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Assessment of Groundwater Potential Zones Using Analytic Hierarchy Process a Case Study of Damoh District of Madhya Pradesh India

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Abstract Locating prospective ground water reservoir zones is difficult, especially in arid places and hilly locations. In the twenty-first century, satellite remote sensing may hold new potential for locating surface and subsurface water resources in less time and at a lower cost. The current study was conducted to identify groundwater potential zones in drought-prone areas of the Damoh district of Madhya Pradesh, India. The hydrogeomorphology, lithology, slope, drainage density, lineaments density, land use/land cover, and soil surface factors were employed in this study, which was based on remote sensing and geographic information systems. Analytical Hierarchical Process (AHP) was used to assign weightages to the factors, and distinct classes within each parameter were prioritized according to their relative relevance for groundwater potentiality. The study classified several groundwater potential zones as Very-High, High, Medium, Low, and Very Low. Corresponding from Very Low to Very High the potential zones were found to be 1%, 20%, 34%, 43%, and 2%, of the study area respectively. As a result, the findings may be useful. It is possible to conclude that the current technique, which employs AHP with expanded parameterization, has a greater chance of accurately identifying and mapping of groundwater potential zones, and that it may be used to reduce drought risk in abroader region.

Keywords: *groundwater potential zone, analytic hierarchical process (AHP), GIS technique*

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1. Introduction

Nowadays ground water is not only the main source of drinking water but it is also used for irrigation purposes. In India, it becomes very difficult to meet the increasing demand induced by the growing population and socio-economic development through the present ground water resources [1]. The depletion of groundwater levels is not a new account in central India but it has been continued for at least a decade. The demand of annual water increases because of agricultural and industrial activities. It adds to the depletion of groundwater resources and the arid climate aggravates the situation. These resources are scarce in nature, as the hydro geologic system characterization and artificial recharging of aquifers might help to solve the problem to some limit. In water resources management the practice of artificial recharging is increasingly emerging as a powerful tool [2]. The formation of water bearing earth's crust act as conduits for transmission and also as reservoirs for storing water. The occurrence of groundwater in a geological formation and the scope for its exploitation primarily depends on the formation of porosity. Topographical depressions increase infiltration. Whereas high relief and steep slopes impart higher runoff. On the other hand, surface water bodies like rivers, ponds, etc., can act as recharge zones. A large volume of data from various sources requires for a groundwater developing program. Therefore, identification and quantization of these features are important for generating a groundwater potential model of a study area. At present, groundwater is gaining more attention due to drought problem, rural water supply, irrigation project and low cost of development. Despite the extensive research and technological advancement, the study of groundwater has remained risky, as there is no direct method to facilitate observation of water below the surface [3,4,5]. Groundwater is known to be a dynamic and renewable natural resource but in hard rock landscape like red and lateritic zones availability of groundwater is limited. Damoh experience a wide range of temperature and erratic rainfall agriculture is mostly rain fed. Due to its low water holding capacity, excessive drainage, surface runoff and high soil-erosion the red lateritic zones are highly susceptible to any change of weather parameter. At the time of summer most of the surface water sources like ponds, streams, etc. dry up completely and groundwater stands as the only option for the water supply. The variability of rainfall and lack of irrigational facility, cultivation becomes challenging and severely affects the level of ground water. One of the most reliable and standard methods for determining locations, the thickness of aquifers and other subsurface information could be test drilling and stratigraphic analysis. These approaches for this analysis are expensive, time-consuming and needs skilled manpower. Numerous techniques for delineating groundwater potential zones (GWPZ) such as frequency ratio, random forest model and logistic regression model have been adopted and implemented by various researchers. The researcher can conclude that, analytic hierarchy process (AHP) based on remote sensing and GIS is considered as a simple, effective, reliable, and also a cost-effective technique. Due to the paucity of studies involving an integrated approach the present study was conducted to delineate the GWPZs in the study area using the parameters like hydro- geomorphology, slope, lineament, drainage density, landuse/land cover and lithology [6].

2. Study Area

Damoh is a district of Madhya Pradesh State located in Central India. The district is part of Sagar Division. It is situated in the north-eastern part of the State and geographically located at 23°09’ north latitude and 79°03’ east longitude. The shape of the district is irregular and elongated from North to South with projection in the East and West. [7] It is at an average elevation of 595 meters (1,952 ft). The district of Damoh has an area of 7,306 square km (2,821sqmi). [8] During the southwest monsoon season, which runs from June to September, Damoh district receives the most rainfall. The average maximum temperature in May is 42.0°C, while the average lowest temperature in December/January is 9.7°C. Damoh district's average annual maximum and lowest temperatures are 32.6°C and 18.9°C, respectively. The average annual rainfall of Damoh district is 117.30 cm. During the monsoon season, 90.4 percent of the yearly rainfall is obtained. Between October and May, just 9.6 percent of the yearly rainfall occurs. Surplus water for groundwater recharge is thus only accessible during the southwest monsoon season. As a result, most rivers are depleted of water before the summer season begins. Most of the water is stored as ground water in the soil. The total irrigated area is 118600 hectares, of which 14400 hectares (12.1 percent of the total irrigated area) is irrigated through canals, 800 hectares (0.6 percent of the total irrigated area) is irrigated through minor irrigation tanks, 28300 hectares (23.7 percent of the total irrigated area) is irrigated through open wells, 29800 hectares (25.3 percent of the total irrigated area).

