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# Integration of Hydrogeological Factors for Identification of Groundwater Potential Zones Using Remote Sensing and GIS Techniques

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**Abstract** Remote sensing data can be used as a reconnaissance and features identification tool for identifying surface and sub-surface water potential zone. The present study has been carried out to evaluate the potential zones for groundwater targeting using an integrated remote sensing data, Survey of India (SOI) topographical sheets and field verification. Four features (geomorphologic units, slope, drainage density and lineaments density) that influence groundwater occurrence were extracted and integrated to evaluate the hydrogeomorphological characteristics of the study area and demarcate the groundwater potential zones. Thematic maps of the extracted features were prepared and integrated through geography information system (GIS) environment. The groundwater potential map was prepared by overlaying the thematic layers. Weightage percentages were assigned to the different parameters according to their relative importance to groundwater potentiality. The integrated map of the area shows different zones of groundwater prospects, viz. very high (0.77% of the area), high (35.57% of the area), moderate (54.53% of the area), while poor and very poor are made up of 9.13% of the area.

***Keywords:*** *geomorphologic units, hydrogelogy, remote sensing, GIS, groundwater*

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## 1. Introduction

Groundwater is a form of water held under the ground in the saturated zone that fills all the pore space of soils and geologic formations. It is formed by rainwater or snowmelt water that seeps down through the soil and into the underlying rocks [1]. It is the major resource of water supply for about half of the nations. It plays a key role in Nature. It provides more than half of humanity's freshwater for everyday uses such as drinking, cooking, and hygiene, as well as thirty percent of irrigated agriculture and industrial development [2]. Groundwater potential zones can be said to be water bearing formation of the earth crust that acts as conduits for transmission and as reservoirs for storing water. Its identification and location is based on indirect analysis of some observable terrain features such as geologic, geomorphic, landforms and their hydrologic characteristics.

Conventional approach of groundwater exploration using geological, hydrogeological, and geophysical methods are expensive due to high cost of drilling and time consuming investigation [3,4]. Furthermore, these methods of surveys do not always account for the different factors that control the occurrence and movement of groundwater [5]. Remote sensing technique is popular due to several advantages of spatial and spectral data, having access to large coverage and inaccessible areas with regular revisit capability [6]. It is also rapid and cost-effective tool that integrates valuable data on geology, geomorphology, lineaments, slope, morphometric etc. that helps in evaluating groundwater potential zone.

The use of remote sensing and GIS techniques is a fast emerging field in groundwater resource identification, mapping and planning. Remote sensing provides an opportunity for better observation and more systematic analysis of various geomorphic units, landforms, lineaments and drainages, due to its synoptic and multi-spectral coverage of a terrain [7]. The techniques is increasingly used in prospecting for groundwater potential zones, because of their ability to identify and outline different ground features that may serve as direct or indirect indicators of the presence of groundwater resources [8].

Reviewed papers on the application of remote sensing and GIS in groundwater potential mapping can be found in [9,10,11,12,13] More recent studies have been carried out on the use of remote sensing data and GIS tools for defining the spatial distribution of different groundwater prospecting classes on the basis of hydrogeomorphological units and other associated parameters [14-20]. In this study the technique of remote sensing data and GIS were used to evaluate the

hydrogeomorphological characteristics of the study area and demarcate the groundwater potential zones for investigation and exploration of the resource in shallow aquifer using thematic maps of geomorphologic units, slope, drainage density and lineaments density. Result obtained from this analysis will help to narrow down the targeting area for further geophysical exploration for the resource.

