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Original Article

Identification of Groundwater Potential Zone in Bundelkhand and Vindhyan Region Using Geoinformatics Techniques

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Abstract *- Groundwater availability in urbanized areas is under high demand due to overconsumption and lack of recharge area. It is important to consider the groundwater scenario of the cities and industrial areas for its safe consumption and management. Groundwater is a vital resource for sustaining agricultural and domestic activities in Chitrakoot District, Uttar Pradesh. Chitrakoot district is located in the Southern part of Uttar Pradesh. It comes under part of hard rock terrain, which is mainly covered by Bundelkhand granite and Vindhyan system (Semri limestone, Rewa Sandstone, Shale and Kaimur Sandstone). This study utilizes various thematic layers, including lithology, land use /land cover, slope, drainage density, rainfall and soil texture, to generate a groundwater potential zone map using the Analytical Hierarchy Process (AHP) method. The study findings indicate that the southern part of the district has poor to nill while the western and central parts of the district have moderate groundwater potential. In contrast, the Northern and Eastern parts of the study area have good to very good potential zones.*

Keywords *- Groundwater potential zone, AHP method, Thematic layers, High-resolution satellite image, GIS Software.*

1. Introduction

Groundwater is one of the most important and vital natural resources which is stored in the subsurface geological formations in the critical zone of the earth's crust [6]. It serves as a source of water for domestic, industrial and agricultural uses and other developmental initiatives [4,6,15,16,20]. The ever-increasing demand for water to meet human requirements and developments has imposed immense pressure on this limited freshwater resource. The occurrence and distribution of groundwater are depended on the various natural and anthropogenic factors [7,8,11,25,27]. It serves as a source of water for domestic, industrial and agricultural uses and other developmental initiatives. Chitrakoot district is located in the Southern part of Uttar Pradesh, where groundwater is a crucial resource for agriculture and domestic activities. Groundwater levels have been declining in recent years, resulting in water scarcity and depletion of groundwater resources. Therefore, mapping the groundwater potential zones in the district is necessary for sustainable groundwater management. The availability of groundwater depends on various factors, including geology, hydrology, and topography; mapping the groundwater potential zones is crucial for sustainable water resource management. Remote sensing and GIS techniques provide an efficient and cost-effective method for groundwater prospecting. In this study, we aimed to map the groundwater potential zones of the Chitrakoot district surrounding of Vindhyans and Bundelkhand region using remote sensing and GIS techniques.

2. Study Area

Chitrakoot District is located in the Southern Indian state of Uttar Pradesh, situated at the border of Madhya Pradesh. The study area stretches in between Lat. 24° 48′ to 25° 12′ N and Long. 80° 58′ to 81° 34′ E. The study area is covering total geographical area of 3,164 Sq.Km and is located at a distance of about 250 Kilometers from the state capital, Lucknow.

The district is divided into four sub-districts (Tehsil), Karwi, Manikpur, Mau and Rajapur. It has a total of five blocks, which are Karwi, Mau, Manikpur, Ramnagar and Pahari, as shown in Figure 1. It is considered a holy town by Hindus and is believed to be the place where Lord Rama, Sita, and Lakshmana spent their 12 years of exile. The town is also known for its natural beauty, as it is surrounded by lush green forests, waterfalls, and rivers [33].