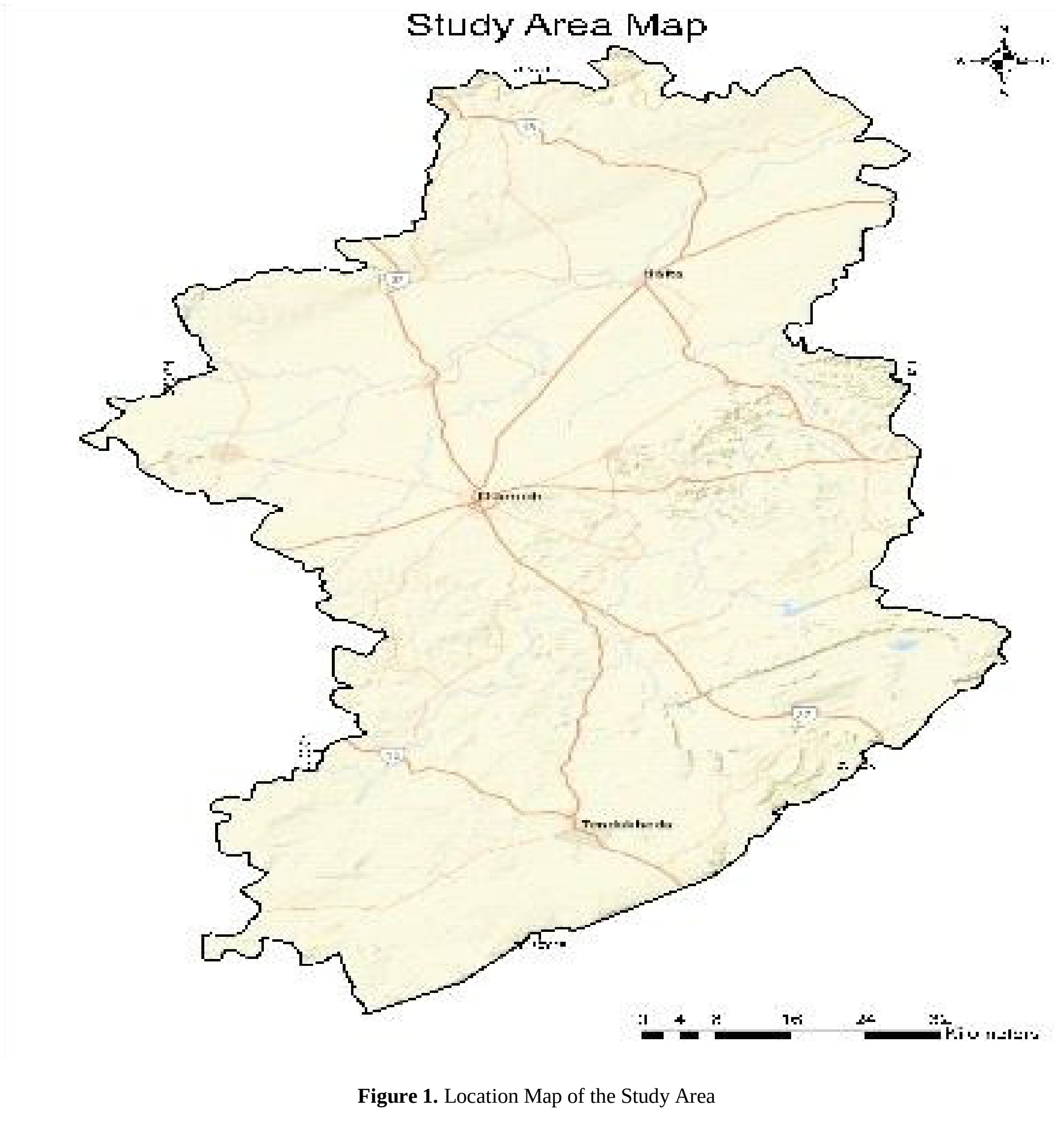

Figure 1. Location Map of the Study Area

3. Data Used

From satellite data and existing maps, six distinct types of thematic maps for geomorphology, lineament, slope, land use/land cover, drainage density, and Lithology were created for the current research region. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) Digital elevation model (DEM) at 30-m spatial resolution was acquired from United States Geological Survey Earth Explorer to create elevation, slope, and drainage density maps (earthexplorer.usgs.gov). The Geological Survey of India provided the geological map (GSI). The Survey of India provided topographical maps (Nos. 73 I/11, 73I/12, 7I/15, and 73I/16). LISS-IV (Lin- ear image sensing sensor) pictures with a spatial resolution of 5.8 m were used to create land use/landcover and Lithology maps.

