Indian Journal of Ecology (2023) 50(6): 1910-1923
DOI: https://doi.org/10.55362/IJE/2023/4155

Manuscript Number: 4155
NAAS Rating: 5.79

Delineation of Groundwater Potential Zones in Low-hills of Himachal Pradesh using Remote Sensing and GIS

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Abstract: Over-exploitation of groundwater for industrial and developmental activities over the years has imposed immense pressure on groundwater resources in low-hills of Himachal Pradesh. For this reason, delineating the groundwater potential zone is highly essential for meeting future demands. Therefore, the current study utilizes remote sensing (RS) and Geographic Information System (GIS) by using weighted overlay method to prepare a groundwater potential zone map of two districts lying in low-hills of Himachal Pradesh. A total of 8 thematic layers viz. slope, geology, aspect, soil, land use land classification, drainage density, and lineament were integrated and weightage values were assigned to each of these factors. The groundwater potential zones thus obtained were divided into five categories: very high, high, moderate, low and poor. In Sirmaur district, very high zone comprises 3.76% of the area, high zone covers 3.05%, 3.83% of the region comes under moderate zone, low zone covers 15.27% of the area and 74.62% of the area was under poor zone. In Una district very high zone covers 1.24% of the area, 1.80% falls under high zone, moderate zone comprises 15.61% of the area, low zone covers 63.83% while poor zone comprises of 17.52%. The results of the current investigation may be useful for future groundwater potential zones plans and for evaluating groundwater potential zones in similar low-hill regions.

Keywords: Groundwater, Remote sensing, GIS, Groundwater potential zones

Groundwater is necessary to sustain various forms of life and is one of the important water sources for agriculture, industry, and domestic use worldwide (Singh et al 2019). Occurrence, distribution and movement of groundwater are highly influenced by terrain features such as geology, lithology, tectonic framework and geomorphology of the area (Srivastava 2002). Knowledge about the status of groundwater is as important as to its quantity, as it helps in determining the suitability of water for various purposes. The groundwater quality variation in any area is a function of physicochemical quality parameters which is greatly influenced by its geological formations and anthropogenic activities of the area (Subramani et al 2005). Groundwater potential mapping (GPM) can be defined as a tool for the systematic development and planning of water resources (D´ıaz-Alcaide and Mart´ınezSantos 2019). It can classify the areas of a given watershed or a region based on the possibility of groundwater occurrence (Jha et al 2010). Groundwater occurrences in a region depend on the characteristics of rocks, soils, and geological structures (Maniar et al 2019).

Delineating the potential groundwater zones using remote sensing and GIS is an effective tool. In recent years, extensive use of satellite data along with conventional maps and rectified ground truth data has made it easier to establish the base line information for groundwater potential zones (Chowdhury et al 2010). Thus, since the past few decades, geospatial techniques have become a useful tool for groundwater mapping (Murthy 2000). Remote sensing (RS) and geographical information system (GIS) have benefited from joining together primary and numeral data-set (Shailaja et al 2019). Remote sensing has played a vital role to map and analysis at synoptic scales (Chen et al 2019). A combination of geospatial technologies datasets was processed in the RS and GIS software and used to delineate and interpret the suitable groundwater areas (Mahato et al 2018). Keeping in view all these, an attempt was made to delineate the groundwater potential zones in low-hills of Himachal Pradesh.

MATERIAL AND METHODS

Study area: The present study is conducted in industrial areas of districts Sirmaur and Una lying in the low hills of Himachal Pradesh, India. Kala-Amb industrial area in Sirmaur district and Mehatpur industrial areas in Una district has seen a significant increase in the number of industries in the area since 1980 when a large number of industries were. A total of 15 sampling wells were taken in each district to validate the remotely sensed data (Table 1, Fig. 1). The climate of the Sirmaur district is sub-tropical to temperate depending upon the elevation. The average annual rainfall in the district is about 1405 mm, out of which 90% occurs during the monsoon season. The mean maximum and minimum temperatures of 30°C and-0°C respectively experienced in the district. Sirmaur district presents an intricate mosaic of high mountain ranges, hills and valleys with altitudes ranging from 300 to 3000 m above mean sea level (amsl). The soil in the district varies from thin and bare soil of high mountains to rich deep alluvial soil of the valleys. The climate of the Una district is tropical to temperate in nature, as the terrain varies from plains to high hills. Temperature varies from a minimum of 4°C in winter to a maximum of 46°C in summer. The area receives rainfall during the monsoon period, extending from June to September, and also during the non-monsoon period. The annual average rainfall in the area is about 1040 mm, with about 55 average rainy days. The winter season starts in November and continues till the middle of March.

Hydrogeology: Hydro-geologically, the unconsolidated and semi-consolidated/ consolidated rock formations form aquifers in Sirmaur district. Intergranular pore spaces in the sedimentary formations and secondary fissured porosity in hard rocks, topographical set up coupled with precipitation in

Table 1. Sampling wells along with depth to water level

Sampling wells	Source	Latitude	Longitude	Elevation (m amsl)	Depth to water level (mbgl)
District Sirmaur					
1	Borewell	30º30'39"N	77º13'08"E	353	22
2	Borewell	30º30'35"N	77º12'57"E	351	5
3	Borewell	30º30'26"N	77º13'05"E	359	16
4	Borewell	30º31'31"N	77º12'10"E	352	13
5	Borewell	30º31'13"N	77º12'04"E	353	8
6	Borewell	30º31'01"N	77º12'03"E	350	14
7	Handpump	30º31'25"N	77º11'55"E	342	17
8	Handpump	30º30'32"N	77º12'20"E	339	11
9	Borewell	30º30'30"N	77º12'55"E	338	6
10	Borewell	30º30'09"N	77º12"34"E	376	12
11	Handpump	30º31'08"N	77º13"43"E	380	15
12	Handpump	30º29'52"N	77º12'41"E	385	13
13	Borewell	30º31'05"N	77º12'32"E	346	7
14	Borewell	30º30'37"N	77º12'38"E	358	16
15	Handpump	30º30'39"N	77º12'40"E	351	11
District Una					
1	Borewell	31º24'33"N	76º20'52"E	400	16
2	Borewell	31º24'47"N	76º20'47"E	381	13
3	Borewell	31º24'40"N	76º20'49"E	377	15
4	Borewell	31º24'37"N	76º20'53"E	382	14
5	Borewell	31º24'41"N	76º20'56"E	386	13
6	Borewell	31º24'35"N	76º20'49"E	390	9
7	Borewell	31º24'28"N	76º20'33"E	398	8
8	Borewell	31º24'46"N	76º20'25"E	391	10
9	Borewell	31º25'15"N	76º20'12"E	383	16
10	Handpump	31º25'10"N	76º21'05"E	388	15
11	Handpump	31º25'29"N	76º20'09"E	398	12
12	Borewell	31º25'09"N	76º20'43"E	410	13
13	Borewell	31º24'22"N	76º20'08"E	393	11
14	Borewell	31º24'18"N	76º20'09"E	386	7
15	Borewell	31º24'22"N	76º20'17"E	384	9

the form of rain and snow, mainly govern occurrence and movement of ground water. Porous alluvial formation occurring in the valley area forms the most prolific aquifer system where as the sedimentary semi-consolidated formations and hard rocks form aquifer of low yield prospect. Major parts of the district are hilly & mountainous with highly dissected and undulating terrain. These areas are underlain by semi-consolidated and consolidated hard rocks of tertiary and pre- tertiary period. Ground water potential in such areas is very low due to its hydro-geomorphic set up. Springs are the main ground water structures that provide water supply for domestic and irrigation in major rural and urban areas. The springs, locally called C*hasma,* have discharges varying from seepages to 15 liters per second. *Bowries*, a type dug well, are another structure constructed in the hill slopes to tap the seepages. Such *Bowries* are common and observed all southern part of the district. In the last more than a decade, state government have drilled shallow bore wells fitted with hand-pumps to provide domestic water. These hand pumps have depth up to average 50-60m and have low discharges up to 1 lps. Ground water occurs both under phreatic and confined conditions. Wells and tube wells are the main ground water abstraction structures. Ground water is being developed in the area by medium to deep tube wells, dug wells, dug cum bored wells. Depth to water level shows wide variation from near surface to more than 35 m bgl. Yield of shallow aquifer is moderate with well discharges up to 10 lps.