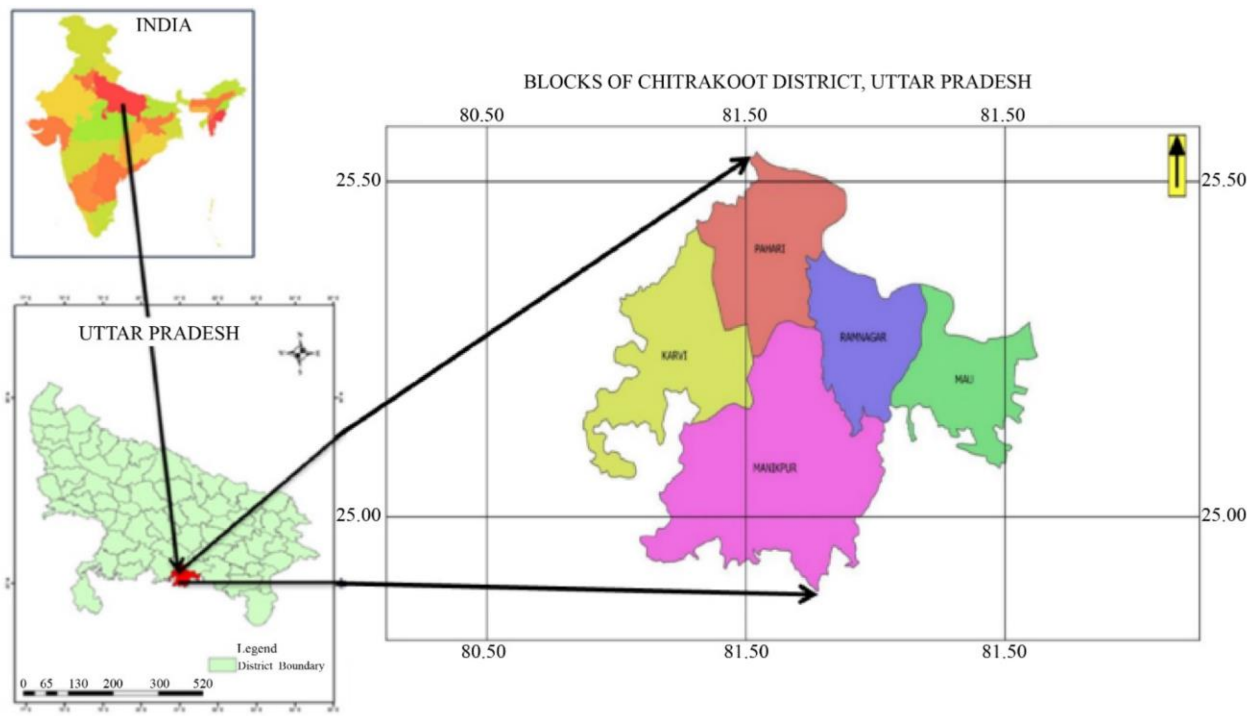

Fig. 1 Location map of the study area

The population of Chitrakoot district, as per the 2011 Census of India, is around 990,626, with a population density of 326 persons per square kilometer. The literacy rate of the district is 60.32%, which is lower than the national average of 74.04% [34]. The economy of Chitrakoot district is primarily agricultural, with a large portion of the population engaged in farming and related activities. The major crops grown in the area include wheat, rice, pulses, and oilseeds. The district also has some small-scale industries, including handloom weaving, pottery, and handicrafts.

3. Materials and Methods

This study utilizes base and thematic layers, including Lithology, Geomorphology, Land use/ Land cover, slope, drainage density, lineament density, rainfall, and soil, to generate a groundwater potential zone map. Each thematic layer was assigned weights based on its significance in groundwater occurrence, and the Analytical Hierarchy Process (AHP) method [26] was used to combine the thematic layers and generate a composite map of groundwater potential zones. Sentinel-2 satellite data have been used for thematic mapping in the ArcGIS 10.4 software environment.

4. Results and Discussion

4.1. Lithology

With a detailed study of literature, published reports/maps of GSI and CGWB, Northern region, Lucknow, the original classification proposed by Auden (1933) and Krishnan (1968) was modified by Sastry & Moitra (1984), Banergee et al. (2006). I have prepared a Lithology map. The alluvium of the Quaternary age occupies the major part of the area in the North. In contrast, the area in the south is exposed to Kaimur, Rewa sandstones, shales and Tirohan limestones of the Vindhyan system. The western and southwestern parts, adjacent to the MP border, area characterized by well-exposed Bundelkhand Granite Gneiss, which is devoid of primary porosity but weathered and fractured parts from the potential aquifers [5,12,17,18,24] as shown in Table1 and Figure 2.