## 2. Study Area

Geologically the study area is situated in the Vindhyan basin in Central India. It falls within the survey of India toposheets 63L/9, 63L/10, 63L/13, 63L/14 located in the southern part of Uttar Pradesh state, bounded by 82° 40' – 83° 00' east of longitude and 24° 40' – 24° 50' north of latitude (Figure 1). The relief ranges from 250 m over the plains to the highest elevation of 389 m. It is underlain by the Kaimur Group of the Vindhyan Supergroup. The series comprises of sandstones and quartzites which are prominent horizons with wide distribution. All the major sandstone horizons form the scrap while the shale horizons form gentle slopes [21]. The area is covered by thin surface soil with varying thickness ranging from 1-4m and few exposures of sandstones rocks [22]. The bedrock (Vindhyan Super Group of rocks) is expected below the surface soil cover since the study area is lying in close vicinity of the Vindhyan exposures. The area is mainly flat and gently undulating terrain except in few parts. The occurrence and movement of groundwater is mainly restricted within the weathered and fractured sandstone/shale [23]. The amount of water that can be extracted from the fractured zones depends on the size and location of fractures [24].

The climatic condition comprises of a mean temperature ranging from 4.4°C in January to above 46.6°C in May. The rainfall is uncertain and erratic with about 84 percent of the annual rainfall in the monsoon period, with an annual average of about 1,530 mm. The area is covered by the Kaimur hills which constitute the greater part of the tableland. The Soils of the area are excessively drained, highly permeable and have low to medium productivity. The red soil is comprised mainly of red loam and is very easy for cultivation purposes and responds to good manure and other treatments. This soil is particularly suited for growing vegetables. Patches of laterite soil are found all over the area.

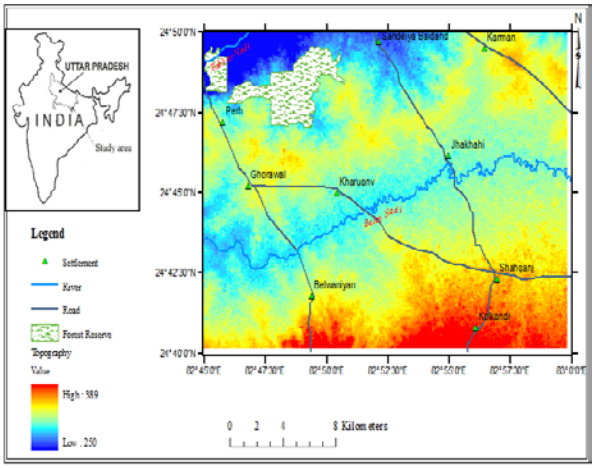


**Figure 1.** Location and topographic map of the study area

## 3. Material and Methods

Remote sensing data which comprises of 90 m interval Shuttle Radar Topographic Mission (SRTM), Digital Elevation Model (DEM) and Landsat image along with Survey of India (SOI) toposheets and field observation data were used in this study.

The methodology includes generation of thematic maps showing drainage pattern, lineament, slope and geomorphologicic units through processing and visual interpretations of remote sensed data. The identification and delineation of various units on the thematic maps was based on tone, texture, shape, colour etc. Thematic layers of geomorphologic units, slope, lineament and drainage density were generated and integrated in GIS environment to determine suitable zones for groundwater prospecting.

## 4. Hydrogeomorphological Analysis

The relief, slope, depth of weathering, type of weathered material, thickness of alluvium, nature of the deposited material and the overall assemblage of different landforms play an important role in defining the ground water regime, especially in the hard rocks and the unconsolidated sediments [7]. Hydrogeomorphological investigations include the delineation and mapping of various landforms, drainage characteristics and structural features that could have a direct control on the occurrence and flow of groundwater. Many of these features are favourable for the occurrence of groundwater and are classified in terms of groundwater potentiality as poor, moderate, good and very good prospecting zones [25,26,27].

## 5. Result and Discussion

The result of the study have brought out five distinct geomorphic units (Figure 2), which are discussed systematically here with respect to groundwater prospect;

