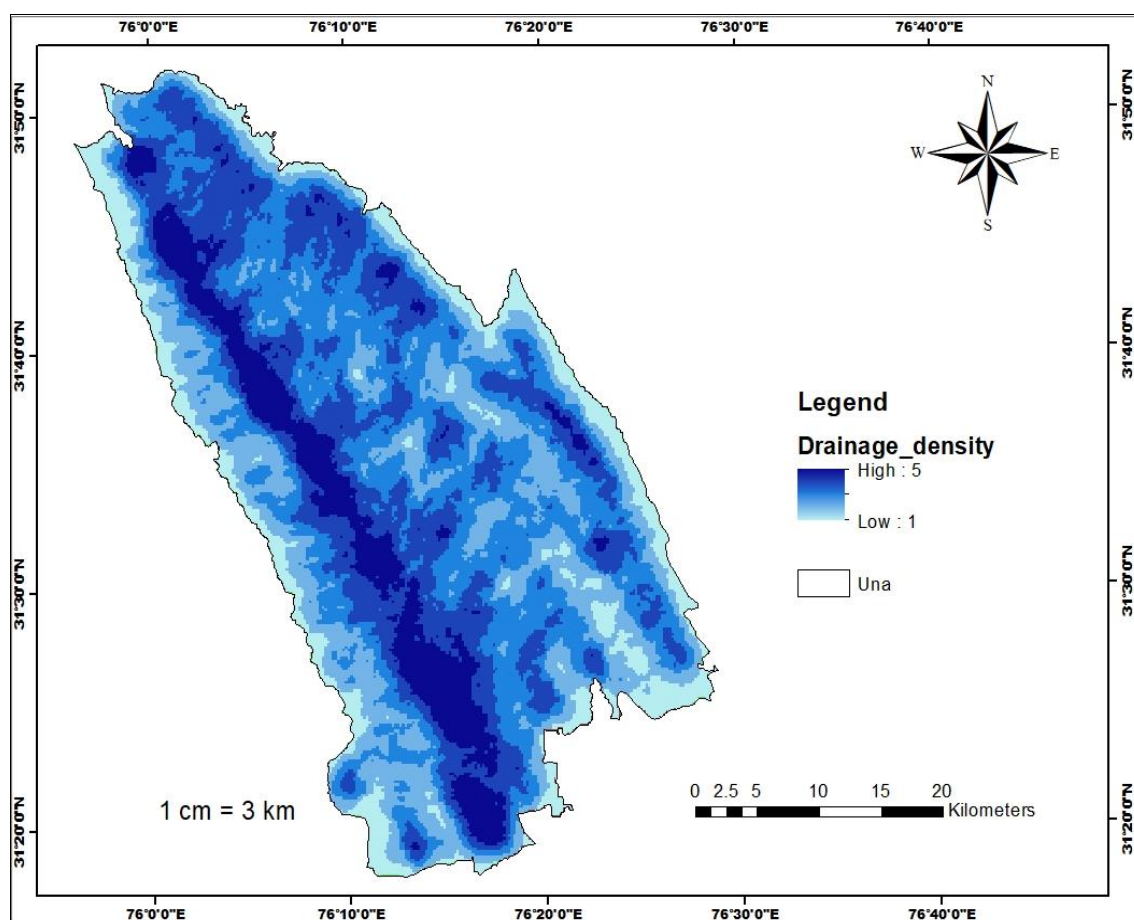


Fig 6: Drainage density map of the district Una