4. Methodology

The process for determining groundwater potential zones are depicted in Figure 2. Groundwater availability is influenced by six thematic layers (Hydrogeomorphology, Slope, Lineament Density, Drainage Density, Land Use/Land Cover, and Lithology) (Mukherjee et al. 2012; Agarwal et al. 2013). The GWPZs were created by superimposing all of the thematic layers using the weighted overlay technique [5].

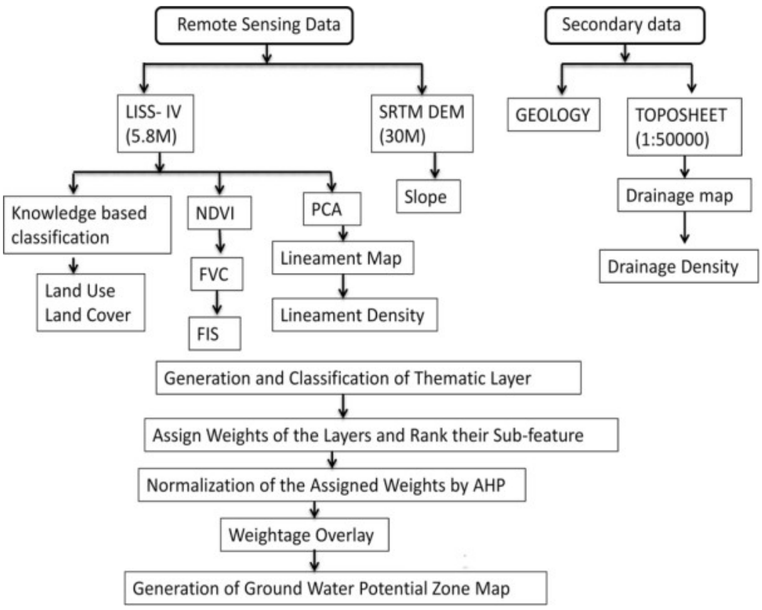

Figure 2. Methodology flow Chart

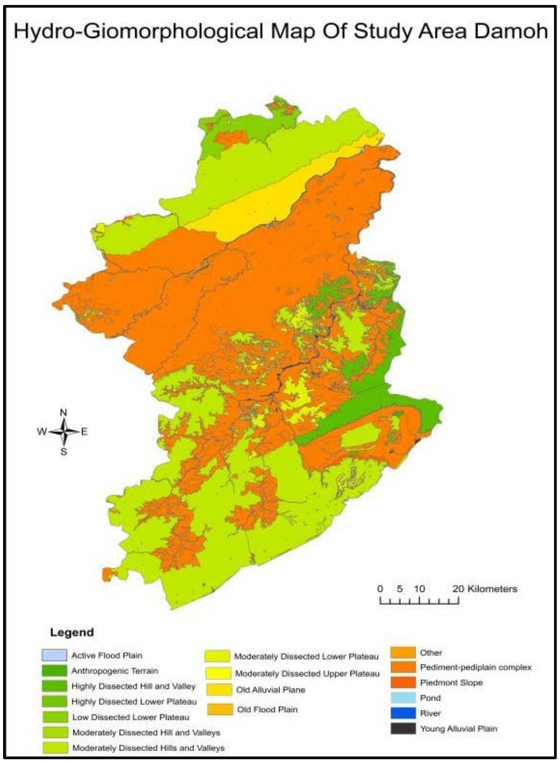

Figure 3. Hydro-geomorphological map of study area Damoh M.P India

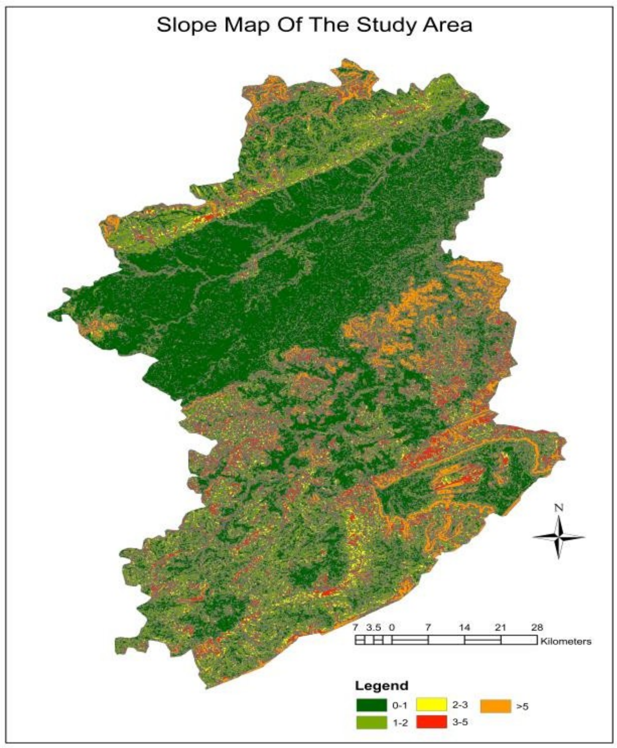

Figure 4. Slope map of study area Damoh M.P India

4.1. Creation and Categorization of Thematic Layers

4.1.1. Hydrogeomorphology

At https:/bhukosh.gsi.gov.in a full map of Hydro geomorphological features with properties such as active flood plains and Young Alluvial plane is accessible. The relevant Geomorphology data is bulk extracted from the complete Geomorphology Map of India using ArcGIS' clip feature.