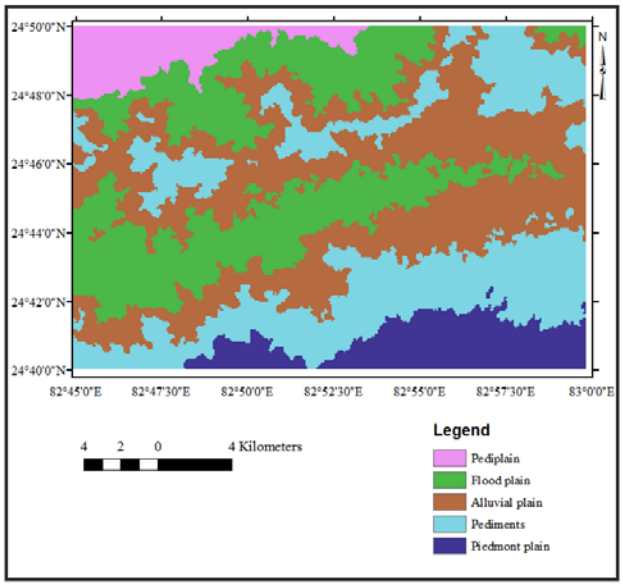


**Figure 2.** Map of geomorphic units of the study area

### 5.1. Piedmont Plain

Piedmont plain are gently sloping longitudinal strip of land running parallel to foot hills traversed by innumerable rivulets with parallel to sub-parallel drainage; comprising of unconsolidated sediments of sand, silt and clay with boulders and pebbles. This unit covers a total area of 39.43 $km^2$, which is about 8.5 % of the study area and are mainly found in the southern part of the study area at an elevation of above 313 m above msl. The groundwater prospect of this unit is generally poor, but moderate prospect can be expected where fracture/lineament are located.

### 5.2. Pediments

Pediments are gently sloping rock flooring areas with erosional bedrock of low relief between hills and plains developed by the process of weathering and consisting of a veneer of detritus, alluvial sand and gravel that thickens downslope. They show massive and compact rocky nature surfaces, with numerous fractures/joints permitting infiltration and storage of groundwater [26]. In the continuous process of pedimentation, when pediment gets buried by detritus and regolithic cover, it is termed as a buried pediment in which the sub-surface rock subsequently undergoes weathering. Groundwater prospecting in pediments can be considered as moderate to poor, but the presence of lineaments or fractures can provide some good scope for groundwater prospecting. This unit occupies 25.9 % of the study area with a total area of about 129.21 $km^2$ found in the southern part with some patches towards the north that flanks from west to east of the study area.

### 5.3. Alluvial Plain

This is a gently sloping plain that consist of thick unconsolidated sediments comprising mostly of loamy soil formed by fluvial action. It shows smooth texture and extensive agricultural activity. It is classified as shallow and deep alluvium plain depending on the thickness of the unconsolidated material. It acts as a good recharge zone and as such represent a good to very good potential zone for groundwater exploration depending on the thickness of the alluvium and the weathered column underlying the formation.

The unit occupies an area of about 157.82 $km^2$ which represent 34.0 % of the total study area. It mainly occupied the central portion of the map

### 5.4. Flood Plain

This consists of unconsolidated sediments of sand, silt, clay with kankar layers mixed with cobbles and pebbles, gravels and alluvial materials derived from surrounding uplands and deposited by fluvial action along the floor of river channels. It is highly permeable zone helping the partial bank recharge, while the flow of subsurface groundwater occurs under semi-confine to perched water table condition [28]. The unit occupies the central part of the survey area just along the course of the main river (Bellan Nadi) that cuts across the study area and some occupying an area up north. The unit covers a total area of about 118.83 $km^2$ which is about 25.6% of the study area and is considered as very good groundwater potential zone.

### 5.5. Pediplain

This is a generally flat and smooth surface of weathered pediplain of granite gneiss weathered material usually covered with red soil. In hard rocks, this landform forms very good recharge and storage zones depending upon the thickness of the weathering/accumulated material and its composition [29]. Moderate to good yields are expected in this geomorphic unit. Faults/ fracture zones passing through this unit act as conduits for movement and occurrence of ground water. Good yields are expected along these fractures/lineaments. The unit is made of 5.9 % of the total study area covering an area of about 27.44 $km^2$ at the north-western end of the map.