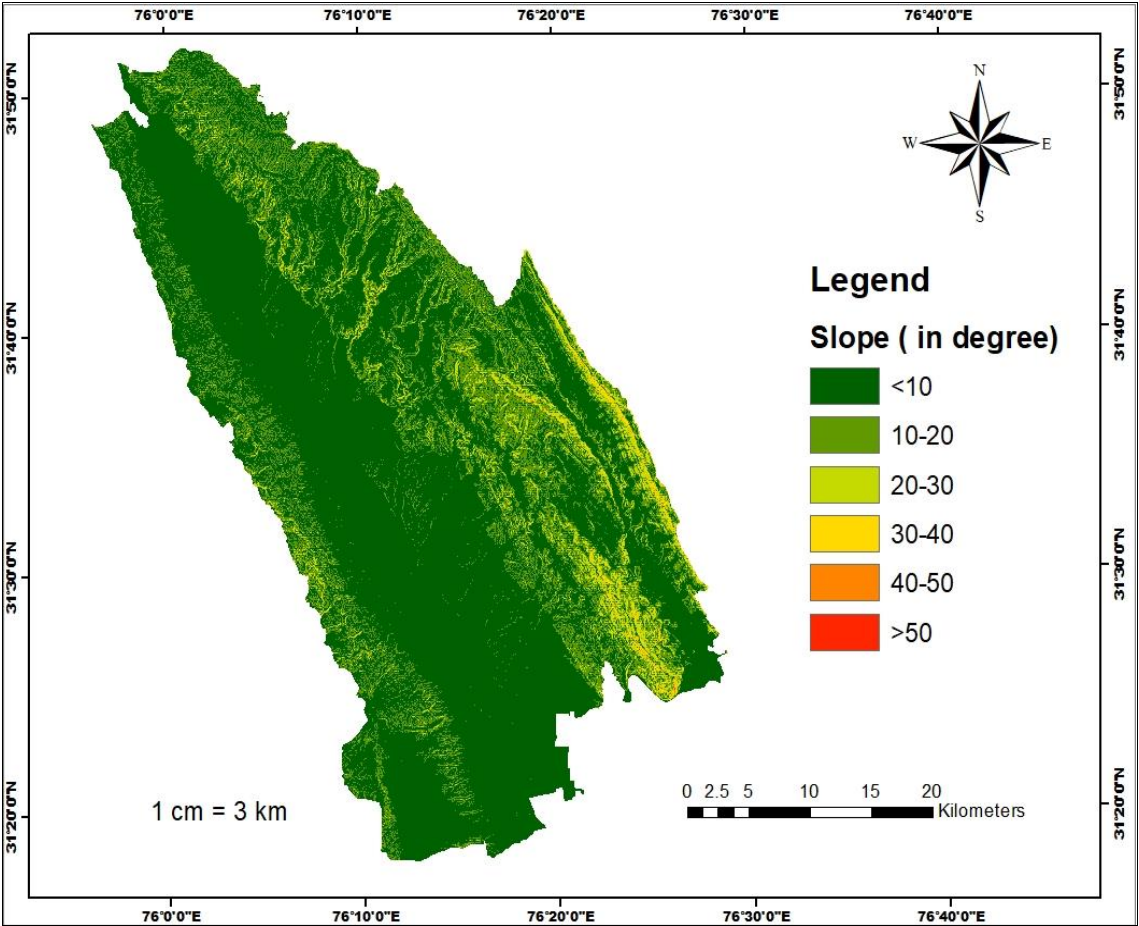


Fig 7: Slope map of the district Una

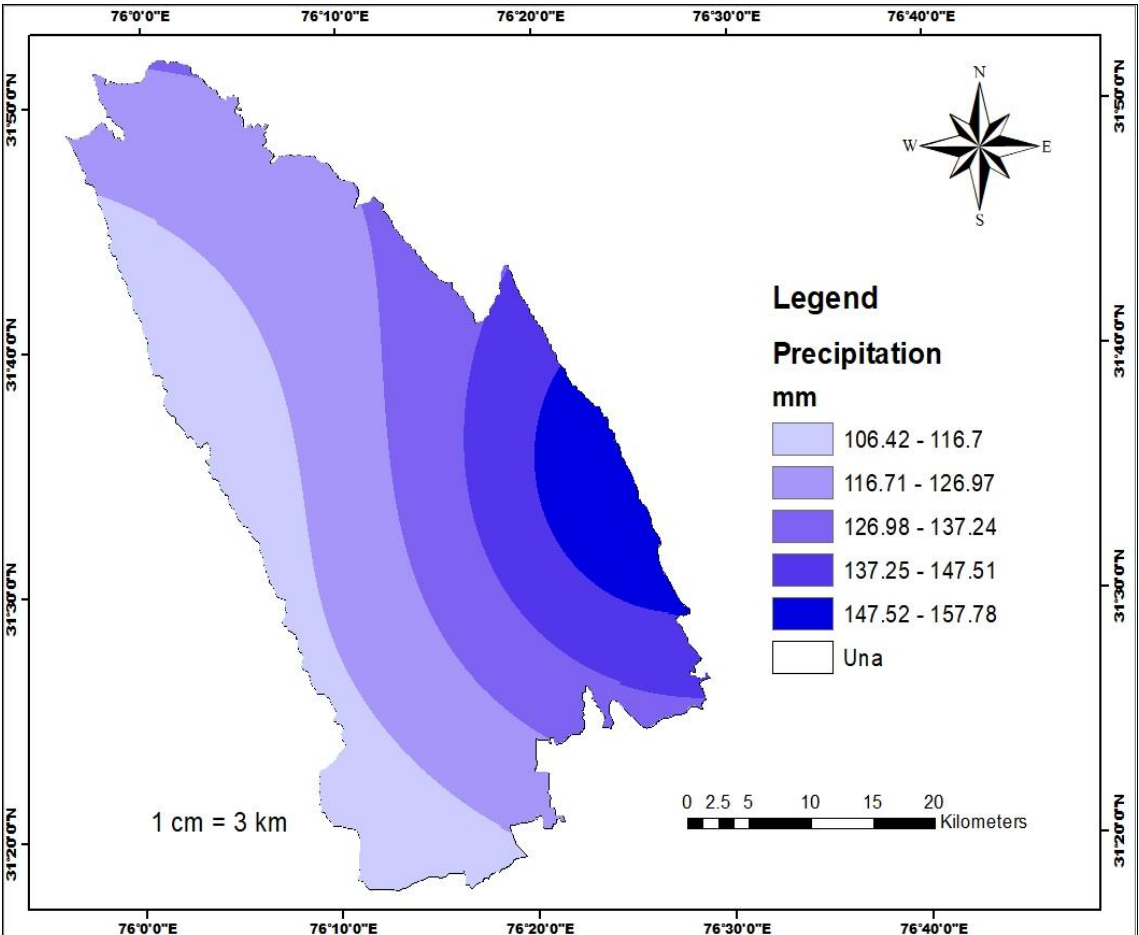