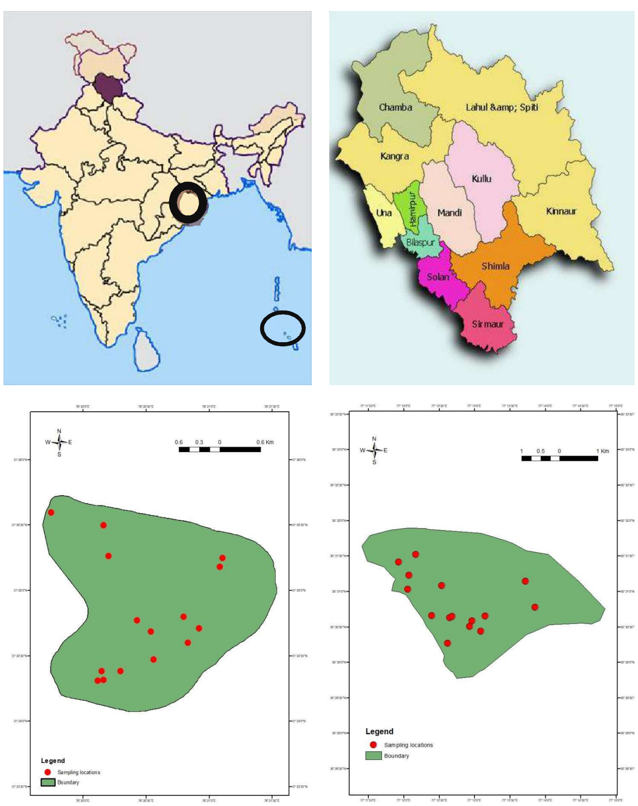

Fig. 1. Location map of study area along with sampling well locations

In Una district hydro-geologically, the unconsolidated valley fill or alluvial formations, occurring in the valley area and semi-consolidated sediments belonging to Siwalik Group form aquifer system. Porous alluvial formation, forms the most prolific aquifer system in the valley area, where as the sedimentary semi-consolidated formation form aquifer of low yield prospect. The ground water in the Siwalik group of rocks occur under the unconfined to semi confined conditions, mainly in the arenaceous rocks viz., sandstone, siltstone, gravel boulder beds etc. Siwalik sediments underlie hilly/undulating areas, where springs (mostly gravity/contact type) and *bowries* are the main ground water structures apart from hand pumps. The discharges of the springs, varies from seepages to 0.50 lps. In the low lying areas underlain by Siwalik rocks, dug wells and hand pumps are the main ground water structures that range in depth from 3.00 to 25.00 m bgl, where in depth to water level ranges from 2.50 to 15.00 m bgl. In upland/plateau areas, the water level is generally deep. In B*eet* area water level is more than 60 m below land surface has been observed. In Una valley area, the ground water occurs in porous unconsolidated / alluvial formation (valley fills) comprising sand, silt, gravel, cobbles / pebbles etc., and forms prolific aquifer.

Methodology: Geospatial techniques were applied in this study to delineate the groundwater potential zones of the study area. ArcGIS 10.8 have been used for creating various digital maps, compiling geographic data, analysing mapped information, sharing and managing geographic information database. The base map was created from SOI toposheets 53F and 53E for Sirmaur district and 53A and 53M for Una district at the scale of 1:50,000. For Georeferencing, the GCS WGS 1984 projection coordinate system was used. The objects were then stored as thematic maps for further delineation of groundwater potential zones.

Creation of digital maps: Various digital maps such slope, geology, aspect, soil, land use/land cover (LULC), drainage and lineament were created by vectorizing the geodatabase in ArcGIS 10.8. The geology and soil maps were collected and digitized from Geological Survey of India and National Bureau of Soil Survey, respectively. The IRS LISS-III geo-coded false color composite data was used for the preparation of LULC. Drainage density and lineaments map were digitized from DEM by using ArcGIS 10.8 Hydrology tools and Spatial Analyst Tool-Hill shade respectively. The slope and aspect maps were generated from DEM (Digital elevation model) with the help of ArcGIS 10.8 Spatial Analyst Tool-Slope and Aspect respectively.

Ranking of thematic maps and assigning weight: The groundwater potential zones for the study were obtained by overlaying all the thematic maps viz., slope, geology, aspect, soil, land use land classification, drainage density, and lineament density using weighted overlay method in the spatial analysis tool of ArcGIS 10.8. During this weighted overlay analysis, ranks have been assigned for each individual thematic maps and weight was assigned according to the influence of individual maps. The ranks and weights have been assigned considering previous works executed by researchers (Saraf and Chowdhary 1998, Waikar and Nilawwar 2014). Table 2 indicated the assigned individual ranks and weights for the various factors in consideration.

Groundwater Potential Zone map: After the digitization of various thematic maps such as geology, soil, land use/land cover (LULC), drainage density, lineament, aspect and slope, the groundwater potential zone map was prepared by integrating these thematic maps and classified into various potential zones (Fig. 2).

Validation: In order to validate the results obtained from analysis through GIS and RS, a field survey was conducted in both the districts during the period 2020-2022 and 15 observation wells (handpump/borewells) were taken in each of the districts along with their GPS locations. Generally, the groundwater potential map is validated with well yield data (Kumar and Krishna 2018), but in this case, the well yield data is not available, so the validation is done by using water depth data. Based on the water depth, the sampling wells have been divided into five categories viz. 3-5 m, 6-9 m, 10-12 m, 13-15 m, and >15m which were referred to as very low, low, medium, high, and very high (Table 6). Lower water depth indicates a high chance of it being in a potential zone (Raju et al 2019). An accuracy assessment was also carried out in order to know the relationship between the groundwater potential zones and the observed well data by superimposing the sampling wells with the potential zone map. The overall accuracy was obtained by using the formula given by Jensen (1996).

$$\text{Overall accuracy \%} = \frac{\text{No. of Correct observation wells}}{\text{Total no. of observation wells}} \times 100$$

Table 2. Classification of weighted factors for delineating groundwater potential zones

Parameter	Classes	Groundwater prospect	Weight (%)	Rank
Slope classes	Very gentle	Very good	15	5
	Gentle	Good		5
	Moderate	Moderate		4
	Moderately steep	Poor		3
	Steep	Poor		2
	Very steep	Very poor		1
Geology	Quarternary	Good	10	4
	Lower Shivalik	Moderate		3
	Upper Siwalik	Moderate		3
Aspect	Flat	Moderate	10	3
	North	Poor		2
	Northeast	Poor		2
	East	Moderate		3
	Southeast	Good		4
	South	Very good		5
	Southwest	Good		3
	West	Moderate		2
	Northwest	Poor		
Soil	Sandy loam	Good	10	4
	Sandy clay loam	Good		4
	Loamy clay	Moderate		3
	Clay loam	Moderate		3
Land use/land cover	Forest	Very good	20	5
	Agriculture land	Very good		5
	Water body	Good		4
	Shrubs	Moderate		3
	Building	Poor		2
	Open/waste land	Very poor		1
Drainage density (km/km^2)	0-1.2	Very good	20	5
	1.2-2.4	Good		4
	2.4-3.6	Moderate		3
	3.6-4.8	Poor		2
	4.8-6	Very poor		1
Lineament (km)	Major	Very good	15	5
	Minor	Good		4

Kappa (K) analysis represents a multivariate approach for accuracy assessment and it provides a Khat statistic which means a measure of accuracy (Usman et al 2015). It is calculated as:

$$\text{Kappa coefficient} = \frac{\text{Total accuracy} - \text{random accuracy}}{1 - \text{random accuracy}}$$

Kappa coefficient value lies from 0 to 1 where a value of 1 means perfect agreement whereas a value close to 0 means that the agreement is no better than would be expected by chance.

