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Towards Sustainable Water Solutions: Investigating Groundwater Possibility in Dindori District of Madhya Pradesh, India

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ABSTRACT

Groundwater is a crucial resource, as approximately 45% of irrigation and around 80% of domestic water needs in India are fulfilled by groundwater reservoirs. Therefore, it is essential to determine where the probability of groundwater availability is high and where it is low. In areas with low probability, there is a need for the rapid development of recharge structures. GIS and remote sensing technology is a crucial tool for obtaining information about availability of ground water potential as well as finding suitable site for recharge structures. The investigation will involve geological surveys to understand the hydrogeological characteristics of the region, including aquifer properties, recharge mechanisms, and groundwater quality. Additionally, environmental impact assessments will be conducted to evaluate the sustainability of groundwater extraction and its potential implications on the surrounding ecosystems. Furthermore, socio-economic analyses will explore the existing water usage patterns, community needs, and stakeholders' perspectives to develop inclusive and equitable groundwater management plans.

"This study focuses on the Dindori district in Madhya Pradesh, India. There are different factors affecting groundwater recharge, including topography, slope, land use and land cover, drainage density, geology, soil distribution, rainfall, lineament, etc. Satellite images provide information about land use/land cover, geomorphology, and DEM delineate slope, drainage, and lineament. They are classified into different classes and assigned weights. ArcGIS software was used for data integration and weighted overlay analysis to create a groundwater potential map for the Dindori district. The groundwater potential map is categorized into five classes: 'Excellent' (0.01%), 'Good' (9.78%), 'Moderate' (70.04%), 'Poor' (19.97%), and 'Very Poor/Nil' (0.17%)."

Keywords- Ground Water, AHP, Weighted Overlay Analysis, Topography, GIS.

I. INTRODUCTION

Groundwater is a vital source of drinking water. Of the total potable water available for human, 68.7% exists in the form of polar ice and glaciers, making it challenging to utilize. Surface water, which includes lakes, rivers, and ponds, accounts for only 1.2%, and while easily accessible, its quantity is quite limited. The remaining significant portion, accounting for 30.1%, is groundwater. It is the most substantial source and plays a crucial role in drinking water needs. (Source: USGS Geological Survey). Ground water is not equal distribute over the world. It very difficult to find out where good or less possibility of ground water without study.

Groundwater potential zone mapping is a crucial aspect of hydrogeological studies aimed at assessing and managing groundwater resources.[1] This process involves the identification and delineation of areas with high, moderate, and low potential for groundwater availability. The primary goal is to understand the spatial distribution of groundwater potential within a region, helping policymakers, water resource managers, and environmental scientists make informed decisions about sustainable water use and management.[2] The process of groundwater potential zone mapping typically integrates various geological, hydrogeological, and remote sensing data to create a comprehensive understanding of the subsurface conditions. Some key factors considered in this mapping include geological formations, soil characteristics, land use patterns, topography, and hydrological parameters. [1,3] These factors influence the recharge, storage, and movement of groundwater in a given area. Groundwater potential zone mapping plays a crucial role in addressing water scarcity issues, especially in regions where groundwater is a significant source of freshwater. By identifying areas with high potential, authorities can prioritize sustainable groundwater development projects and implement effective conservation measures. Conversely, areas with low potential can be targeted for groundwater recharge projects to enhance water availability. [2,4]

Advancements in technology, including Geographic Information System (GIS) tools and remote sensing techniques, have significantly improved the accuracy and efficiency of groundwater potential zone mapping. [1,3,5] These tools allow for the integration and analysis of large datasets, enabling a more comprehensive understanding of the complex interactions between geological and hydrological factors. Integration of various hydro-morphological factors give us reliable information about the possibility of ground water. [4-6] By synthesizing scientific findings with community insights, this study aims to provide evidence-based recommendations for policymakers, water resource managers, and local communities to promote sustainable water solutions in Dindori District. The outcomes of this research are anticipated to contribute to the development of resilient water infrastructure, enhance water security, and support the overall socio-economic advancement of the region, while also addressing the challenges posed by water scarcity and environmental degradation.

II. OBJECTIVES

The main objectives of groundwater potential zone mapping include: Identifying Water Resource-Rich Areas and Assisting Optimizing Water Resource Management, Informing Infrastructure Development, Enhancing Decision-Making.