4.1.2. Slope

Using the spatial analysis tool in Arc- GIS10.3 software, [5] the slope map was created using the SRTM digital elevation model [6].

4.1.3. Lineament Density

A lineament is a geographical aspect that is the result of an underlying geological form, like a fault. A fault-aligned valley, a sequence of fault or fold-aligned hills, it can also be a straight shoreline, or a combination of these characteristics. All of the above examples are called lineaments. A hill shade map is created by using the Spatial Analysis Tool in the Arc toolbox, We detect and designate these Lineaments utilizing a manual digitizing process with the use various Hill shading maps, and editing tools in ArcGIS a Lineament Density Map is created.

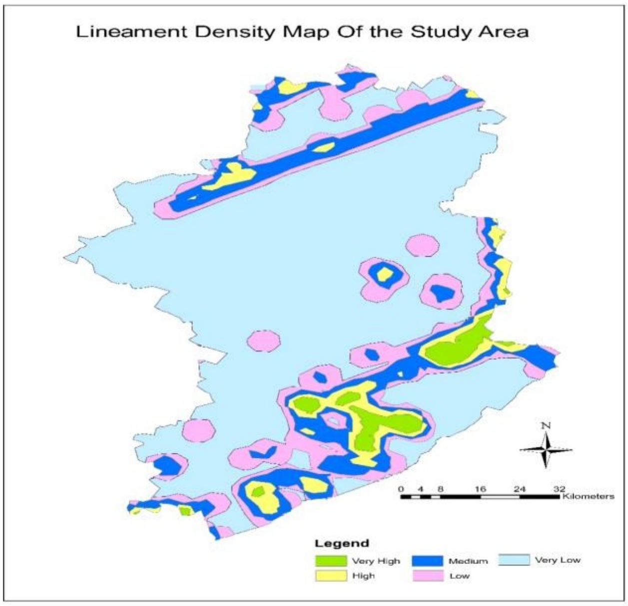

Figure 5. Lineament Density map of study area Damoh M.P India

4.1.4. Drainage Density

For Drainage Density Map ArcGIS's automated drainage extraction approach is used. In this procedure, we use the Spatial Analysis Tool – Hydrology Tool where the Input Surface Raster is the clipped SRTM DEM of the study Area .In the following steps a flow direction map is created The flow direction output is used as the input for flow accommodation further for conditional and stream order map and finally drainage density map is created.