RESULTS AND DISCUSSION

Slope: Slope is one of the important terrain parameters for identifying groundwater potential zones. Higher degree of slope leads to rapid runoff and erosion rate increases with feeble recharge potential (Magesh et al 2012). Larger slope produces smaller recharge because the water received from precipitation flows rapidly down a steep slope during rainfall

Table 3. Rating criteria of Kappa statistics

Kappa statistics	Strength of agreement
<0.00	Poor
0.00 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost perfect

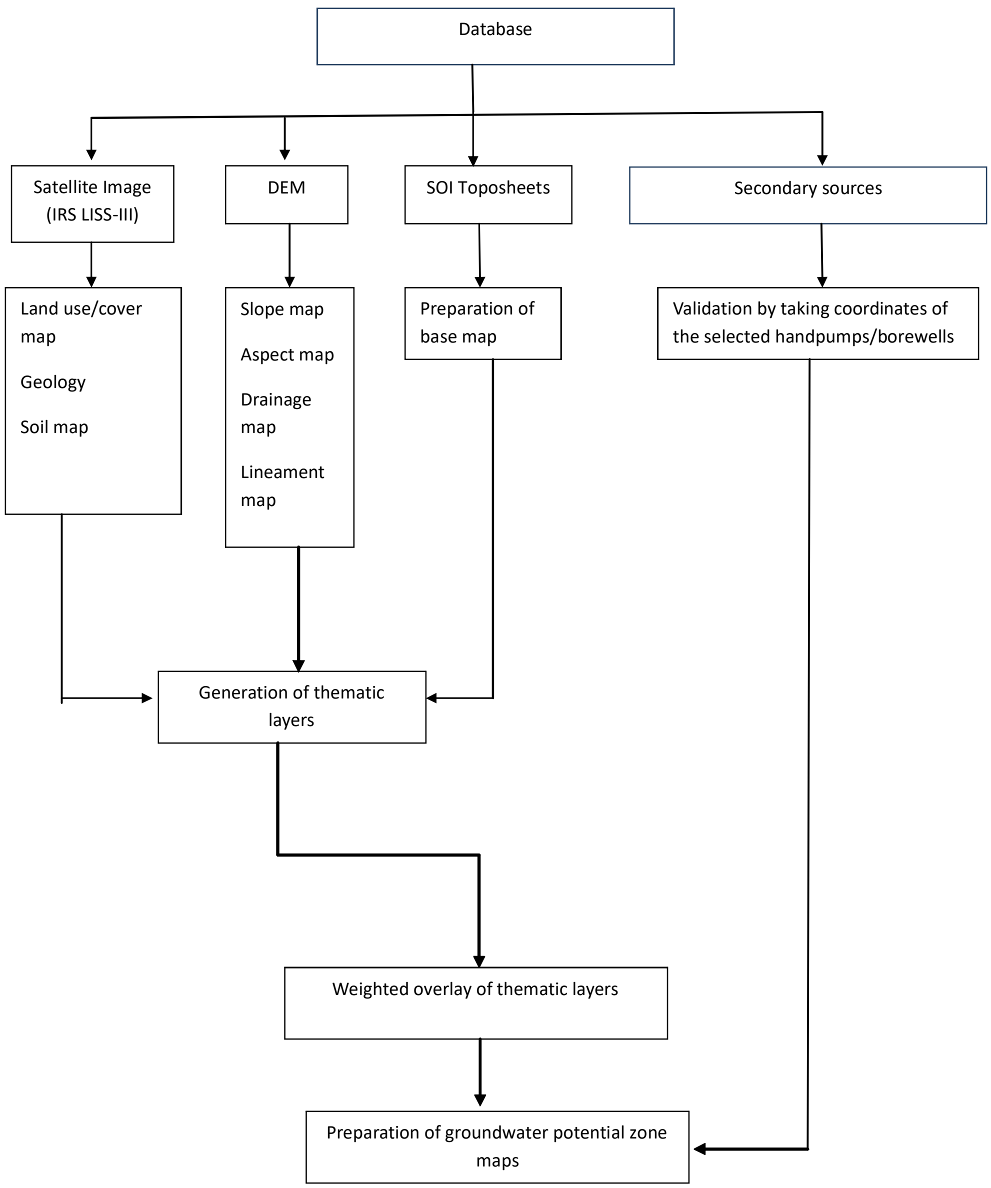

Fig. 2. Flow chart showing methodology of the work

(DeReu et al 2013). Based on the slope, the study area was divided into 6 classes (Table 4). The slope map of both the districts cover 0.30 km^2 (2.55%) (Figs. 3 and 4) These steep slopes may cause relatively high runoff and low infiltration, if there is absence of vegetation. But, in the study area, forest and shrubs were found in these steep slopes which may slow down the runoff rate. Moderately steep slopes cover an area of 0.51 km^2 (4.40%) while moderate slopes cover 0.99 km^2 (8.49%). Majority of the area came under gentle slope with an area of 7.09 km^2 (60.61%). In District Sirmaur out of the 11.7 km^2 study area, very steep slopes cover an area of only 0.18 km^2 (1.51%) while steep slopes cover 0.30 km^2 (2.55%). These steep slopes may cause relatively high runoff and low infiltration, if there is absence of vegetation. But, in the study area, forest. In District Sirmaur out of the 11.7 km^2 study area, very steep slopes cover an area of only 0.18 km^2 (1.51%) while steep slopes shrubs were found in these steep slopes which may slow down the runoff rate. Moderately steep slopes cover an area of 0.51 km^2 (4.40%) while moderate slopes cover 0.99 km^2 (8.49%).

Majority of the area came under gentle slope with an area of 7.09 km^2 (60.61%) to very gentle slopes which cover an area of 2.63 km^2 (22.44%) These gentle to very gentle slopes can be considered good for groundwater storage with high infiltration rate. In District Una, the slope varies from very gentle to moderate. This indicated that the surface runoff is slow allowing more time for rainwater to percolate. Very gentle slopes cover most of the region (74.05%) with an area of 4.60 km^2 followed by gentle slopes with a cover of 1.55 km^2 (24.97%). Moderate slopes were found in minute patches covering about 0.06 km^2 (0.98%).

Geology: geology map of the study region was digitized from a published geological map obtained from the Geological Survey of India and presented in Figures 5 and 6 for District Sirmaur and Una respectively. Based on processing and interpretation of the remotely sensed data, the study area in

Table 4. Slope category

Slope category	Slope (%)
Very gentle	0-1.5
Gentle	1.5-4
Moderate	4-8
Moderately steep	8-13
Steep	13-19
Very steep	19-34