III. STUDY AREA

Dindori is a district of Madhya Pradesh situated in the North-East direction of the state. The geographical coordinates of the district are approximately 22° 56' 30.4548" N latitude and 81° 4' 36.6348" E longitude. An average annual rainfall of the district is1350m.The maximum temperature recorded 43.6°C and minimum temperature 3.1°C. The district is bordered by the river Narmada, serving as a boundary between Anuppur and Dindori districts. Anuppur and Umariya district make the border at North of the district. Jabalpur situated at West from the Dindori district and Mandla in South. Eastern part of the district share boundary with Chhattisgarh state. Dindori is a tribal district, with the Gond and Baiga tribes being predominant in the region .The Baiga Chak of Madhya Pradesh situated at Dindori district. The district is known for its tribal communities, contributing to its cultural and ethnic diversity.

The Dindori district separated from Mandla in 1998. The district is divided into two parts by the river Narmada. Dindori covers a total area of 7470 square kilometers and is characterized by 927 villages distributed across 7 blocks. Farming is the main source of livelihood and agriculture depends on monsoon. Dindori is the most unirrigated district of Madhya Pradesh. Hence here produce crops that require less water like kodo, kutke, ramtil etc. Rice, Soyabeen, Wheat Gram also produce but kodo and kutki are identity of the district.

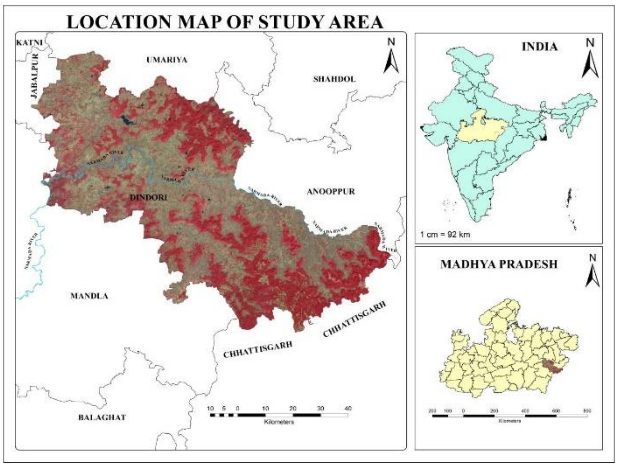
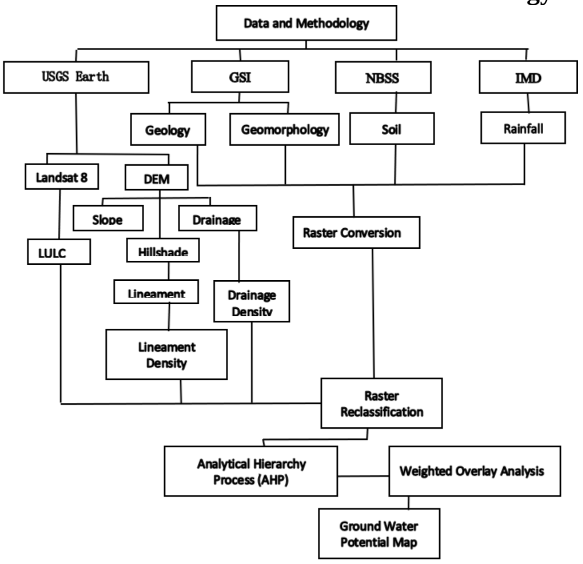


Fig. 1: Map of Study area

IV. DATA AND METHODOLOGY

There are 8 factors integrated in Geo-spatial technique for mapping of ground water prospect zone. All these factors collecting from different-different source and methodology. Landsat 8 used for LULC classification which is 30 m resolution. But enhance the resolution of Landsat 8 used pan merge with band 8 which is 15 m resolution. DEM (Digital Elevation Model) downloaded from USGS Earth Explorer for slope analysis and lineament extraction of the study area. The geological survey of India provides different types of data in various formats.[7] The geology and geomorphology shape-file were downloaded from here. Rainfall data taken from IMD. Drainage delineates from DEM and validate from satellite image. The Soil map of Dindori taken from NBSS. The calculation of weights for each parameter was chosen using the Analytic Hierarchy Process. In this process, weights are assigned based on the importance of parameters for groundwater potential. Weighted Overlay Analysis method adopted for this study. Weighted Overlay Analysis is a spatial analysis technique used in Geographic Information Systems (GIS) to combine multiple layers of spatial data, each representing different factors or criteria, into a single, composite layer. This composite layer helps in making decisions by assigning weights to each factor based on its relative importance and then combining them to identify suitable locations or areas based on predefined criteria.