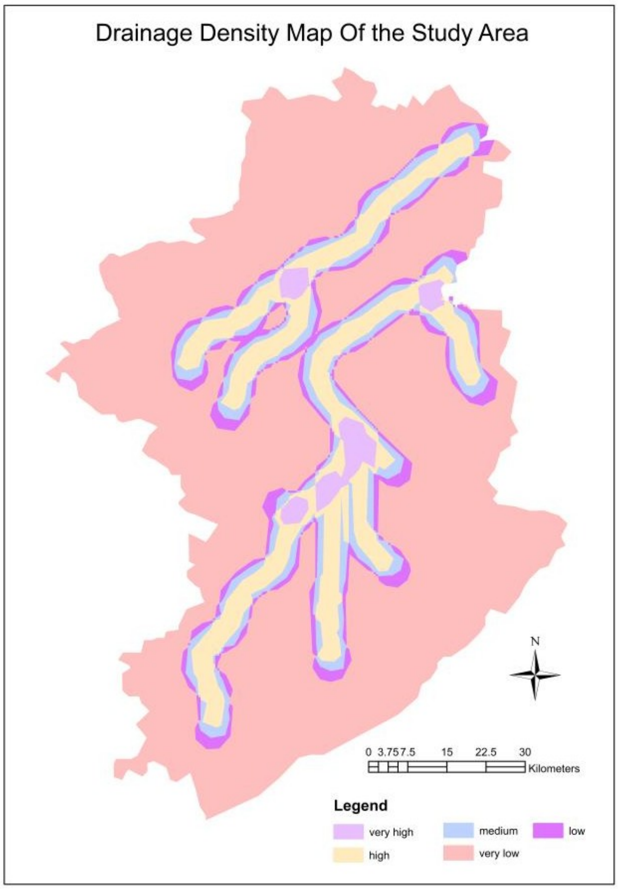

Figure 6. Drainage Density map of study area Damoh M.P India

4.1.5. Land use-Landcover

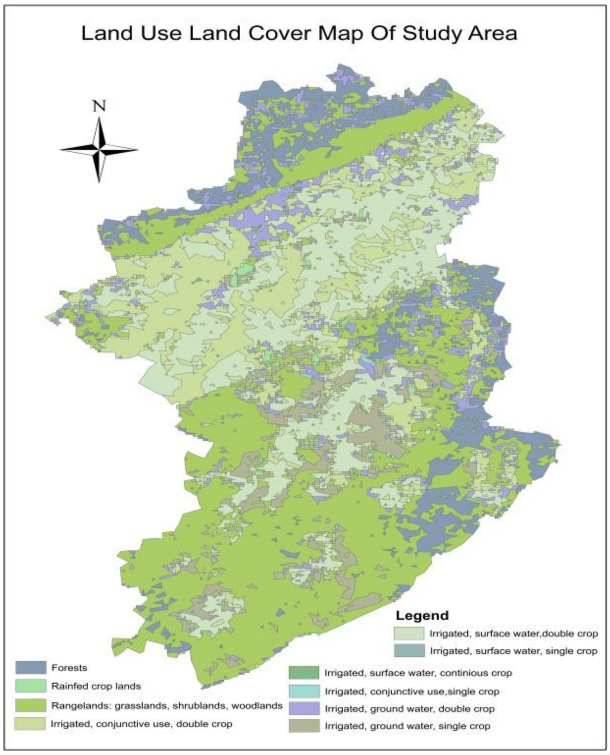

Figure 7. Land use - Landcover map of study area Damoh M.P India

For The surface cover whether it be plant, urban infrastructure, water, bare soil, is referred to as land cover. Land cover identification, delineation, and mapping is important for global monitoring, studies and cannot be overstated. A full map of Land Use and Land Cover characteristics, including Forest Cover. Coverage of vegetation Irrigation fields of the whole Indian subcontinent are available online at https:/bhukosh.gsi.gov.in the form of closed polygons. The needed Land Use Land Cover map is bulk extracted from the whole Land Use Land Cover map of Indiausing ArcGIS' clip feature.

4.1.6. Lithology

A lithological map is a map that defines the gross physical characteristics of a rock or rock formation. A full map of lithology and rock type, including features such as rock type and availability areas, is accessible online at https:/bhukosh.gsi.gov.in the form of closed polygons for the entire Indian subcontinent. The relevant Lithological data is extracted by mass from the entire Lithological and Mineral map of India using the clip function in ArcGIS.

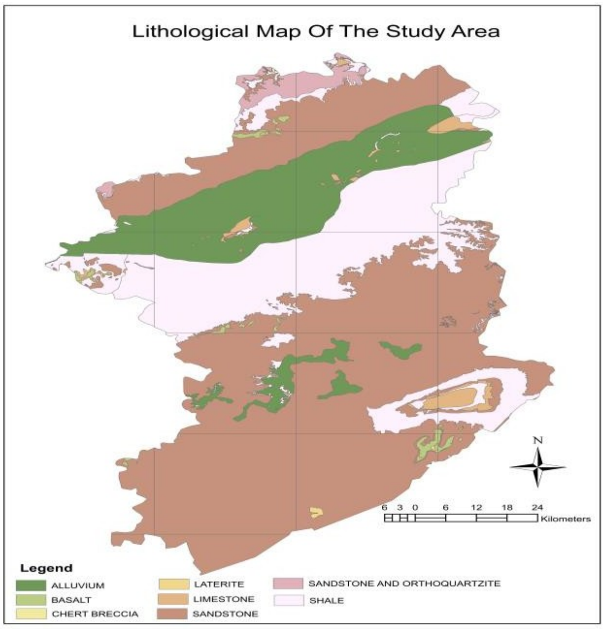

Figure 8. Density map of study area Damoh M.P India

4.1.7. Soil

A soil map is a geographical representation that depicts the variety of soil types and/or soil attributes (soil pH, textures, organic matter, horizon depths, and so on) in each region. A soil map, is usually the ultimate result of a soil survey inventory. A detailed map of soil, including soil type and availability areas, is available online at https://bhukosh.gsi.gov.in the form of closed polygons for the whole Indian subcontinent. The relevant soil data is bulk scraped from the full soil map of India using the clip function of ArcGIS. Only two types of soil are identified in our research location.

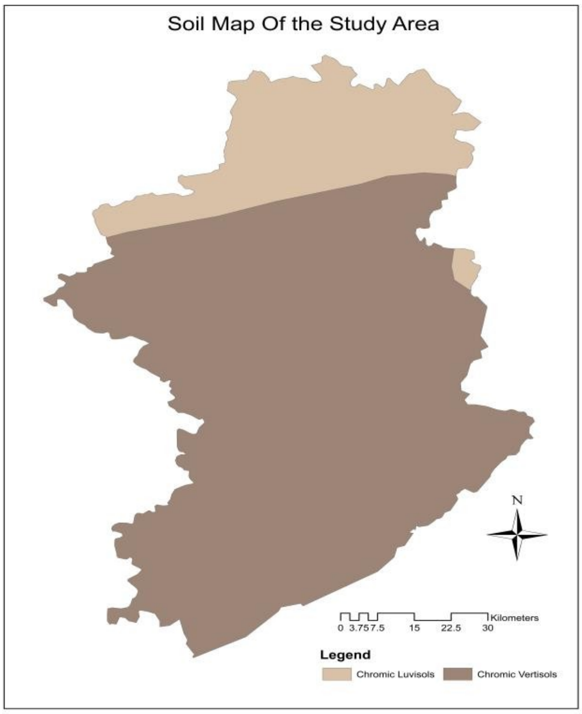

Figure 9. Soil Map Of the Study Area

4.2. Assigning Ranks and Weightages

- The groundwater potential zones were evaluated using a weighted overlay technique that included all other geographical layers.
- Individual spatial layers were reclassified to a uniform rank of 1–7, with 1 representing poor groundwater potential and 7 representing excellent groundwater potential [5], prior to the overlying operation.
- AHP-based pairwise comparisons matrix was used to allocate weights (Table 1).
- While assigning weightages for sub parameters ranks for individual spatial layers were reclassified to a rank of 1–5, where 1 represents poor groundwater potential and 5 represents excellent groundwater potential.
- The ranks were assigned to the respective parameters considering the field survey experiences, stakeholder consultation, and expert opinion surveys as well as consulting the existing literature. [5]