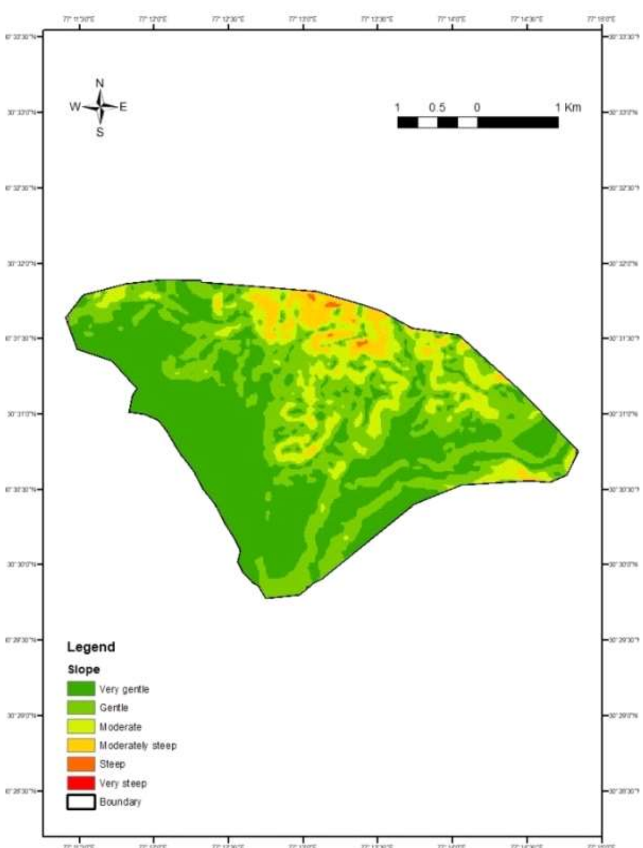

Fig. 3. Slope map of District Sirmaur

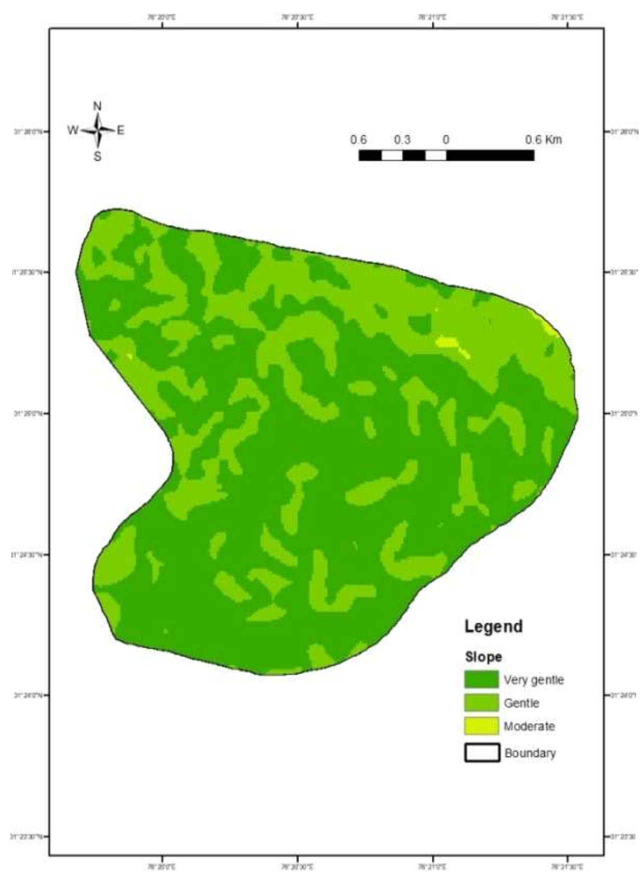

Fig. 4. Slope map of District Una

District Sirmaur consisted of three different rock units. On the north and north-eastern parts, upper Siwalik deposits are found which comprise of boulder deposits and rocks. The lower Siwalik which consisted of fine to medium grained sandstones occupies rest of the study area. The quaternary deposits comprising of porous alluvial formations are considered to have excellent groundwater recharge conditions and were found near the river beds. In District Una, the whole study area comprise of quaternary rocks with alluvium, fluvial and terrace formations containing sand, silt, clay, gravel and pebbles.

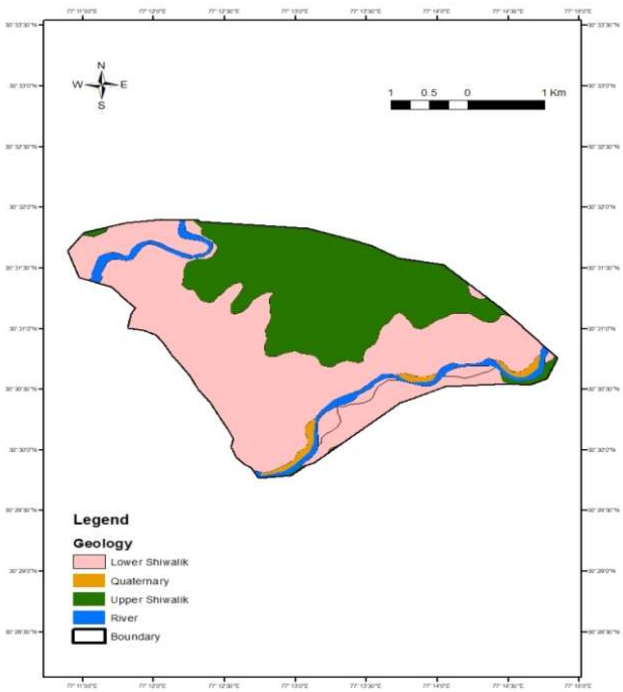

Fig. 5. Geology map of district Sirmaur

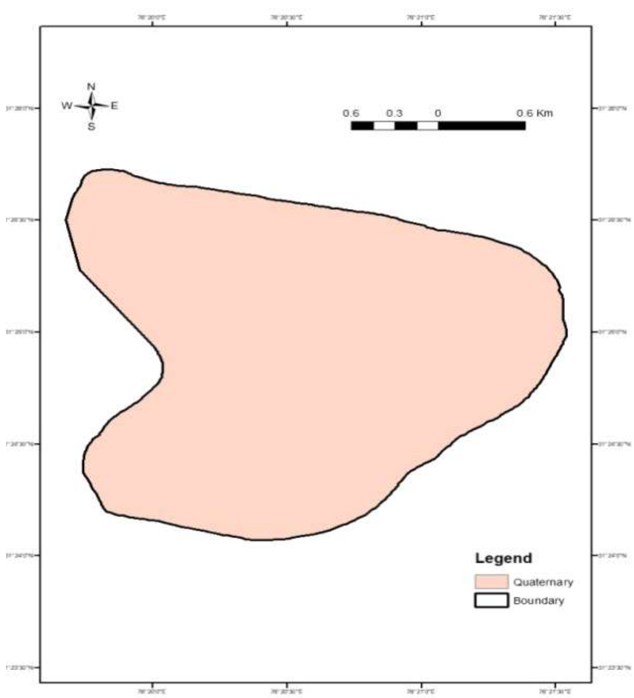

Fig. 6. Geology map of district Una

Aspect: Aspect was used as an important explanatory variable for generating groundwater potential maps because this variable is correlated with evapotranspiration and describes the direction of water flow that influences groundwater recharge and storage (Singh et al 2019). The aspect map is given in Figures 7 and 8 while areas under various aspects in the study area have been presented in Table 5. It is evident that in both the districts, majority of the areas fall under southerly aspects which can be considered good for groundwater recharge.

Soil: Soil properties i.e. soil type, soil texture, etc. show to have a main role in the spatial variation of groundwater recharge (Mehra et al 2016). Soil texture can be described in the ratio of sand, silt, and clay applying texture triangles which determine soil infiltration and water holding capacity. Groundwater recharge depends on runoff, water holding capacity, soil thickness, soil porosity, etc. (Zomlota et al 2015). Figure 9 and 10 depicts the soil map of the study areas. In District Sirmaur, the study area is mainly covered by clay loam soils (6.87 km^2) followed by loamy clay (4.54 km^2) while sandy loam was only found in minute patches (0.29 km^2). The sandy loam soils have excellent percolation capacity because of high sand proportion (Saravanan 2021); hence, it is assigned with a high rank. In District Una, 41.64% of the area was covered by sandy loam soils while sandy clay loam soils cover 39.84 % stretching towards the northern parts of the area. Clay loam soil cover 18.52% of the area and is found in the central to south-eastern parts.