Chart.1. Flow Chart of Data and Methodology



V. RESULT AND DISCUSSION

Geology

Geology provides information about the composition and materials of the Earth, as well as its history. It serves as the foundation for assessing groundwater potential zones by offering critical data on aquifer characteristics, recharge mechanisms, flow patterns, water quality, and spatial distribution. Integrating geological knowledge with interdisciplinary approaches enhances the accuracy and reliability of groundwater resource assessments and management practices. The infiltration capacity and Availability of pores depend on geology, which determines flow direction and groundwater possibility. There are 5 types of geology found in the Dindori district.

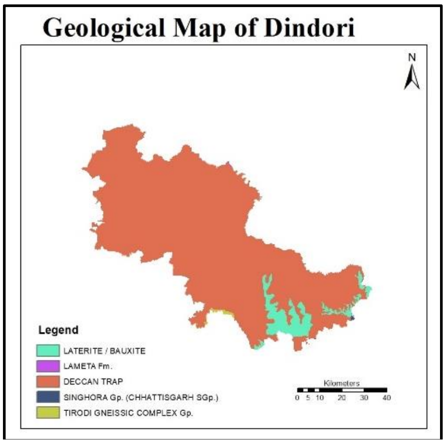


Fig. 2 Geology map of Dindori

Laterite/bauxite, deccan trap, Lameta Fm, singhora Gp, tirodi geneissic complex Gp.are the major geological categories in the dindori. The deccan trap covers around 94.08% of the area and very good for water recharge. The 5.49% area comes under laterite/bauxite type of geology.

Geomorphology

By integrating geomorphological data with hydrogeological and hydrological parameters, groundwater potential zone mapping becomes more comprehensive and accurate. It enables effective groundwater resource management, sustainable water supply planning, and identification of suitable sites for groundwater extraction and recharge structures. Therefore, geomorphology serves as a fundamental component in the assessment and mapping of groundwater potential zones.

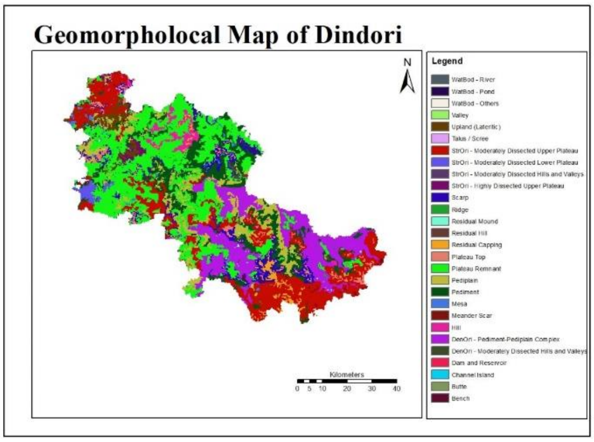


Fig. 3 Geomorphological map

The variation of geomorphology in Dindori is so vast. According to GSI classification around 26 types of geomorphology exist in the Dindori. The highly possibility of found ground in plain areas. The mountains and hilly areas are not suitable for ground water possibility.

LULC

Land Use/Land Cover (LULC) plays a pivotal role in mapping groundwater potential due to its direct influence on the hydrological cycle and groundwater recharge processes. Understanding LULC patterns allows for the identification of areas with higher permeability, such as forests or grasslands, which facilitate infiltration and recharge of groundwater. Conversely, urban areas with impervious surfaces tend to inhibit infiltration, leading to decreased groundwater recharge. By analysing LULC data alongside hydrogeological parameters, such as soil characteristics and topography, groundwater potential maps can be generated to delineate areas with high, moderate, and low potential for groundwater availability. These maps serve as valuable tools for sustainable groundwater management, aiding in decision-making processes related to water resource planning, land use planning, and environmental conservation efforts. Moreover, incorporating LULC data into groundwater potential mapping enhances the accuracy and reliability of assessments, providing valuable insights for addressing water scarcity challenges and ensuring the long-term sustainability of groundwater resources. Land use & land cover of Dindori district divided into five major classes like agriculture, water bodies, built-up, forest, and wasteland. Each class have own unique capacity for recharging ground water. Water bodies and forest are very high possibility to recharge water into the ground. Agriculture land moderate possibility but built-up and wasteland have very less chance to recharge.