## 6. Lineaments Density Map

A lineament is usually defined as a straight or somewhat-curved feature in an image. In a satellite image, lineaments can be the result of man-made structures such as transportation networks (roads, canals, etc.), or natural structures such as geological structures (faults/fractures, lithological boundaries, unconformities) or drainage networks (rivers). Generally lineaments are underlain by zones of localized weathering and increased permeability and porosity. Previous studies have revealed a close relationship between lineaments and groundwater flow and yield [30,31]. Meanwhile, some researchers studied relationships between groundwater productivity and the number of lineament within specifically designated areas or lineament density rather than the lineament itself [32]. Therefore mapping of lineaments closely related to groundwater occurrence and yield is essential to groundwater surveys, development, and management.

Lineaments are usually extracted and interpreted from satellite imagery manually or automatically. PCI-Geomatica Version 10 software was used in this work to automatically extra lineament from satellite image of the survey area. The extracted linear features were further screen for non-geological features such as roads, fences, field boundaries, by comparing the lineament map with the corresponding toposheet map of the survey area and field verification, thereby deleting non-geological features and leaving only possible geological lineament (Figure 3a). Lineament density map was prepared by dividing the study area into 1 km/1 km grids. The total length of lineament in each grid was measured and plotted in the respective grid centres. These values are joined by isolines to prepare a lineament density map as shown in Figure 3b. The extension of large lineaments representing a shear zone or a major fault and can extend from hilly terrain to alluvial terrain [27]. It may form a productive groundwater reserve. Similarly intersection of lineaments can also be probable sites of groundwater accumulation. Therefore, areas with high lineament density may have important groundwater prospects even in hilly regions which otherwise have nil groundwater prospects than area with low density.

## 7. Slope

Slope analysis is an important parameter in geomorphic studies. The slope elements, in turn are controlled by the

climatomorphogenic processes in the area having the rock of varying resistance [33]. Slope plays a key role in groundwater occurrence as infiltration is inversely related to slope [34]. Slope map of the survey area was generated from DEM data using spatial analyst tool in ArcGIS. The slope varies between zero and 24 degree (Figure 4). Area of high slope value will cause more runoff and less infiltration thus, have poor groundwater prospect compared to low slope region.