Land use/Land cover (LULC): LULC gives the essential information on infiltration, soil moisture, groundwater,

Table 5. Areas under various aspects

Aspect	District Sirmaur		District Una	
	Area (Km^2)	%	Area (Km^2)	%
Flat	0.02	0.17	0.01	0.16
North	0.56	4.79	0.28	4.51
North-east	0.33	2.82	0.17	2.74
East	0.51	4.36	0.41	6.60
South-east	1.17	10.00	0.52	8.37
South	2.78	23.76	1.75	28.18
South-west	2.71	23.16	1.14	18.36
West	2.56	21.88	0.61	9.82
North-west	1.06	9.06	1.32	21.26

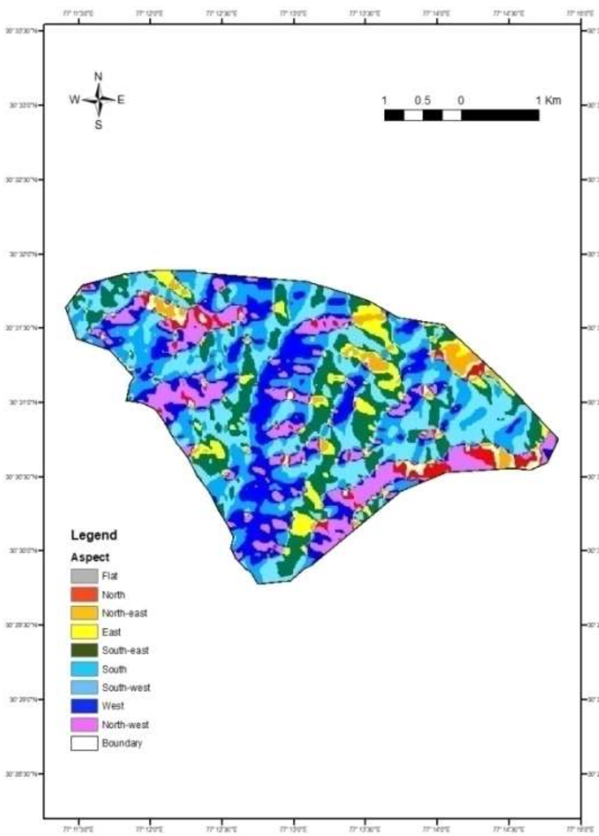

Fig. 7. Aspect map of district Una

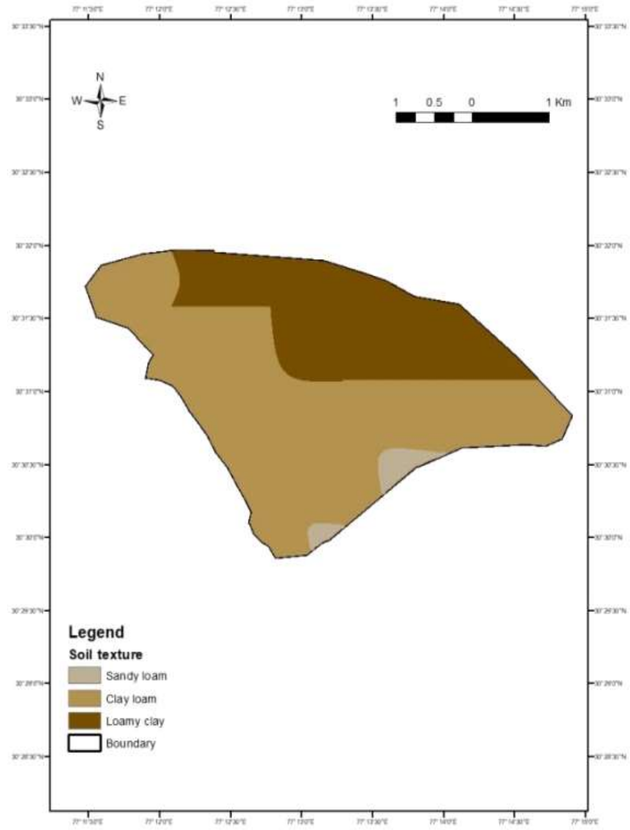

Fig. 9. Soil map of district Sirmaur

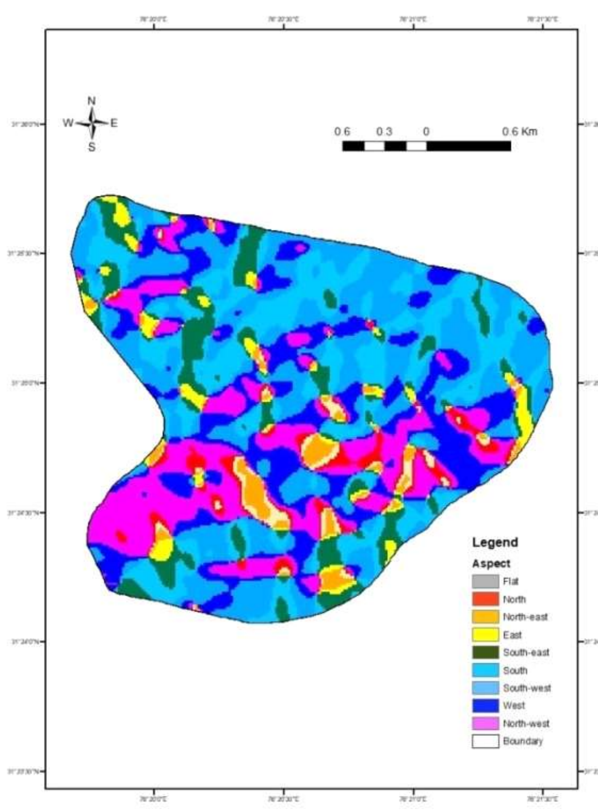

Fig. 8. Aspect map of district Una

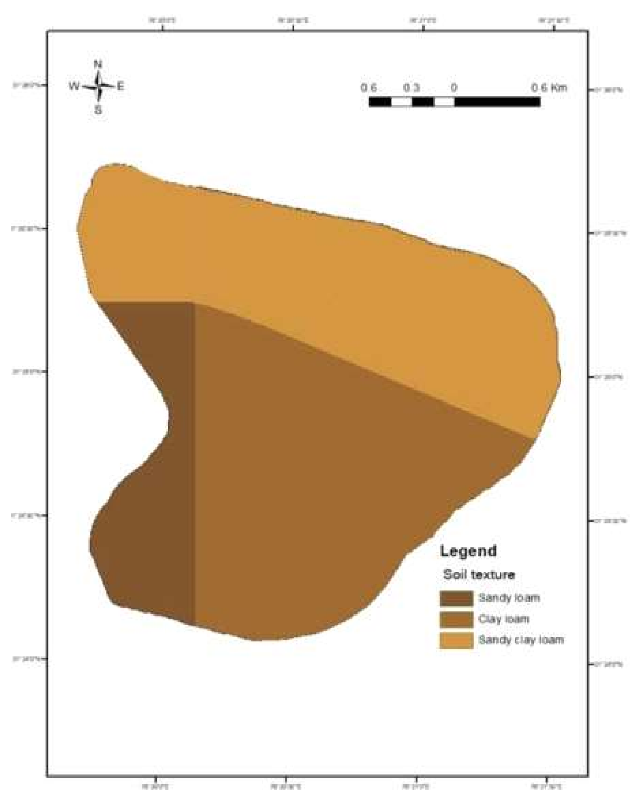

Fig. 10. Soil map of district Una

surface water etc., in addition to providing indication on groundwater requirements (Yeh et al 2016). Reliable and precise information is provided by land-use for sustainable water resource management. Land use pattern controls the infiltration and permeability process. Figures 11 and 12 showed the LULC map of both the districts in study. The study area was classified into six classes namely; building, agriculture land, forest area, open land/ waste land, shrubs and water body. In District Sirmaur, the highest land use was of forest area (27.44%) with an area of 3.21 km^2 followed by open land/waste land (26.41%) with area coverage of 3.09 km^2. Agriculture takes up 16.92% of the area while buildings occupied 14.96% of the area. Shrubs cover 1.54 km^2 (13.16%) while water bodies occupy 0.13 km^2 (1.11%). Built-up/buildings are impervious surfaces, which increase the storm runoff and reduce the infiltration capacity. On the other hand, agriculture, grassland and forest areas have high infiltration and moderate runoff capability, which helps to increase groundwater recharge (Abhijith et al 2020). In District Una, majority (56.13%) of the area was covered by agriculture land (3.48 km^2) which was the highest coverage followed by buildings (18.22%) with an area of 1.13 km^2, open land/wasteland (15.81%) with area coverage of 0.98 km^2 and forest (7.42%) with area cover of 0.46 km^2. The least land use was that of shrubs (2.42%) with an area covering 0.15 km^2. The high area cover of agriculture land coupled with gentle slopes in the district can be considered favorable for groundwater recharge.