Table1. Litho-Stratigraphy sequence of study area(Modified after Sastry & Moitra (1984) and Banergee et al (2006))

	Group	Lithology
Quaternary	Younger Alluvium Older Alluvium	Sand, Silt, Clay, Gravels, Kankar etc.
Vindhyans	1. Kaimur Group	Kaimur Sandstone
	2. Rewa Group	Shale, Sandstone
	----------Unconformity----------	
	3. Semri Group	Tirohan Lime stone
	4. Upper Glouconitic Limestone	Dolomite Sandstone, Pallet
----------Unconformity----------		
Archean	Bundelkhand Gneissic Complex	Bundelkhand Granite Gneiss

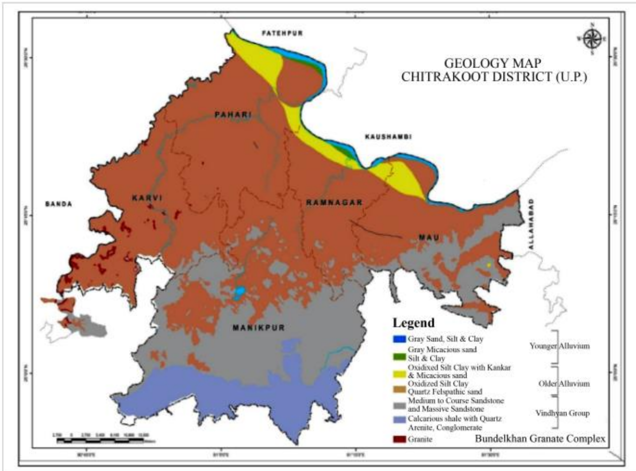

Fig. 2 Geological map of the study area

4.2. Geomorphology

Geomorphological mapping involves the identification and characterization of the fundamental units of landscape. The underlying lithology, slope and the type of existing drainage pattern influence the genesis and processes of different geomorphic units (V.B. Rekha et al., 2011) [29]. It is characterized by the occurrence of Vindhyan systems and Bundelkhand granite, gneiss in southwestern parts of the district, having weathered mantle of colluvial and alluvial materials [5]. This region comprises various geomorphic units such as pediments /inselberg complex, shallow pediplains and residual hills. The pediplain/ inselbergs consist of granite gneiss and undulating uneven tablelands of Kaimur sandstones with very steep marginal escarpments. There is little infiltration in these zones. These geomorphological units act as runoff zones and are not favorable for groundwater development. The residual hill units have moderate relief, and the groundwater occurrence in this unit is very poor. This includes other geomorphic units, viz. moderately weathered Pediplain and deeply buried pediplain. The moderately buried pediplain is characterized by gentle to moderately undulating terrains of low relief having thicknesses between 5 to 15 m.

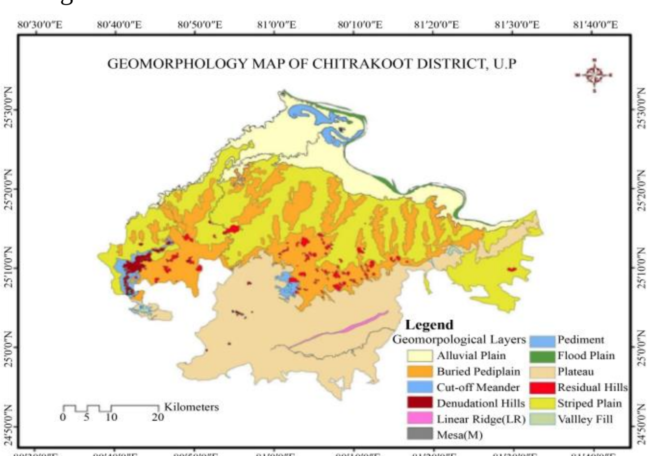

Fig. 3 Geomorphology map of the study area

This unit is highly eroded older alluvial sediments. The superficial alluvial sediments, constituting an average thickness of 40 to 50 m, form a good aquifer system from a groundwater prospect point of view. The superficial alluvial sediments of deeply buried pediplain and underlying Vindhyan sandstone form potential aquifers within 60m below ground level (GSI & CGWB Lucknow). This region prevails in Mau, Ramnagar, Pahari and Karwi blocks, as shown in Figure 3.

4.3. Land Use /Land Cover

Based on a brief reconnaissance survey with additional information from previous research in the study area, a modified Land use and Land cover classification scheme has been developed for the study area [13, 19].