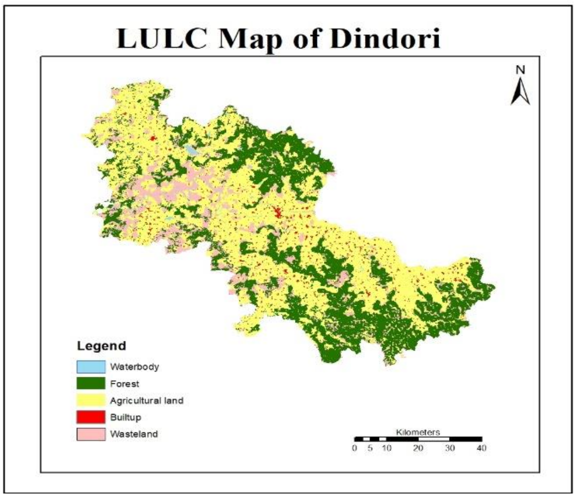


Fig. 4 Land Use and Land Cover Map

Based on the distribution of land use and land cover in the district, there are five categorized types: Waterbody (0.82%), Forest (32.15%), Agricultural land (49.32%), Built-up (2.23%), and Wasteland (15.45%). By analysing this distribution, we can map the potentiality of groundwater resources.

Soil

The influence of soil on the movement and storage of water within the subsurface is pivotal in groundwater mapping. Understanding soil characteristics is essential for assessing the potential for groundwater recharge, as well as the vulnerability of aquifers to contamination. One key aspect of soil that affects groundwater mapping is its permeability, which refers to its ability to allow water to pass through. Soils with high permeability, such as sandy soils, allow water to infiltrate more easily, potentially leading to greater groundwater recharge. Conversely, soils with low permeability, such as clay soils, may inhibit infiltration, reducing recharge rates. Coarse-textured soils like sand have larger pore spaces, allowing water to move more freely through the soil profile. Fine-textured soils like clay, however, have smaller pore spaces, which can restrict water movement and increase the potential for water logging or surface runoff.

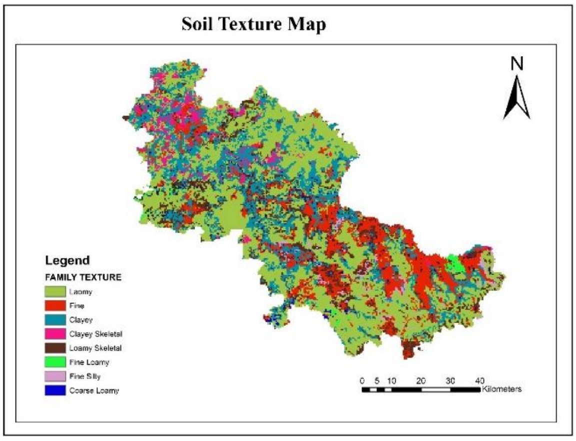


Fig. 5 Soil texture map of Dindori

The fig.5 shows the distribution of soil texture. The Loamy, fine, and clay type of soil texture present in the study area. The soil serves as a critical component in groundwater mapping efforts due to its permeability, texture, depth, structure, and chemistry. By understanding these soil characteristics, hydrogeologists and environmental scientists can better assess groundwater resources, recharge potential, and vulnerability to contamination, ultimately aiding in sustainable groundwater management and development.

Rainfall

The average rainfall in any area determines the subsurface water zone because rainwater is the primary source for recharging water beneath the surface.[8] If rainfall is plentiful, the possibility of recharge is higher. The distribution and intensity of rainfall directly influence the recharge of aquifers, which are underground layers of rock or sediment that hold water. In regions with high rainfall, such as tropical or temperate climates, there tends to be more groundwater recharge due to increased infiltration of water into the soil and subsequent percolation into the aquifers below. Conversely, areas experiencing low rainfall or prolonged droughts may face challenges in replenishing groundwater levels, leading to depletion and potential water scarcity issues.

Moreover, the spatial and temporal variability of rainfall patterns are essential considerations in groundwater mapping efforts. Detailed analyses of long-term rainfall data help identify areas prone to frequent recharge and those susceptible to water stress. By correlating rainfall data with hydrogeological parameters such as soil types, geological formations, and land use patterns, hydrologists and geologists can develop comprehensive groundwater maps that depict the spatial distribution and potential yield of groundwater resources within a given region.