Drainage and drainage density: The drainage map consists of water bodies, rivers, tributaries, perennial and ephemeral streams and ponds. Figures 13 and 14 indicated the drainage map of both the districts in study. The majority of the study area in both the districts comes under gentle to very gentle slopes and areas with high drainage density are influenced by high groundwater recharge and low runoff. Therefore, the entire drainage density map is divided into five categories for both the districts (Table 6, Fig, 15, 16). Majority of the drainages in both the district comes under medium to high drainage density while only a few patches comes under very high drainage density.

Lineament: Lineaments are structurally controlled linear or curvilinear features, which are identified from the satellite imagery by their relatively linear alignments. Thus, in the present study lineaments were classified into major lineaments for quantification purpose, lineament with length > 1km is classified as a major lineament and minor lineaments for quantification purpose, lineament with length < 1km is classified as a major lineament. Figure 17 and 18 indicated the lineament maps for District Sirmaur and Una respectively. As evident from the figures, most of the lineaments falls under major lineaments in both the districts and only a few minor lineaments could be found.

Groundwater potential zone map: In District Sirmaur, the area with very high groundwater potential zone comprises 0.44 km^2, covering 3.76% of the area. Similarly, an area of 0.36 km^2 falls under high zone, covering 3.05% of the study area. Another 3.83% of the region comes under moderate zone with area coverage of 0.45 km^2. Low groundwater potential zone covers 1.79 km^2 making up 15.27% of the area. Majority (74.62%) of the area comes under poor zone covering an area of 8.66 km^2(Table 7, Fig. 19).

According to ground truthing results, very high to high groundwater potential zones were found in areas where the slope was relatively gentle, present near river and lineaments, has medium to very high drainage densities with presence of agriculture land to forest areas, therefore having excellent infiltration ability and low runoff. The region under sandy loam soils also comes under the high potential zone thus indicating the high percolation and infiltration capability by these soils. The moderate zones were found in patches spreading in the southern parts and towards south-west as well as south-eastern parts. These were areas mostly covered with open/waste land with very little agriculture or forest cover thus having a comparatively higher runoff than the high or very high zones. Low potential zone was found in areas where there was medium to low drainage density with parts of it covered by buildings. In areas with moderate to steep slopes, this low zone was found in areas covered by forest and shrubs which might have slowed down the runoff process. The area with steep to very steep slopes devoid of vegetation falls under poor potential zone. This poor potential zone was found spreading in the most part of the study area.

Table 6. Drainage density category

Class	Km/Km^2	Category
1	0-1.2	Very low
2	1.2-2.4	Low
3	2.4-3.6	Medium
4	3.6-4.8	High
5	4.8-6	Very high

Table 7. Groundwater potential zones

Potential zones	District Sirmaur		District Una	
	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)
Very high	0.44	3.76	0.08	1.24
High	0.36	3.05	0.11	1.80
Moderate	0.45	3.83	0.97	15.61
Low	1.79	15.27	1.09	63.83
Poor	8.66	74.62	3.96	17..52

There was presence of built-up/buildings even though the slope was gentle which might have increased the runoff thus making the infiltration capacity much lower. Drainage density was also found to be low to very low in these areas thus disabling groundwater recharge.

In District Una, 1.24% of the area falls under very high potential zone with an area of 0.08 km^2 while 1.80% falls under high zone covering an area of 1.80 km^2 (Fig. 20). Moderate zone comprises of 0.97 km^2 which is about 15.61% of the area. Low potential zone covers the largest area