Fig 8: Rainfall map of the district Una

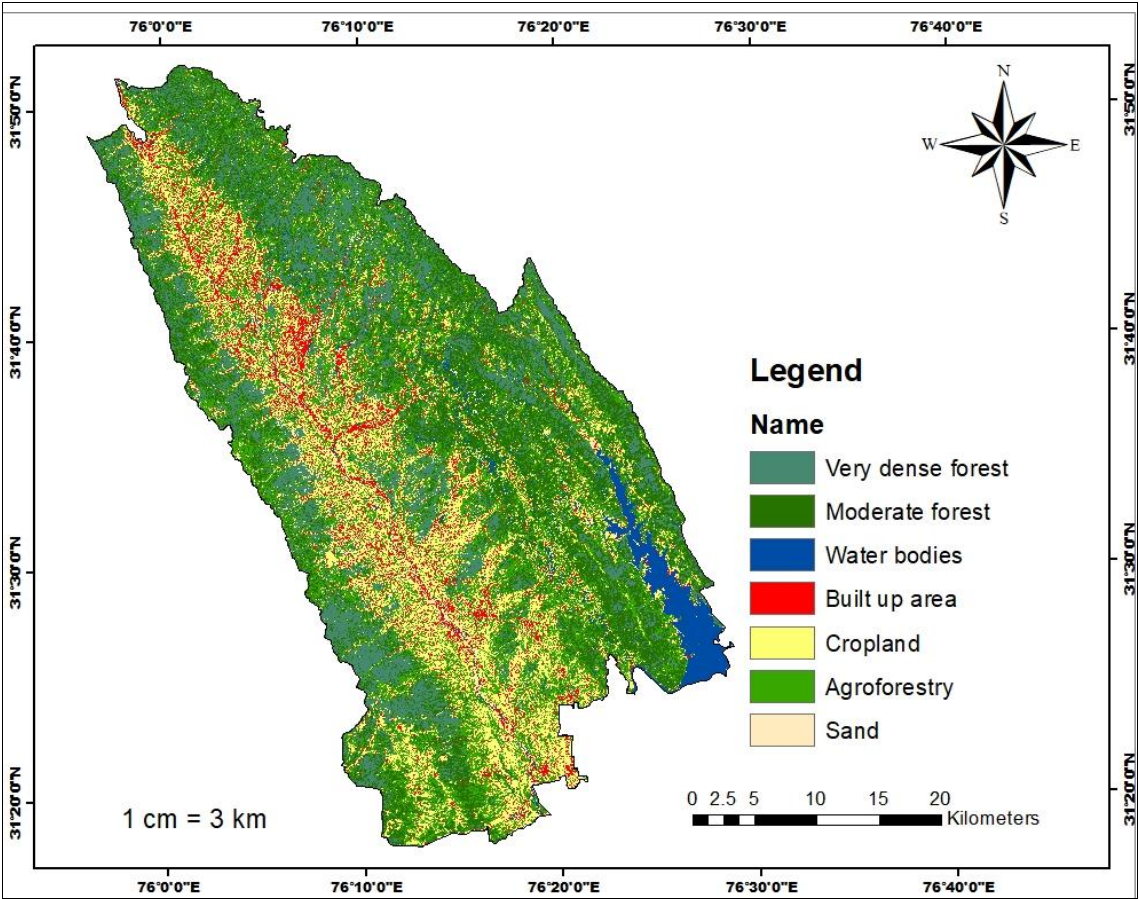