After all the ranks being assigned to the variables and sub-variables the individual weightages are being multiplied to the rank and finally multiplied to hundred to fine the total weightage of the sub-variable.

- The Table 2 shows the weightage calculation of sub-variables

Table 1. Weightage Calculations of Variables

Sno	Factor	HG	LD	LI	SL	SO	LU	DD	Weightage
1	HG	7	6	5	4	3	2	1	0.39
2	LD	3.5	3	2.5	2	1.5	1	0.5	0.19
3	LI	2.33	2	1.67	1.33	1	0.67	0.33	0.13
4	SL	1.75	1.5	1.25	1.00	0.75	0.50	0.25	0.10
5	SO	1.4	1.2	1	0.80	0.60	0.40	0.2	0.08
6	LU	1.17	1	0.83	0.67	0.5	0.33	0.17	0.06
7	DD	1	0.86	0.71	0.57	0.43	0.29	0.14	0.055
	TOTAL	18.15	15.56	12.96	10.37	8.11	5.19	2.59	1

Table 2. Weightage Calculations of Sub-Variables

FACTORS	WEIGHT	RANK	TOTAL WEIGHTAGE
GEOMORPHOLOGY			
Active Flood Plain	39	5	195
Anthropogenic Terrain		4.23	164.97
Highly Dissected Hilland Valley		2	78
Highly Dissected LowerPlateau		3	117
Low Dissected LowerPlateau		1	39
Moderately DissectedHill and Valleys		1.6	62.4
Moderately DissectedLower Plateau		1	39
Moderately DissectedUpper Plateau		1	39
Old Alluvial Plane		3	117
Old Flood Plain		4.12	160.68
Other		1	39
Pediment-pediplaincomplex		2.78	108.42
Piedmont Slope		2	78
Pond		5	195
River		5	195
Young Alluvial Plain		5	195
FACTORS	WEIGHT	RANK	TOTAL WEIGHTAGE
LINEAMENT DENSITY			
Very High	19	5	95
High		4	76
Medium		3	57
Low		2	38
Very Low		1	19
FACTORS	WEIGHT	RANK	TOTAL WEIGHTAGE
LITHOLOGY			
ALLUVIUM	13	5	65
BASALT		2.94	38.22
CHERT BRECCIA		1	13
LATERITE		1.47	19.11
LIMESTONE		2	26
SANDSTONE		2	26
SANDSTONE AND ORTHOQUARTZITE		2.7	35.1
SHALE		4.45	57.85
FACTORS	WEIGHT	RANK	TOTAL WEIGHTAGE
SLOPE			
2 to 3	10	5	50
3 to 4		4	40
4 to 5		3	30
above 5		2	20
FACTORS	WEIGHT	RANK	TOTAL WEIGHTAGE
SOIL			
Chromic Luvisols	8	2	16
Chromic Vertisols		4	32
FACTORS	WEIGHT	RANK	TOTAL WEIGHTAGE
LANDUSE LAND COVER			
Forests	6.5	1.12	7.28
Irrigated, conjunctiveuse, double crop		4.8	31.2
Irrigated, conjunctiveuse, single crop		4.45	28.925
Irrigated, ground water,double crop		4.8	31.2
Irrigated, ground water,single crop		4.8	31.2
Irrigated, surface water,continious crop		5	32.5
Irrigated, surface water,single crop		5	32.5
Irrigated, surface water,double crop		5	32.5
Rainfed crop lands		3	19.5
grasslands, shrublands,woodlands		2.5	16.25
FACTORS	WEIGHT	RANK	TOTAL WEIGHTAGE
Drainage density			
Very High	6	5	30
High		4	24
`Medium		3	18
Low		2	12
Very low		1	6

4.3. Discussion

4.3.1. Hydrogeomorphology

Hydrogeomorphology, which is influenced by landform, lithology, and underlying rock structure, influences groundwater potential and prospect. The prevailing stony topography, undulating surfaces, and erosional and depositional hydro-geomorphic processes define the studied region

4.3.1.1. Structural Hills

These are rocky wide uplands with a noticeable height change. It was discovered that the soil was quite shallow and coarse loamy. It is largely covered with open to deep woodland and plantation, making it unsuitable for cultivation or orchards. The hills serve as high run-off zones for groundwater, resulting in poor infiltration mostly owing to moderately steep to extremely steeply slopes.