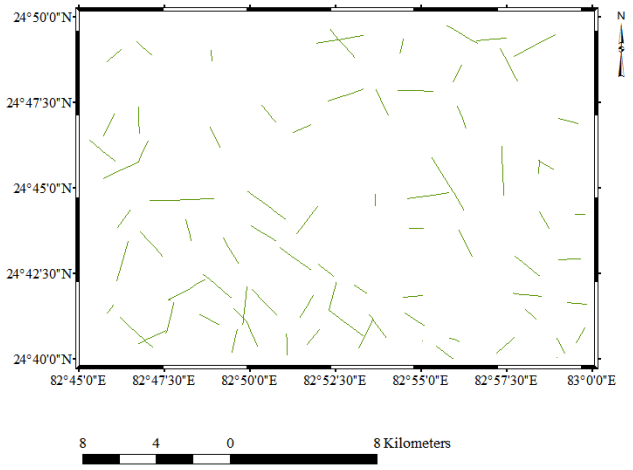


**Figure 3a.** Lineament map of the study area

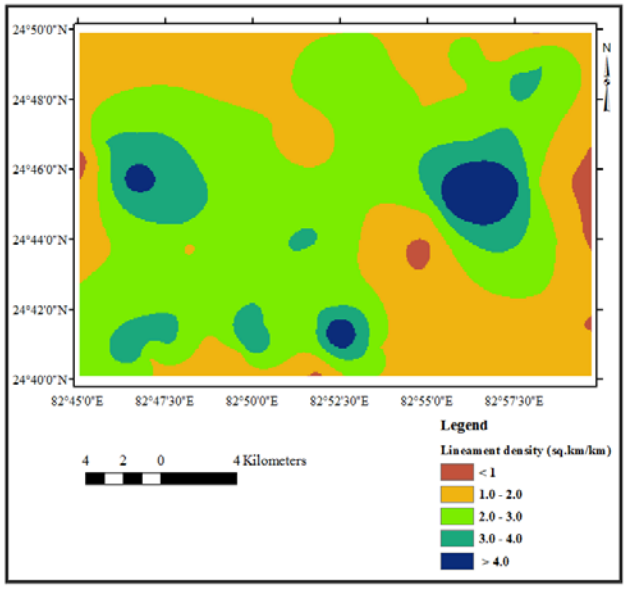


**Figure 3b.** Lineament density map of the study area

## 8. Drainage Density Map

The drainage is expressed as density map for easy characterization of runoff and infiltration of rainwater in the survey area. The drainage density map was prepared in similar way as the lineament density map by dividing the study area into 1 km/1 km grids. The total length of stream in each grid was measured and plotted in the respective grid centres. These values are joined by isolines and the resultant density map was plotted in arcgis (Figure 5).

Drainage density is an inverse function of permeability, and therefore it is an important parameter in evaluating the groundwater zone [34]. Area of high drainage density indicates less infiltration which favours runoff and hence acts as poor groundwater prospect, because major part of the rainwater over the area is lost as surface runoff with little infiltration for recharging the groundwater reservoir. On the other hand low drainage density areas permit more infiltration and recharge to the groundwater reservoir, hence can be described as a good potential zone for groundwater prospect.

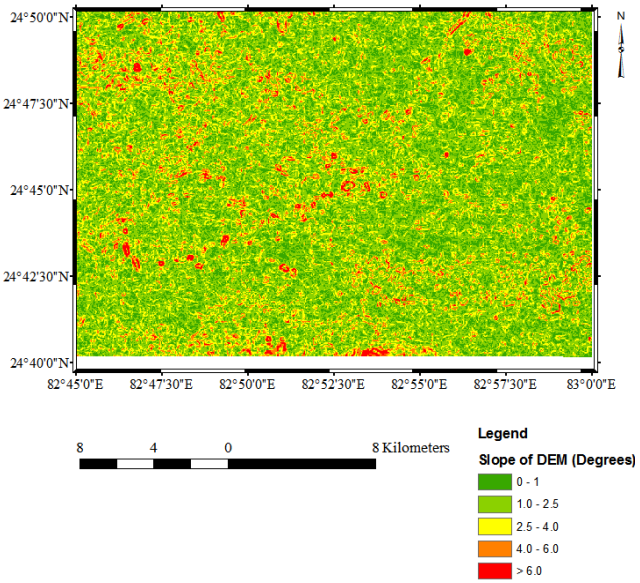


**Figure 4.** Slope map of the study area

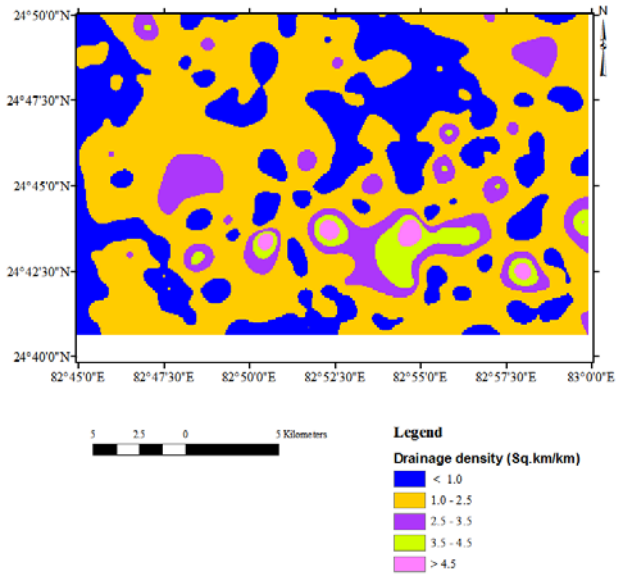


**Figure 5.** Drainage density map

## 9. Mapping Groundwater Potential Map

In this study the weighted index overlay analysis (WIOA) using a multi-criteria approach was used to investigate the potential zone for groundwater prospecting through integration of hydrogeomorphological map, slope, lineament and drainage density map. All the thematic maps generated for the study area were integrated and projected to a common co-ordinate system through spatial analysis in ArcGis and reclassified for weighted index

overlay analysis (WIOA). The weighted index overlay analysis is a technique that applies a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis using a multi-criteria approach. This analysis according to [35] has no standard scale, but incorporates human judgment for its efficiency. For this work, each of the thematic maps was assigned a weight that represents its importance in respect to groundwater reserve based on criteria of previous work [35,36,37].