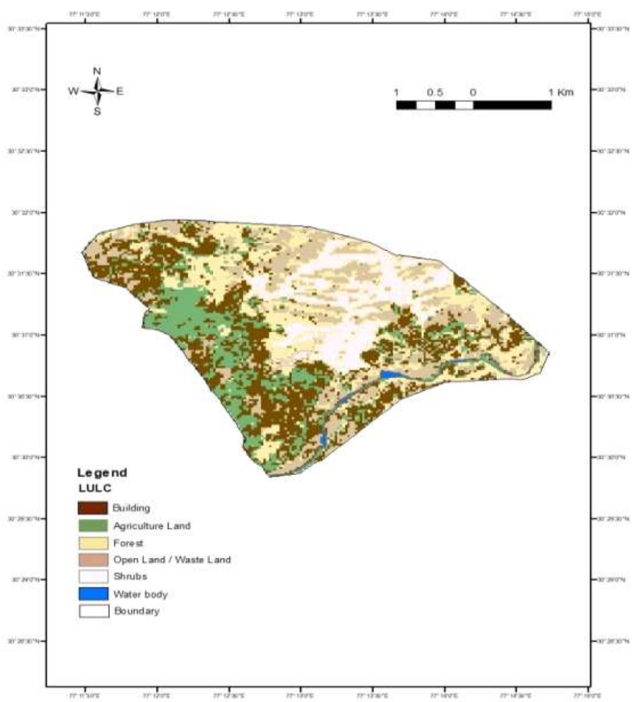

Fig. 11. LULC map of district Sirmaur

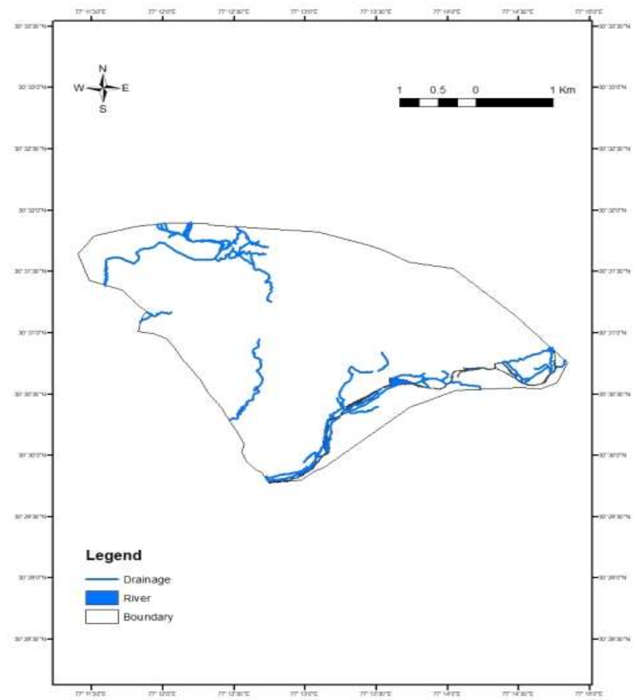

Fig. 13. Drainage map of district Sirmaur

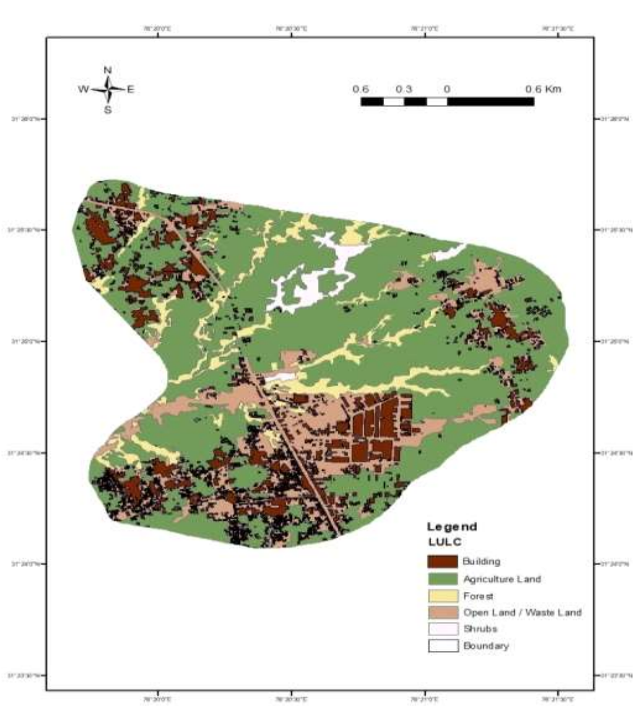

Fig. 12. LULC map of district Una

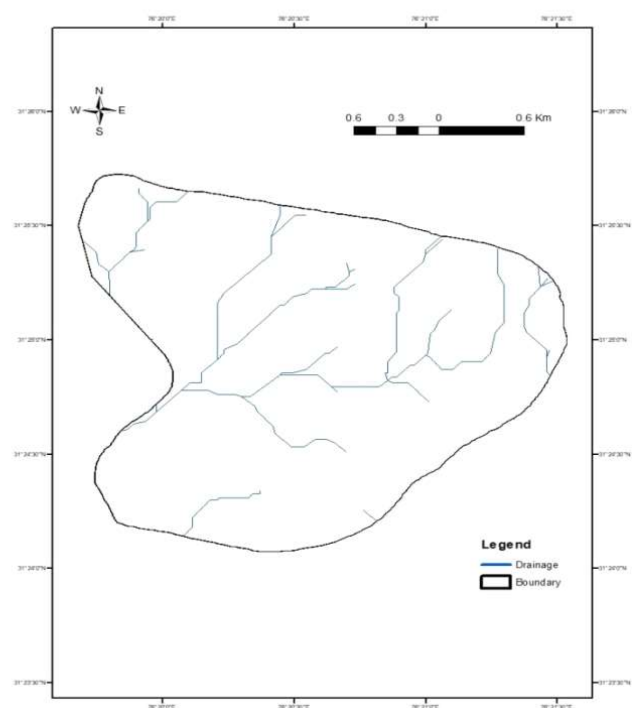

Fig. 14. Drainage map of district Una

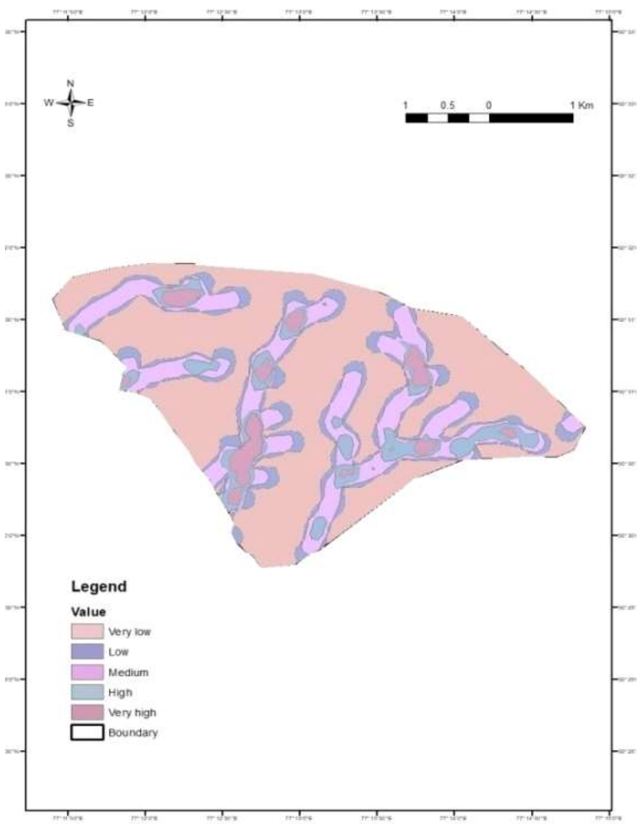

Fig. 15. Drainage density map of district Sirmaur

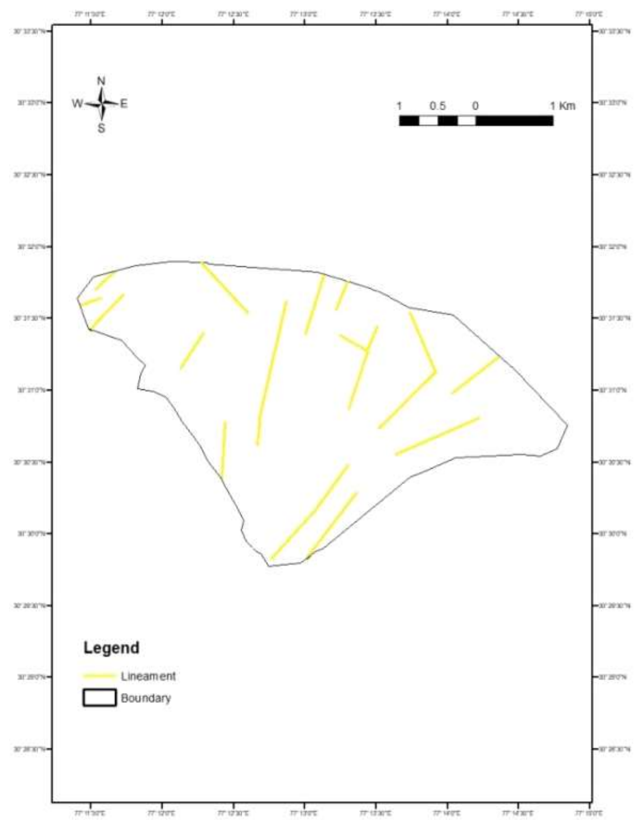

Fig. 17. Lineament map of district Sirmaur

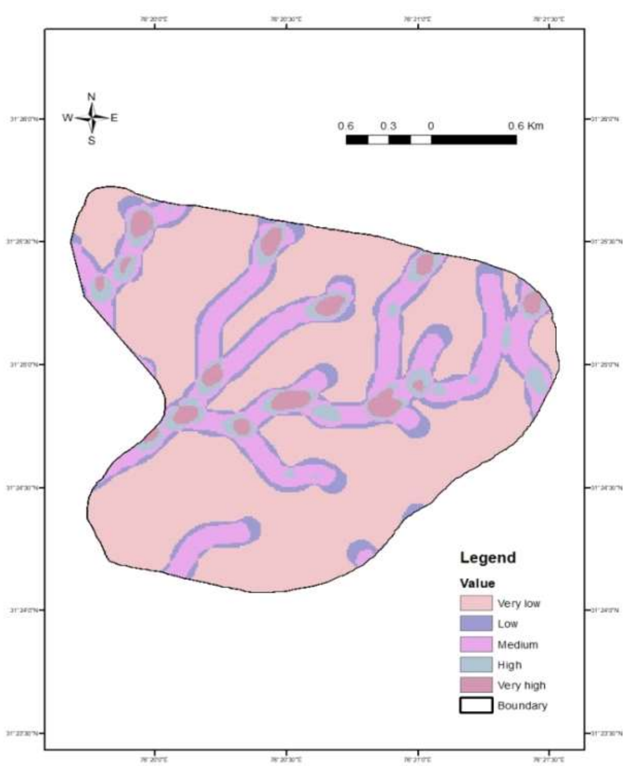

Fig. 16. Drainage density map of district Una

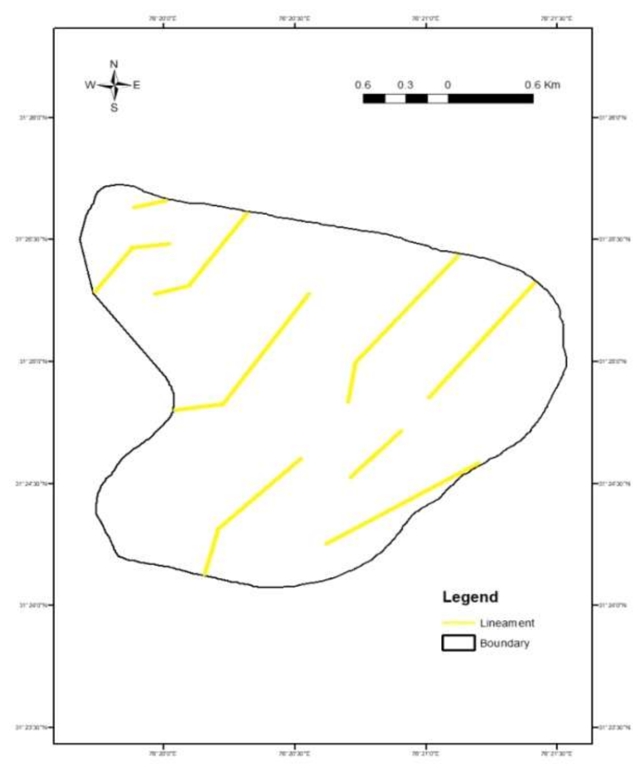

Fig. 18. Lineament map of district Una

(63.83%) with 3.96 km^2 coverage while poor zone comprises of 17.52% covering 1.09 km^2. Very high groundwater potential zone was found in small patches in the north-western and north-eastern parts. This has been verified by ground truthing. These are regions with very high drainage density, have southerly facing aspect with gentle slopes and were found in agriculture land and forest areas with sandy clay loam textures that allow high percolation and slow to runoff. High potential zones were found in the northern to central parts of the study area with most of it under agriculture and shrub coverage with gentle to very gentle slopes and having high to medium drainage densities. Moderate zones were present distributed throughout the whole area with only a few patches in the southern side. The area under these zones have medium to low drainage density, mostly covered by shrubs and forest with parts under agriculture land and present near lineaments. Majority of the area under this zone comes under west to north-western aspects. Low potential zone has the highest coverage in the area with low to very low drainage densities covering most of the built-up areas as well as open/waste lands and has northerly aspects indicating a higher evapotranspiration and lower percolation in these areas. Poor potential zone was found in patches distributed throughout the whole area but mostly concentrated towards central to southern parts. Even though the slope is gentle, these are areas covered by buildings and open land/waste lands and hence there is more runoff and low infiltration capacity leading to low groundwater recharge.

The error matrix table has been presented in Table 8 for Sirmaur and Una respectively. In district Sirmaur, the overall efficiency was 80% with a kappa coefficient of 0.73, which means there is substantial agreement between the potential zone map and the well data. In district Una, the overall efficiency of the groundwater potential zone map was 86.67% with a kappa coefficient of 0.81, which indicated an almost perfect agreement. Mahato et al *(*2021) also delineated groundwater potential zones in Papumpare district of Arunachal Pradesh where their analysis showed