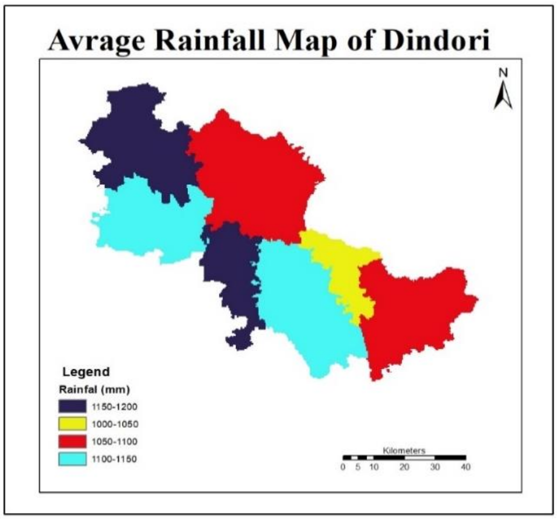


Fig.6 Average Rainfall Map

The average rainfall of the district is 1450 mm, while the average rainfall of Madhya Pradesh is 1160 mm. Typically, Block Shahpura receives the highest rainfall, averaging around 1320.00 mm, while Block Bajag experiences the lowest rainfall in the district, with an average of 990.00 mm.

In conclusion, rainfall serves as the cornerstone for groundwater mapping, providing valuable insights into the dynamics of groundwater replenishment and availability. By integrating rainfall data with hydrogeological analyses, stakeholders can develop effective strategies for the sustainable management and utilization of groundwater resources, ensuring their continued resilience in the face of changing climatic conditions and human activities.

Slope

Slope analysis is a fundamental technique utilized in groundwater mapping, offering valuable insights into the movement and distribution of water within a landscape.[9] By examining the slope or gradient of the terrain, hydrologists and geologists can identify potential pathways for groundwater flow and pinpoint areas of groundwater recharge and discharge.

In slope analysis, the topography of an area is assessed using various tools such as Geographic Information Systems (GIS) and digital elevation models (DEMs). These tools enable the calculation of slope gradients across the landscape, ranging from gentle slopes to steep gradients. Areas with gentle slopes tend to promote groundwater infiltration and recharge, as water can percolate through the soil more easily. Conversely, steep slopes may hinder infiltration and promote surface runoff, reducing opportunities for groundwater recharge.

Moreover, slope analysis helps identify features such as valleys, ridges, and depressions that play significant roles in groundwater dynamics. Valleys often serve as conduits for groundwater flow, channelling water from recharge areas to discharge zones such as streams or springs. Ridges, on the other hand, may act as barriers to groundwater movement, influencing the formation of groundwater divides and influencing the direction of flow.

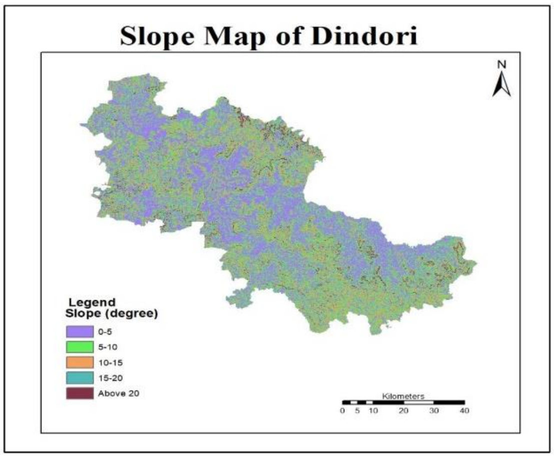


Fig. 7 Slope Map

The slope map of Dindori indicates significant undulation in the area. Slopes ranging from 0 to 5 degrees represent lowlands such as valleys, plains, and possibly depressions, indicating a high likelihood of groundwater presence. Areas with slopes between 5 and 10 degrees denote higher elevations compared to valleys, while slopes exceeding 10 degrees typically characterize plateau and hilly terrain, which are less conducive to groundwater potential. The slope analysis plays a vital role in groundwater mapping by providing valuable information on terrain characteristics, groundwater flow patterns, and vulnerability to contamination. By integrating slope data with other hydrological parameters such as rainfall, soil properties, and land use, researchers can develop comprehensive groundwater models and management strategies that promote sustainable use and protection of groundwater resources.