Theme weight and class rank assigned to the different parameters considered for groundwater prospects evaluation in this study are given in Table 1.

**Table 1. Weightage and class rank of different parameters used for groundwater prospects**

| Theme | Classes | Rank | Weight |
|---|---|---|---|
| Hydrogeomorphologic unit | Piedmont | 1 | 35 |
| | Pediments | 2 | |
| | Alluvial plain | 4 | |
| | Flood plain | 4 | |
| | Pediplain | 3 | |
| | | | |
| Slope | 0 - 1 | 1 | 20 |
| | 1 – 2.5 | 2 | |
| | 2.5 - 4 | 3 | |
| | 4 - 6 | 4 | |
| | >6 | 5 | |
| | | | |
| Drainage | 0 - 1 | 5 | 15 |
| | 1 – 2.5 | 4 | |
| | 2.5 – 3.5 | 3 | |
| | 3.5 – 4.5 | 2 | |
| | >4.5 | 1 | |
| | | | |
| Lineament | <1.0 | 1 | 30 |
| | 1.0 – 2.0 | 2 | |
| | 2.0 – 3.0 | 3 | |
| | 3.0 – 4.0 | 4 | |
| | >4.0 | 5 | |

The groundwater potential map of the study area is shown in Figure 6. The groundwater potential zones were grouped into five different potential zones viz; very high, high, moderate, poor and very poor. Analysis of the potential zones shows that the very high groundwater potential zones constitute just less than 1 % of the study area. Few patches of this zone were observed at areas associated flood plain geomorphologic unit in the central and north-eastern end of the map. High groundwater potential zones are seen at the central towards the northern part and constitute 35.51 % of the study area. This zone is associated with geomorphologic flood and alluvial units and part of the pediments with high lineament density in the southern part f the map. Moderate groundwater potential zones occupy the largest area of about 54.53 % of the total study area, scattered all over the map. The poor and very poor potential zone constitute about 9.13 % of the study area and are mostly seen along denudational hills with steep slope and part of the alluvial and pediments units that are associated with high drainage density.

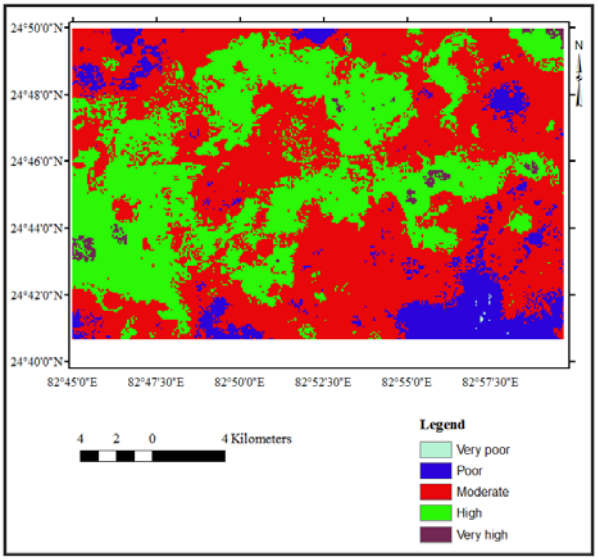


**Figure 6.** Map of groundwater potential zone.

## 10. Conclusion

The study area was able to reveal the use of remotely sensed data in identifying favourable zones for groundwater exploration in hard rock terrain. Groundwater prospects zonation based on this study clearly indicated that the combination of flood plain, alluvial plains, lineament and gentle slope areas are the favourable terrain conditions having good groundwater potential. Pediplain zones have much better prospects as compared to pediments and piedmonts regions due to their colluvial material composition, moderate drainage density, moderate slope and the existence of lineaments/fractures.

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