Fig 9: Land use map of the district Una

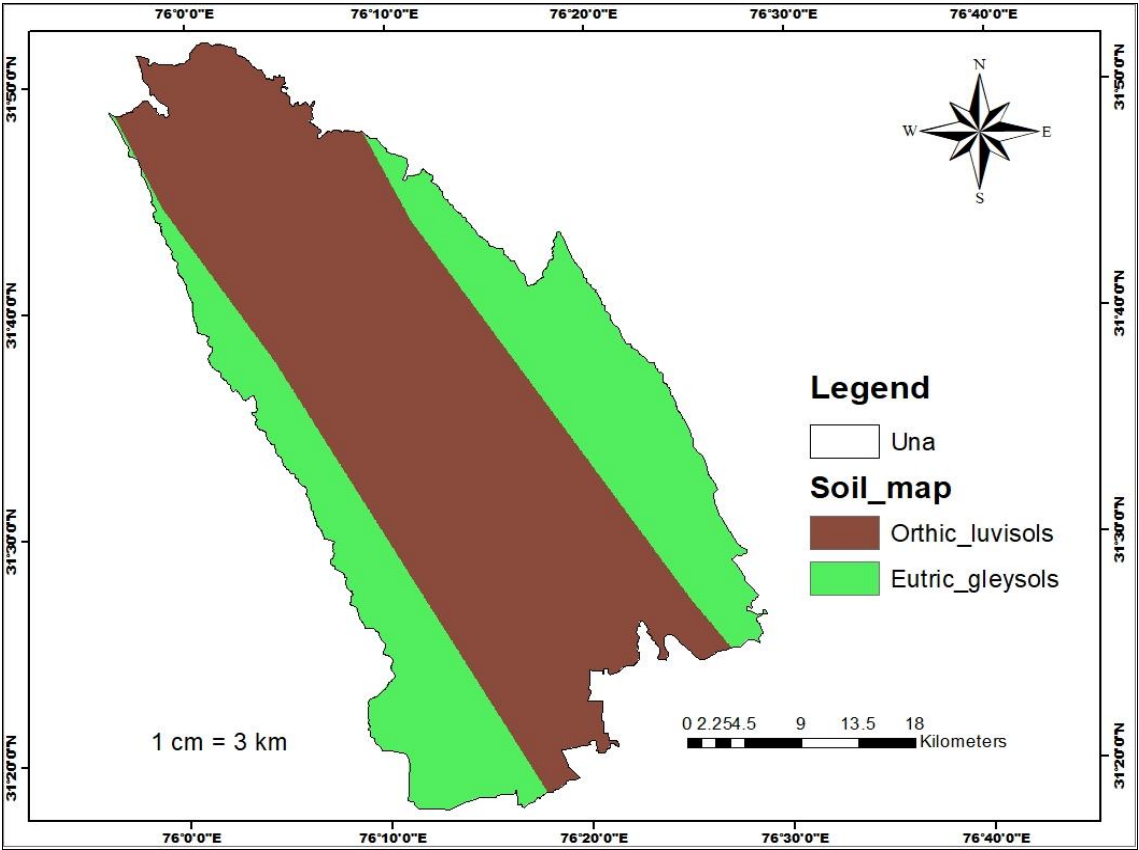


Fig 10: Soil map of district Una.