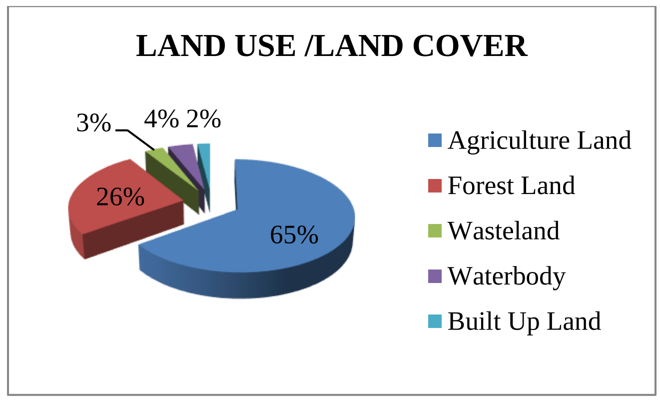

Fig. 4 Geographical representation of LULC of the study area

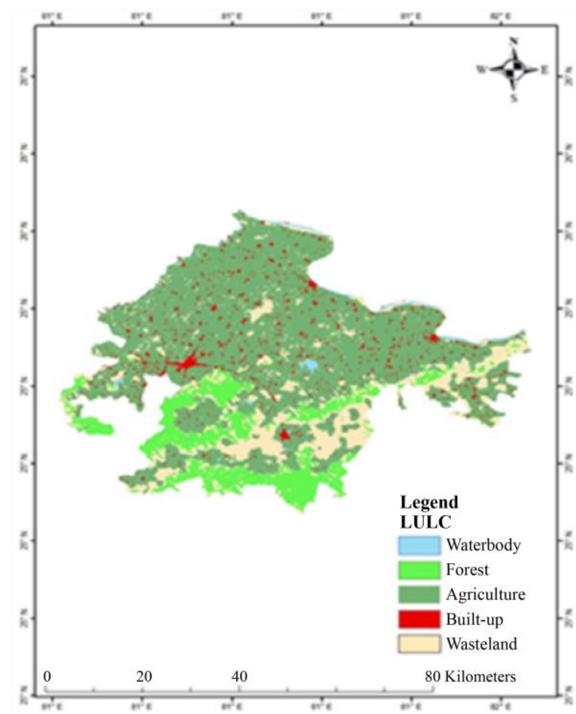

Fig. 5 Land use /Land Cover map of the study area

Land Use / Land cover map was prepared using a Sentinel-2 Satellite Image (2022). Land use /land cover categories were delineated on the basis of spectral signatures and terrain characteristics, which were later supplemented by limited ground truth verification; the thematic maps derived through satellite data were imported to Arc GIS 10.4 software for further analysis, as shown in Figure 4. The result of the work shows the distribution of Built-up land at 2.42 percent, Agriculture land at 64.49 percent, Forest land at 25.45 percent, Wasteland at 3.37 percent, and Waterbody 4.27 percent in 2021-22, as shown in Figures 4 and 5.

4.4. Drainage Density

Drainage density is the stream length per unit area in a region of the watershed (Horton, 1945, p.243 and 1932, p. 357; Strahler, 1952, and 1958; Melton, 1958) [2, 3, 21] is another element of drainage analysis.