4.3.1.2. Valley Fills

These are rocky wide uplands with a noticeable height change. It was discovered that the soil was quite shallow and coarse loamy. It is largely covered with open to deep woodland and plantation, making it unsuitable for cultivation or orchards. The structural hills serve as high run-off zones for groundwater, resulting in poor infiltration mostly owing to moderately steep to extremely steep hill slopes.

4.3.1.3. Buried Pediment (Moderate)

The modest buried pediment has a gradual slope. Over this landform, somewhat deep clay to fine loamy soil with fine texture was noted. Buried pediment (moderate) is best used for a single crop with Rabi crops that are mediocre. In this area, groundwater possibilities are similarly limited. [6]

4.3.1.4. Buried Pediment (Shallow)

The geography in this area is essentially level to gradually slope. It has a shallow to fairly deep loamy soil with a weathered zone on top. With the presence of worn rocky outcrops, the soil texture is coarse. A single crop can also be grown in this area. The region's groundwater prospects are modest to poor. Hydrogeomorphology is one of the key criteria utilized frequently for the definition of groundwater potential zones. [5] It gives information about the distribution of various landforms and topography of a region. The research area's structural hills and inselberg region have sharp yet rough tops, indicating that erosion affects the high surface runoff of the highest sections of the hills. It all started with a very shallow, gritty loamy soil. The lower plateau with valley fill, on the other hand, is found in the river basin's midland and lowland sections, with fine-textured, relatively well-drained loamy to clayey soil. As a result, valley fill is the greatest landform (highest rank) for high groundwater potential, whereas structural hill is the worst (lowest rank). [6]

4.3.2. Slope

In general, flat, and moderately sloping sites have high infiltration and may replenish more groundwater; steeply sloping grounds, on the other hand, encourage significant run-off and little or no infiltration. The slope of the research area varies from 0 to 30 degrees, Slopes of gentle to moderate (0–1°) and steep (> 3°) covered 50% and 20% of the blocks, respectively. Owing to an essentially flat or mild slope associated with high infiltration and low runoff, the class with the lowest slope value is given the highest rank, while the class with the greatest slope value is given the lowest rank due to comparatively high runoff and low infiltration. [5,6]

4.3.3. Lineament

Fractured zones with excellent porosity and permeability are projected to be the most common geological linear features. The area's lineament disposition provides vital information regarding subsurface cracks that may affect groundwater circulation and storage. In the research region, ESE–WNW/EW, NE–SW and NW–SE, N–S/NNE–SSW trending fractures, joints, or lineaments were mostly detected. Areas having a high degree of lineament Due to good porosity and infiltration, areas with a high lineament density (2.5–3.5 km/km2) are considered to have good groundwater potentiality and are assigned a higher rank; however, areas with a low lineament density (0–0.5 km/km2) are considered to have poor groundwater potentiality and are assigned a lower rank. [5,6] As illustrated in Figure 5, the entire region is divided into Five groups based on lineament density.

4.3.4. Drainage Density

Drainage density is determined by the channel spacing and surface properties [9]. Quantifying drainage density and kind of drainage provides information on run-off, infiltration, relief, and permeability. [10] The trellis, rectangular, and parallel drainage patterns are suggestive of structural and lithological controls; the dendritic drainage pattern typically suggests homogeneous rocks; and the trellis, rectangular, and parallel drainage patterns are indicative of structural and lithological controls [11]. Low drainage density is more likely to occur in a flat terrain with highly permeable subsurface under thick vegetation, [5,6] according to observations from diverse geology and climatic zones. In hilly terrain, regions with scarce vegetation, and impermeable subsoil, a high drainage density develops.

Coarse drainage texture has a low drainage density, whereas fine drainage texture has a high drainage density [12]. In comparison to a low drainage density location, a high drainage density region has lesser infiltration, resulting in poor GWPZs [13]. Rivers and other bodies of water are often regarded as critical sources of groundwater recharge. However, if there are too many rivers flowing in a given region, the drainage density rises, resulting in excessive surface runoff, restricted infiltration, and diminished groundwater recharge [14]. Permeability is inversely proportional to drainage density.

As a result, it's a crucial factor to consider while determining the groundwater potential zone. Runoff and groundwater potential are aided by a high drainage density rating. As a result, the low drainage density area receives a high ranking. The largest drainage density was observed in the northern and south-western parts of the research region, whereas the lowest drainage density was identified in the eastern section (Figure 5).

4.3.5. Land Use/Land Cover

The land use/land cover of a region is mainly determined by groundwater resources and, at the same time, plays a key role in resource management. Many hydrogeological processes in the water cycle, including as evapotranspiration, infiltration, and surface runoff, are influenced by it [4,15]. Runoff is normally less, and infiltration is stronger in forest and agricultural land, but in pediment and settlement areas, the rate of infiltration usually declines. As a result, agricultural land and vegetation cover area have a high ranking, whereas pediment and settlement have a poor ranking. Cropland accounts for most of the land use in the district covering 516.14 km2 (59.99%), woodland and vegetation 129.52 km2 (15.05%), pediment 128.31 km2 (14.91%), fallow land 50.33 km2 (5.84%), and other land uses 50.33 km2 (5.84%). and settlement covers 36.06 km2 (4.19%) area (Figure 6)

4.3.6. Land Use/Land Cover

A map defining gross physical character of a rock or rock formation is known as lithological. In the study area around 16 percent is alluvium, 57 percent is sand stone, 23 percent is shale basalt, chert-breccia, laterite, limestone, sandstone, orthoquartzite are 4 percent respectively [15].