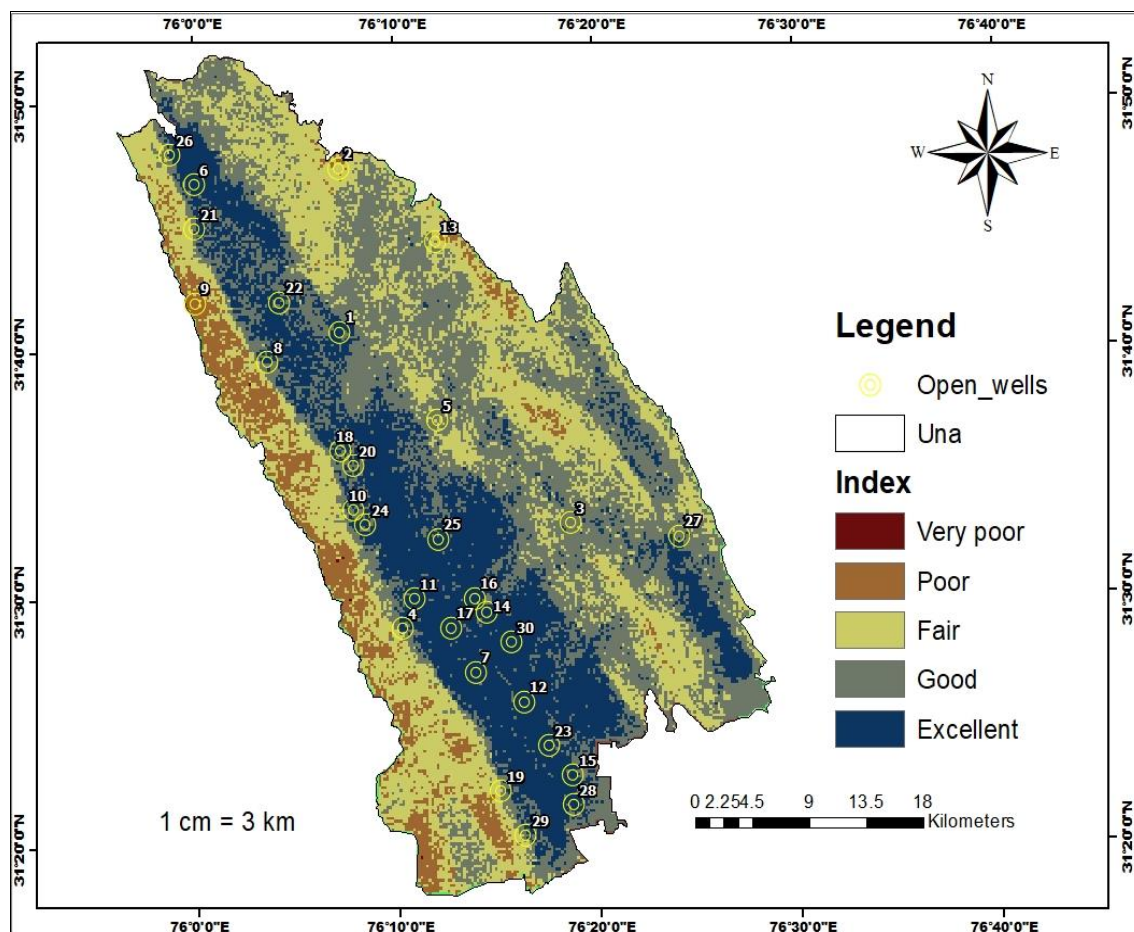


Fig 11: Ground water potential zones of the district Una.

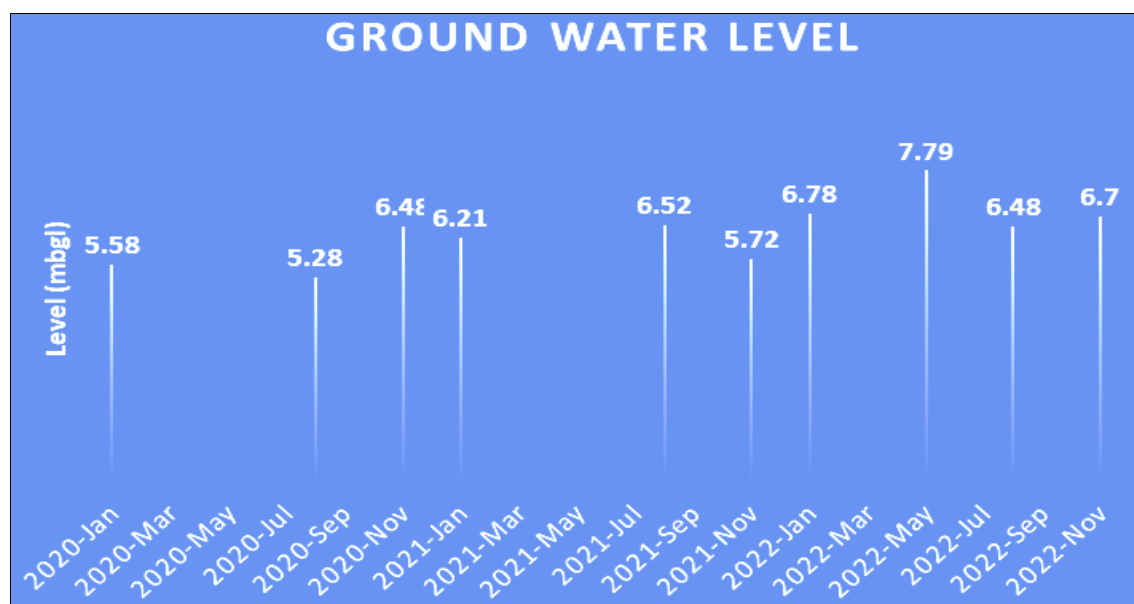


Fig 12: Ground water level in district Una from the year 2020-2022.

Table 1: Data utilised in the groundwater potential study.