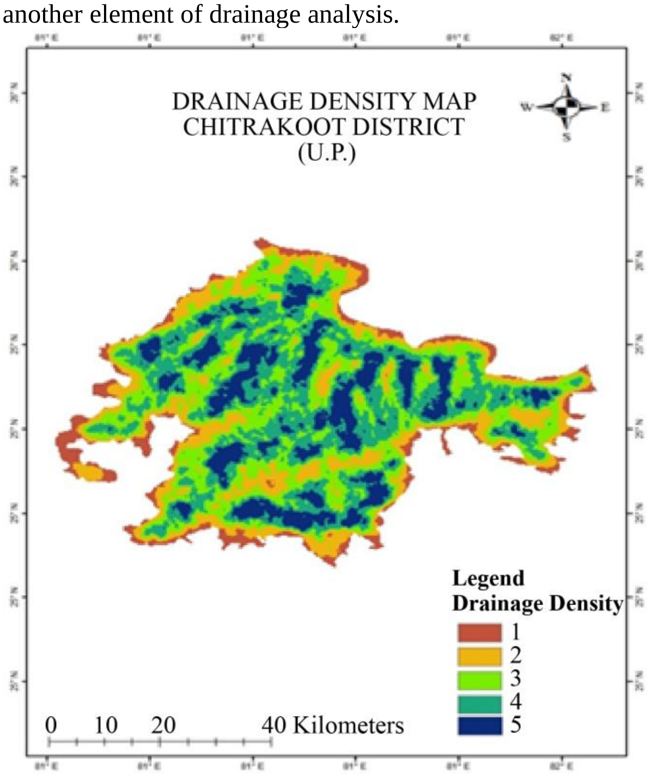

Fig. 6 Drainage Density map of the study area

It is a useful parameter for understanding the drainage characteristics of a region and can provide information about the soil erosion potential, groundwater recharge, and flood risk. Drainage maps have been prepared from Sentinel-2 images using ArcGIS 10.4 Software. The study area is flown by drainage order of 1 to 6. The Drainage Density map is shown in Figure 6.

4.5. Soil

Groundwater is an essential source of water for many communities, and the soil serves as a natural filter and storage system for groundwater. The study area is further classified into two classes' chromic luvisols and orthic luvisols, as shown in Figure 7. Soil data have been taken from the Food and Agriculture Organization of the US (https://www.fao.org/soils-portal) portal and further updated using Sentinel-2 Image (2022) [30].

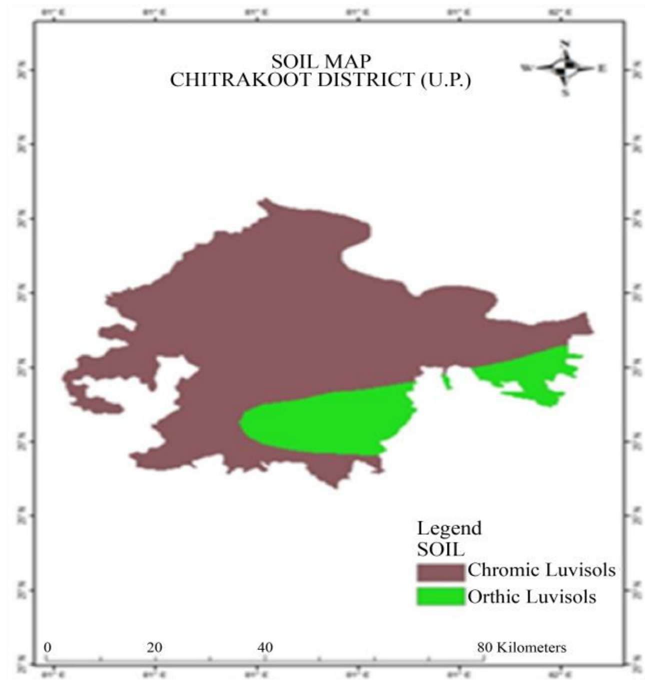

Fig. 7 Soil map of the study area

4.6. Rainfall

Rainfall is one of the most important factors affecting groundwater resources. It is the primary source of recharge for many aquifers, particularly in regions with limited surface water resources. The rainfall data were collected from the Climatic Research Unit (https://crudata.uea.ac.uk/) data portal [32]. The Normal annual rainfall in the district is 876.4 mm for the period 2011 to 2020. The average rainfall map was prepared with the help of IDW techniques in the Arc-GIS 10.4 software environment. The maximum rainfall occurs during the monsoon period, i.e. July to September, i.e. 639.30 mm, and it is 72.94% of the annual average rainfall, as shown in Figures 8(i) & (ii).