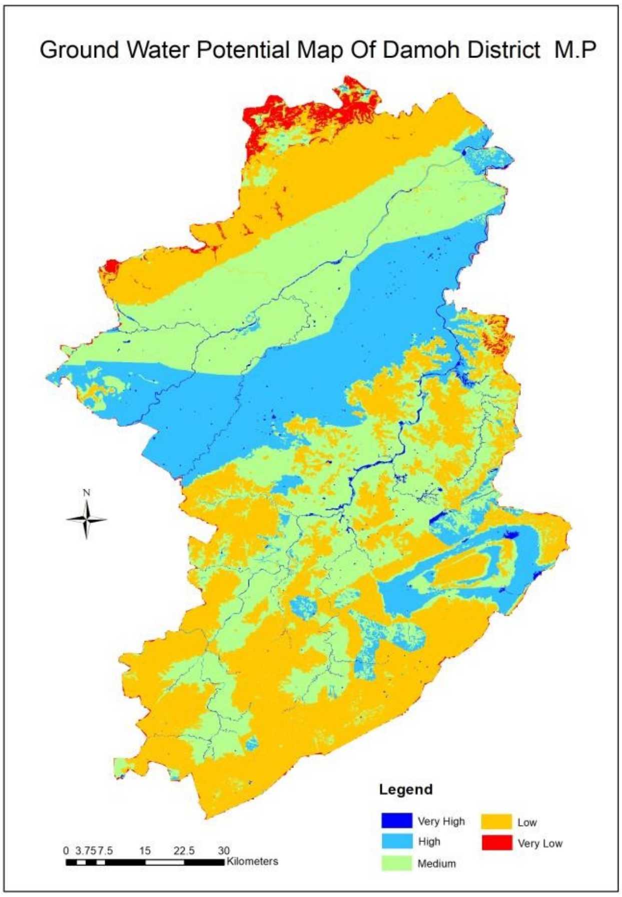

Figure 10. Ground Water Potential Map of Damoh District M.P India

5. Ground Water Potential Zones

5.1. Results

All six thematic layers (hydrogeomorphology, slope, lineament density, drainage density, land use/land cover, and Lithology) were combined on a GIS platform to produce a single groundwater potential map [4,5,6] depicting favorable groundwater zones. (Figure 10).

In a 1–5 scale, GWPZs were classified into four categories: 'Very High,' 'High,' 'Medium,' 'Low' and ‘Very Low’ (Table 3). Groundwater potential zone 'Very High' areas are found to be randomly distributed across the study Area

Results of these studies indicated that out of the total study area, 21% have Very High to High potentiality of groundwater 34% have Medium Ground water potential 45% of area have a Low to very Low groundwater potential. Remote sensing and a GIS-based AHP approach were used to identify ground water potential zone.

Table 3. Potential Zones table

Sno.	Potential zones	Area in Km sq
1	Very High	71.34
2	High	1596.08
3	Medium	2561.76
4	Low	2988.96
5	Very Low	137.67
Total		7355.81

6. Conclusion

Sustainable use of groundwater is necessary to promote long-term sustainability of agriculture as well as for socio-economic development in any area. In the present study area groundwater is being extensively used to the domestic and agricultural needs of the people. The agriculture of the area under study depends largely on rainfall and rainwater harvesting, mostly through ponds and dug wells with limited river lift irrigation. As the onset of monsoon and quantum of rainfall in the month of July and August has become irregular in recent time, the demand of groundwater is increasing to fill up the water deficit not only in the Rabi (winter) sea- son but also during the monsoon months. [5] We have decline the GWPZs in the Damoh District of Madhya Pradesh by the integrated RS and GIS-based AHP methodology. The GWPZs were derived and the results revealed that Very, High, High, Medium, Low Very Low potential zone covered 1%, 20%, 34%, 43%, 2%, respectively. Rainwater is mainly responsible for the groundwater recharge. However, moderate to steep slope area is considered as fair zones for groundwater recharge processes. These areas can be selected for the construction of recharge structures such as check dam, water absorption trench and farm ponds to store the rainwater and to arrest excessive surface runoff. The GWPZ map as an outcome of the present study is envisaged to be useful for locating suitable locations for extraction of water, sustainable groundwater utilization, further land-use planning and water resource management in Damoh District of Madhya Pradesh and can be extended to other areas of India. This integrated remote sensing– GIS framework-based analysis has been used at the micro-scale in the present study but this method can further be scaled up in to make the GWPZ Map of entire India and the world to facilitate better watershed management practices. This study can be used for agricultural and drinking water purposes. The present research reaffirms the efficacy of integration of remote sensing with AHP in terms of being a cost-effective method requiring a reduced workforce and eliminating the time constraints of conventional methods for groundwater potential zone mapping [4,5,6].

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