Data	Sources	Type
DEM	Earth Explorer—USGS https://earthexplorer.usgs.gov	Satellite-borne sensor ASTER
Drainage network	https://earthexplorer.usgs.gov https://earth.google.com http://www.surveyofindia.gov.in	GDEM, SOI Topsheets and Google image
Geomorphology	N.B.S.S. and L.U.P. https://www.nbsslup.in	Reference type
Geology	Geological Survey of India http://www.portal.gsi.gov.in	Reference type
Soil texture	N.B.S.S. and L.U.P. https://www.nbsslup.in	Reference type
Lineament	Geological Survey of India https://www.portal.gsi.gov.in	Reference type
Land-use data	Bhoonidhi https://bhoonidhi.nrsc.gov.in	ResourceSat-2A_LISS3

Table 2: Pairwise matrix analysis for groundwater potential zone.

Factor	Geomorphology	Land-use	Geology	Drainage density	Lineament density	Rainfall	Slope	Soil
Geomorphology	1	7	7	2	3	2	5	7
Land-use	1/7	1	7	8	7	1/5	5	3
Geology	1/7	1/7	1	4	7	1/4	5	4
Drainage density	1/2	1/8	¼	1	2	1/2	3	5
Lineament density	1/3	1/7	1/7	1/2	1	1/3	3	3
Rainfall	1/7	1/0.2	1/0.25	1/0.5	1/0.33	1	3	7
Slope	1/7	1/5	1/5	1/3	1/3	1/3	1	5
Soil	1/2	1/3	¼	1/5	1/3	1/7	1/5	1

Table 3: Standardized matrix for groundwater potential zone.

Factor	Geomorphology	Land-use	Geology	Drainage density	Lineament density	Rainfall	Slope	Soil
Geomorphology	0.3	0.50	0.35	0.11	0.12	0.42	0.2	0.2
Land-use	0.04	0.07	0.35	0.44	0.29	0.042	0.2	0.1
Geology	0.04	0.01	0.05	0.22	0.29	0.05	0.2	0.1
Drainage density	0.17	0.00	0.01	0.05	0.08	0.10	0.12	0.1
Lineament density	0.11	0.01	0.00	0.02	0.04	0.07	0.12	0.1
Rainfall	0.04	0.35	0.20	0.11	0.12	0.21	0.12	0.2
Slope	0.04	0.01	0.01	0.01	0.01	0.07	0.04	0.1
Soil	0.17	0.02	0.01	0.01	0.01	0.03	0.01	0

Table 4: Parameters with AHP ratings and weights.

Parameter	Feature class	Rating	Weight
Geomorphology	Active Flood Plain	0.15	0.282
	Dam and Reservoir	0.05	
	Highly Dissected Hills and Valleys	0.02	
	Moderately Dissected Hills and Valleys	0.02	
	Older Alluvial Plain	0.31	
	Older Flood Plain	0.07	
	Piedmont Alluvial Plain	0.12	
	River	0.03	
	Younger Alluvial Plain	0.23	
Geology	SIWALIK Gp. (LOWER SIWALIK)	0.61	0.124
	SIWALIK Gp. (MIDDLE SIWALIK)	0.25	
	SIWALIK Gp. (UPPER SIWALIK)	0.11	
	UNDIFF.FLUVIAL / AEOLIAN / COASTA & GLACIAL SEDIMENTS	0.03	
Drainage density (km/km ²)	0.1-0.5	0.02	0.088
	0.5-1.5	0.03	
	1.5-2.5	0.09	
	2.5-3.5	0.15	
	3.5-4.5	0.28	
	3.5-5.1	0.43	
Lineament density (km/km ²)	0.94-1.95	0.08	0.0601
	0.58-0.94	0.15	
	0.25-0.58	0.26	
	0-0.25	0.51	
Slope (degree)	0-8.84	0.46	0.045
	8.84-20.01	0.33	
	20.01-33.77	0.11	
	33.77-54.65	0.06	
	54.65-204.95	0.04	
Soil	Orthic_luvisols	0.71	0.038
	Eutric_gleysols	0.29	
Rainfall (mm)	106.42-116.71	0.03	0.172
	116.71-126.97	0.07	
	126.97-137.24	0.15	
	137.24-147.51	0.29	
	147.51-157.75	0.46	
Land-use	Very dense Forest	0.11	0.192
	Moderate Forest	0.13	
	Water bodies	0.03	
	Built up area	0.07	
	Cropland	0.31	
	Agroforestry	0.24	
	Barren land	0.11	