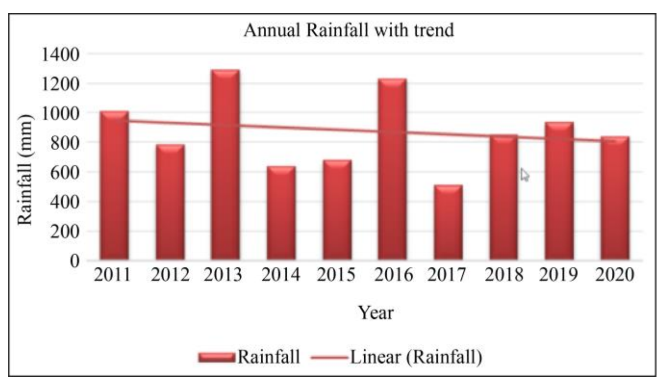

Fig 8(i). Rainfall Trend (2011-2020) of the study area

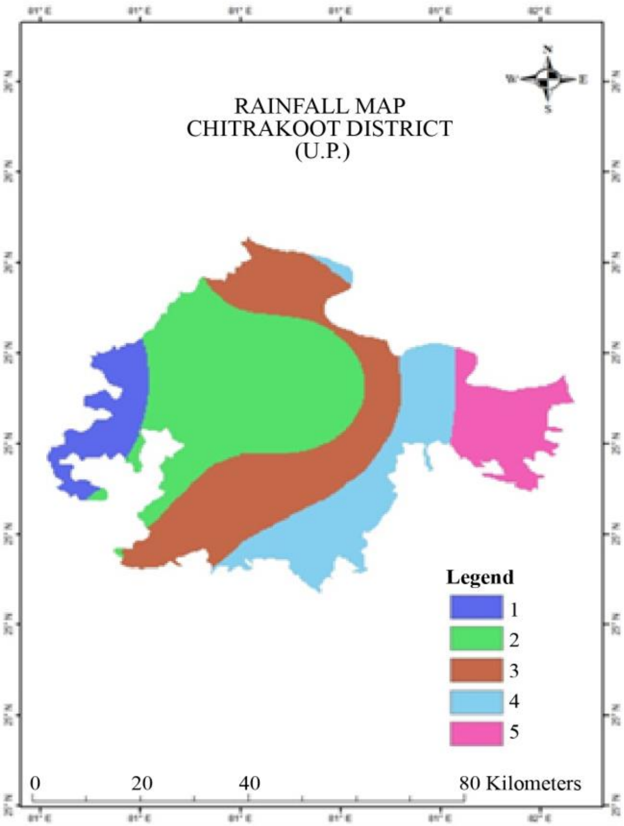

Fig. 8(ii). Rainfall map of the study area

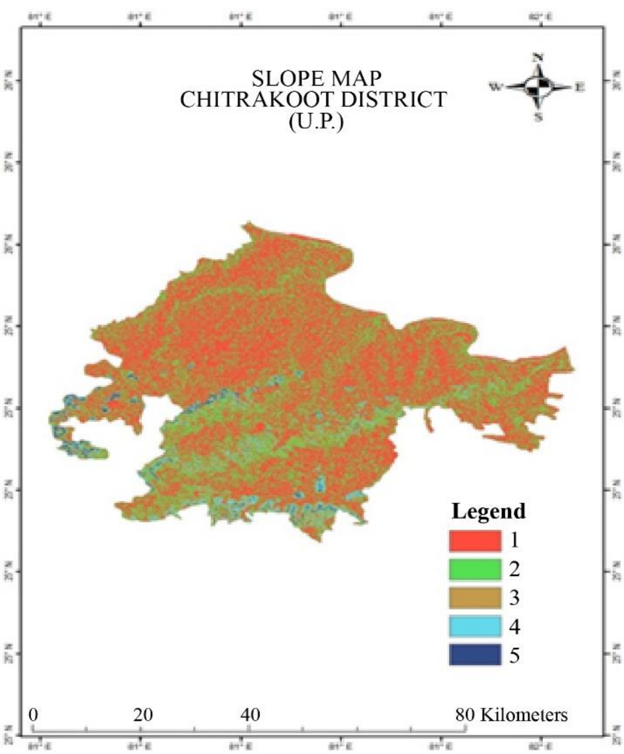

Fig. 9 Slope map of the study area

4.7. Slope

A slope map has been prepared using SRTM DEM (https://www.usgs.gov/) [31]. The slope or gradient of the ground surface is also an important factor in the behavior of groundwater. The slope determines the direction and speed of groundwater movement and can affect the recharge and discharge of groundwater. Low-level slope has high infiltration and low runoff, resulting in good groundwater recharge, while moderate to steep slopes enhance surface runoff. The slope is further classified into five classes, as shown in Figure 9.

4.8. Lineament

Lineament density is a measure of the total length of linear features, such as faults, fractures, and joints, per unit area of a region. It is a useful parameter in geological and geophysical studies for understanding the structural characteristics and tectonic history of a region.