an overall accuracy of 81.25% and a Kappa coefficient of 0.72. The low accuracy level obtained in this study may be attributed to the fact that a relatively lesser number of sampling wells were taken for validation. The factors taken into consideration like slope, aspect, geology, etc. only deal with the physical parameters of the area and climatological parameters like rainfall could not be taken into consideration as there was a similar rainfall distribution pattern in the area.

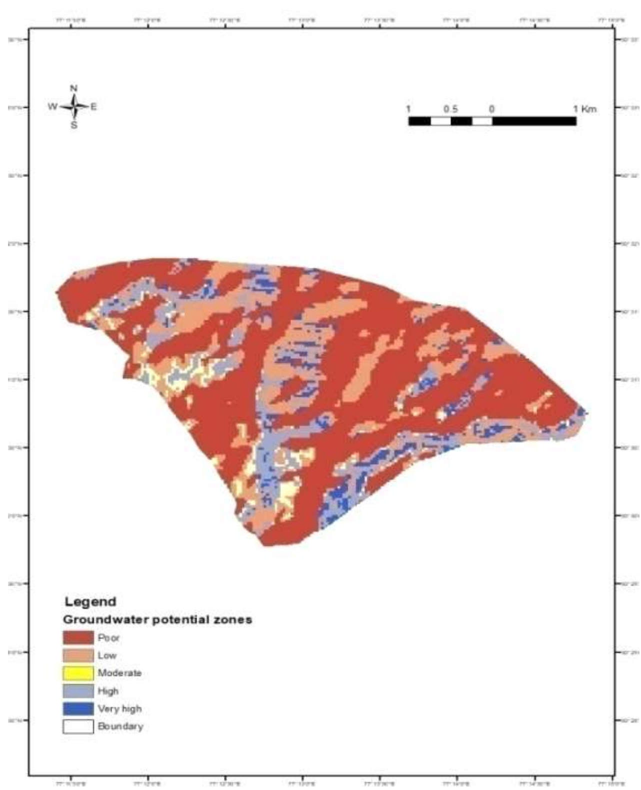

Fig. 19. Groundwater potential zone map of district Sirmaur

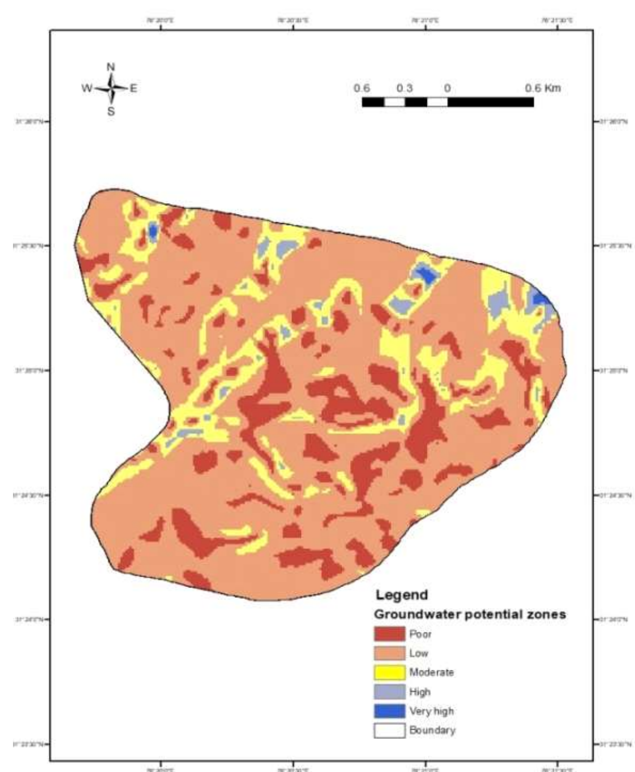

Fig. 20. Groundwater potential zone map of district Una

Table 8. Error matrix of groundwater potential zones in district Sirmaur and Una

GWPZ	Very High	High	Moderate	Low	Poor	Total
District Sirmaur						
Very High	0	0	0	0	0	0
High	1	3	0	0	0	4
Moderate	0	0	2	0	0	2
Low	0	0	1	2	0	3
Poor	0	0	1	0	5	6
Total	1	3	4	2	5	15
Overall accuracy			80.00%			
Kappa coefficient			0.73			
District Una						
Very High	0	0	0	0	0	0
High	0	0	0	0	0	0
Moderate	0	1	4	0	0	5
Low	0	0	1	5	0	6
Poor	0	0	0	0	4	4
Total	0	1	5	5	4	15
Overall accuracy			86.67%			
Kappa coefficient			0.81			

CONCLUSIONS

The present study was conducted to delineate the groundwater potential zones in two districts lying in low-hills of Himachal Pradesh by using RS and GIS techniques. The method involves weighted overlay of various thematic layers (slope, geology, aspect, soil, land use land classification, drainage density, and lineament) after assigning individual ranks and weights to each of the factors. The final groundwater potential zone map was then developed for both the districts and the areas were classified into five distinct groundwater potential zones such as very high, high, moderate, low and poor. In district Sirmaur, majority of the area falls under low to poor groundwater potential zones while only minute patches of high to very high potential zones are found. This indicated that the groundwater resources in the areas have been over-consumed for the industrial and other domestic purposes and appropriate management for groundwater resources is very much needed in the area. In district Una, majority of the area falls under low to moderate potential zones indicating there is some prospects for groundwater utilization but if appropriate steps are not take, the groundwater resources will soon decline in the near future. Assessment of groundwater potential as well as delineation of potential zone map was significant for groundwater resource management and future planning for efficient groundwater uses. Thus, this study can provide an insight about the groundwater status in the study areas and it may be useful for future groundwater management plans.

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Received 12 May, 2023; Accepted 30 September, 2023