Table 5: Categories of groundwater potential zone.

Sr. No.	Category	Area (km ²)	% Area
1	Very poor	17.85	1
2	Poor	114.89	7
3	Fair	453.76	30
4	Good	548.06	36
5	Excellent	392.78	26

Table 6: Well details used for validation.

Sr. no.	Place	Latitude	Longitude	Level (mbgl)
1	Amb	31.68	76.12	4.45
2	Babehr	31.79	75.82	2.7
3	Bawal	31.55	76.31	1.12
4	Bhadsali	31.48	76.17	13.53
5	Bhangana	31.62	76.2	1.53
6	Daulatpur	31.78	76	5.71
7	Dharampur	31.45	76.23	2.65
8	Gagret	31.66	76.06	7.04
9	Ghaneri	31.7	76	6.76
10	Guglahar	31.56	76.13	2.63
11	Ishapur	31.5	76.18	1.95
12	Jankaur	31.43	76.27	4.21
13	Jawar	31.74	76.2	1.37
14	Jhalera	31.49	76.24	4.09
15	Khanpur	31.38	76.31	4.98
16	Khwaja	31.5	76.23	1.66
17	Kuluwal	31.48	76.21	----
18	Kuthera Jaswala	31.6	76.12	5.77
19	Lalehri	31.37	76.25	11.05
20	Loharli	31.59	76.13	3.74
21	Mawa Kalan	31.75	76	15.97
22	Mubarikpur	31.7	76.07	3.75
23	Nangran	31.4	76.29	5
24	Panjawar	31.55	76.14	11.78
25	Panoh	31.54	76.2	2.02
26	Raipur Marwadi	31.8	75.98	12.48
27	Rajli Panjal	31.54	76.4	2.33
28	Santokhgarh	31.36	76.31	4.86
29	Tahliwala	31.34	76.27	1.22
30	Una	31.47	76.26	1.95

Conclusion

Through the integration of multiple geographical characteristics, a detailed study of possible groundwater zones in the Una district has been carried out. To develop a thorough map, factors such as slope, drainage density, precipitation, land use, geology, geomorphology, lineament density, and soil type were meticulously investigated. The evaluation determined that 392.78 km² had outstanding groundwater potential and 548.06 km² have good groundwater potential. The study found that regions appropriate for groundwater development have features such as minor slopes, low lineament density, and high drainage density, all of which are typically found in agriculturally productive areas. Regions with little groundwater potential, on the other hand, were concentrated in Upper Siwalik areas. The bulk of the study region has a high capability for groundwater recharge. To confirm the findings, on-site verification was carried out using farms and groundwater wells in the indicated locations. This not only increases the research's credibility, but it also gives practical insights for agronomists looking for good groundwater exploration areas. This study's ramifications go beyond agriculture, since communities and decision-makers may use the findings to maximize planning and management tactics. The larger community, notably farmers, stands to profit from the identification of possible groundwater sites, particularly in rural,

previously unexplored places. Furthermore, the study advises that future research be conducted to corroborate the identified possible groundwater zones in distant places. This might be accomplished using modern techniques such as electrical and magnetic geophysical surveys, which would provide a more extensive and precise understanding of groundwater supplies in these areas. Overall, this study adds useful information to sustainable water resource management and promotes informed decision-making at several levels.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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