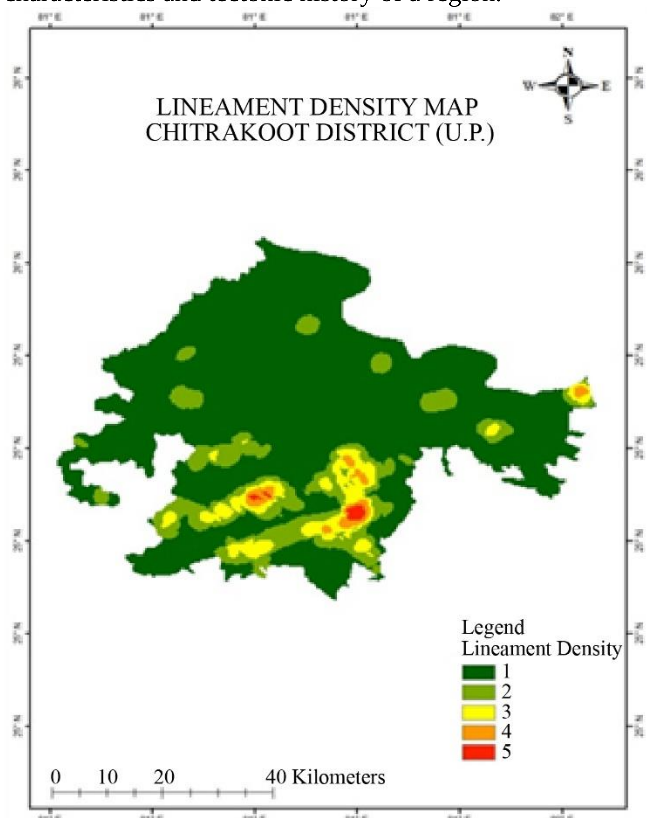

Fig. 10 Lineament density map of the study area

Lineament density is an important parameter in geophysical studies, as linear features can influence the distribution of geological resources such as groundwater, mineral deposits, and hydrocarbons. Lineament maps have been prepared using Sentinel-2 Satellite Images and observed. Some of the lineaments have double intersections near the Manikpur and Karwi block areas, as shown in Figure 10.

Table 2. Weighted Overlay analysis using the Analytical Hierarchy Process (AHP) of the study area

Thematic Layers	Weight	Individual Features	Feature Score
LULC	7	Built-Up	1
		Forest	4
		Agriculture	5
		Waterbody	5
		Wasteland	1
Lithology	20	Newer Alluvium	5
		Older Alluvium	5
		Kaimur	2
		Rewa Sandstone	2
		Semri	1
		Older Supracrustal	1
		Bundelkhand Granitoid Complex	1
Geomorphology	20	Alluvial Plain	5
		Burried Pediplain	3
		Cut of Meander	3
		Denudational Hill	1
		Linear Ridge	1
		Mesa	1
		Pediment	4
		Flood Plain	5
		Plateau	1
		Residual Hill	1
		Striped Plain	3
		Valley Fill	4
Rainfall	23	1	1
		2	2
		3	3
		4	4
		5	5
Soil	4	Chromic Luvisols	3
		Orthic Luvisols	1
Slope	12	1	5
		2	4
		3	3
		4	2
		5	1
Drainage Density	9	1	5
		2	4
		3	3
		4	2
		5	1
Lineament Density	5	1	1
		2	2
		3	3
		4	4
		5	5

4.9. Ground Water Potential Zone Map

Assessment of groundwater potential is a vital step to use and manage resources effectively as well as efficiently [28]. In the present study GIS, Remote Sensing and weighted overlay analysis using the Analytical Hierarchy Process (AHP) model have been applied to analyze all thematic databases of the study area to prepare the Groundwater Potential Zone map, as shown in Table 2. Ground water potential zone has been categorised into five, viz. Very good, Good, Moderate, Poor, and Poor to Nill of the study area as shown in Figure11.