Drainage density

Drainage density refers to the frequency and distribution of natural drainage channels such as streams, rivers, and creeks within a landscape.[10] High drainage density typically indicates a well-developed network of watercourses, suggesting good surface water drainage and potentially higher groundwater recharge rates. The drainage density of a region is calculated by dividing the total length of all streams and rivers by the area of the basin or watershed region. Mathematically, it can be represented as:

$$\mathbf{D = L\backslash A}$$

Where:
D is the drainage density,
L is the total length of all streams and rivers within the basin or watershed, and
A is the total area of the basin or watershed region.

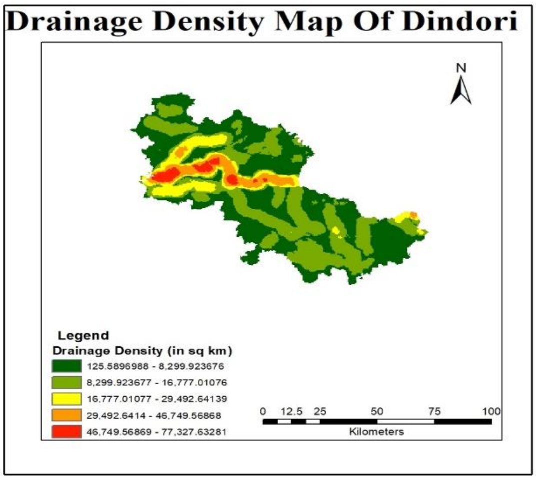


Fig. 8 Drainage Density Map

High drainage density often corresponds to areas with well-defined stream networks and efficient surface water drainage. These regions tend to experience enhanced groundwater recharge rates due to the frequent interaction between surface water and groundwater systems. Additionally, the presence of abundant surface water features facilitates the replenishment of aquifers through infiltration processes, contributing to groundwater availability.

By incorporating drainage density analysis into groundwater mapping studies, hydrologists and water resource managers can better understand the spatial distribution of groundwater recharge zones and identify areas with higher potential for groundwater development. This integrated approach allows for more effective decision-making regarding water resource management, land use planning, and environmental conservation efforts aimed at protecting and preserving groundwater supplies for future generations.

Lineament Density

Lineament density analysis is another important tool used in groundwater potential mapping. Lineaments are linear or curvilinear features on the Earth's surface, such as faults, fractures, joints, and bedding planes, which can influence the movement and storage of groundwater. Lineament density refers to the frequency and distribution of these linear features within a given area and is calculated by dividing the total length of lineaments by the total area of the region.

Lineament Density = {Total Length of Lineaments}/ {Total Area of Region}

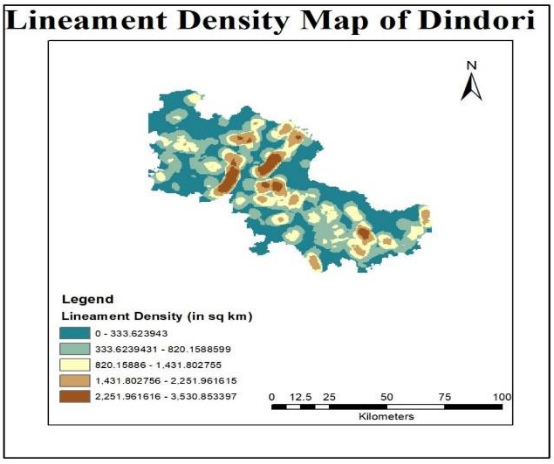


Fig.9 Lineament Density Map

High lineament density often indicates areas with greater structural complexity and increased fracturing within the subsurface geological formations. These areas may serve as preferential pathways for groundwater flow and contribute to enhanced groundwater recharge rates. Additionally, lineaments can act as conduits for groundwater movement, allowing for the transfer of water between different aquifer units.

Integrating lineament density analysis into groundwater potential mapping helps identify regions where geological structures are conducive to groundwater storage and movement. Areas with high lineament density may have higher groundwater potential due to increased recharge rates and more efficient groundwater flow pathways. Conversely, low lineament density areas may still have groundwater potential, but the presence of fewer structural features may result in slower groundwater movement and storage.

Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a decision-making technique widely used in various fields, including business, engineering, environmental science, and healthcare. Developed by Thomas Saaty in the 1970s, AHP provides a structured method for making complex decisions involving multiple criteria and alternatives.

The Analytic Hierarchy Process (AHP) is often integrated with weighted overlay analysis to enhance the accuracy and effectiveness of spatial decision-making in geographic information systems (GIS). Weighted overlay analysis is a GIS technique used to combine multiple raster layers representing different criteria or factors into a single comprehensive map, where each pixel is assigned a weighted score based on its attributes across all layers.