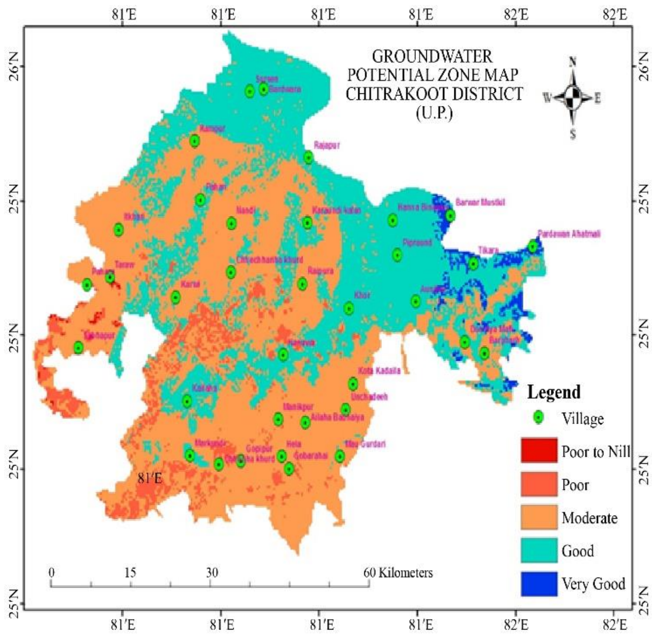

Fig. 11 Groundwater potential zone map of the study area

The resultant model is further cross-verified with the results of the observation well data available in different sites of Central Ground Water Board (CGWB) data.

High transmissivity and storativity values are observed in the area where GWPI is greater than 0.7 and moderate transmissivity and storativity values in the zone where GWPI is between 0.5, while poor transmissivity and storativity values in the study area where GWPI is greater than 0.1 which is shown in Table 3.

Table 3. Groundwater Potential Index of the study area

GW Condition	Average Transmissivity and hydraulic conductivity	Groundwater Potential Index
Very Good	High	0.8 – 1.0
Good	High	0.7 – 0.8
Moderate	Moderate	0.5 – 0.7
Poor	Poor	0.3 – 0.5
Poor to nil	Poor	<0.1

5. Conclusion

Remote Sensing and GIS techniques play an important role in preparing groundwater potential zone maps. In the present study, I have identified very good prospects in Barwar Mustkil, Tikara, Pardwan Ahatmali and Good prospects in Rajapur, Sursen, Bardwara, Hanna Binayka, Pipraund, Aunjhar, Khor, Hanuwa, Kailaha, Markundi, Karaundi Kalan, Dondiya mafi villages and Moderate prospects in Rampur, Pahadi, Nadi, Itkhri, Taraw, Pahara, Sabhapur, Chhechhariha khurd, Gopipur, Chheriha Khurd, Hela, Gobarhai, Mau Gurdari, Manikpur, Aliaha badhaiya, Unchadeeh, Kota kadaila, Raipura, Bargharh villages and rest of villages/ hamlets in hilly and degraded areas comes under poor and poor to nill as shown in Figure 11.

Many recharge structures were constructed during the Rajiv Gandhi National Drinking Water Mission (RGNDWM-2002) in the study area.

Due to heavy rain and flood, most of the recharge structures of RGNDWM-2002 have broken and vanished till now. After site suitability 14 recharge structures have been suggested. Two recharge structures in the Bardaha watershed, three recharge structures in the Mandha watershed, seven recharge structures in the Ohan watershed, and two recharge structures in the Baghain watershed, which are shown in Figure 12. This study is very helpful to farmers, researchers, academic institutions, NGOs, SHG, and government departments.

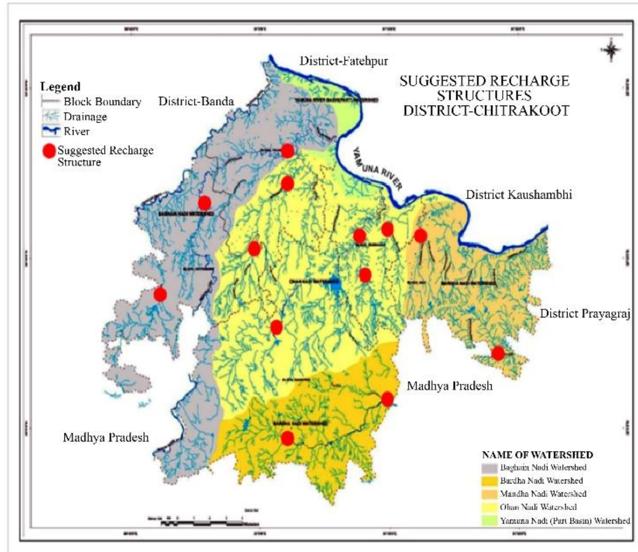

Fig. 12 Suggested recharge structures of the study area

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