In the context of weighted overlay analysis, AHP is employed to determine the relative importance or weight of each criterion or raster layer used in the analysis. This is particularly valuable when dealing with complex spatial problems that involve multiple decision criteria with varying degrees of significance. The process typically begins by defining the decision hierarchy, which consists of the goal, criteria, and alternatives. The goal represents the overarching objective of the analysis, while criteria are the individual factors or attributes that contribute to achieving that goal. Alternatives refer to the spatial units or locations being evaluated, such as potential sites for a new development project.

Conducted pairwise comparison between criteria to assess their relative importance using the AHP methodology. These comparisons involve assigning numerical values to indicate the relative priority of one criterion over another. The resulting pairwise comparison matrices are then synthesized to derive priority weights for each criterion, reflecting their relative significance in relation to the overall goal. The matrix table shows the pairwise comparison and importance of the factors.

Table 1. Pairwise comparison matrix

Matrix		**Rainfall**	**Geomorphology**	**Geology**	**LULC**	**Slope**	**Soil**	**Dranaige density**	**Lineament density**	**Normalized weight**
		1	2	3	4	5	6	7	8	
Rainfall	1	1	1	2	2	1	2	3	2	18.46%
Geomorphology	2	1	1	1	1	1	1	2	1	12.24%
Geology	3	1/2	1	1	1	1	2	2	1	12.44%
LULC	4	1/2	1	1	1	1	2	2	2	13.32%
Slope	5	1	1	1	1	1	1	2	1	12.24%
Soil	6	1/2	1	1/2	1/2	1	1	3	1	12.14%
Dranaige density	7	1/3	1/2	1/2	1/2	1/2	1/3	1	8	11.15%
Lineament density	8	1/2	1	1	1/2	1	1	1/8	1	8.02%

Once priority weights are determined, they are used to weight the corresponding raster layers in the weighted overlay analysis. Each raster layer is multiplied by its respective weight, and the resulting weighted layers are then combined using a predefined combination rule, such as addition or multiplication, to generate a composite suitability map.

Weighted overlay analysis

Weighted overlay analysis is a geographic information system (GIS) technique used to combine and analyze multiple spatial datasets by assigning weights to different input layers based on their relative importance. In this analysis, each input layer is assigned a weight representing its significance in relation to the overall objective or criteria being evaluated. These layers typically represent various factors such as land use, slope, geology, geomorphology drainage density, lineament density average rainfall.

The process involves several steps. First, each input layer is standardized or normalized to ensure comparability, often through rescaling or transformation techniques. Next, the layers are assigned weights based on their relative importance to the analysis, typically determined through expert knowledge, stakeholder input, or statistical analysis.

Once the weights are assigned, the individual layers are combined using a weighted sum or other mathematical operation to generate a single composite output layer, known as a suitability or suitability index raster. This raster represents the overall suitability or desirability of each location based on the combined influence of all input factors. In this study, weights were assigned using Analytical Hierarchy Process (AHP). The highest weightage was given to rainfall because without rain, there is no possibility for ground recharge. Following rainfall, weighting was assigned to land use and land cover. After LULC Similarly, equal weightage was given to geomorphology, geology, slope, and soil. Drainage density and lineament density were assigned lesser weightage compared to other factors. Each factor is divided into different classes, with each class assigning values ranging from 1 to 9.When the value decreases from 9, the possibility also decreases, with 9 indicating an excellent possibility.

Table 2: Value range for possibility of ground water

Value Range	1-2	2-3	3-5	5-7	7-9
Possibility	Very poor/Nil	Poor	Moderate	good	Excellent

Groundwater potential mapping

A groundwater potential map serves as a vital tool in assessing the availability and quality of groundwater resources within a given area. This particular map has categorized the groundwater potential into five distinct classes, each representing varying degrees of accessibility and quality. At the highest end of the spectrum lies the 'Excellent' category, comprising a mere 0.01% of the total area, indicating regions with abundant and pristine groundwater reserves. Following this, the 'Good' class covers 9.78% of the area, indicating areas with favourable groundwater conditions, though not as plentiful or pristine as the 'Excellent' category. The 'Moderate' class encompasses the largest portion, accounting for 70.04% of the territory, suggesting regions with average groundwater availability and quality.

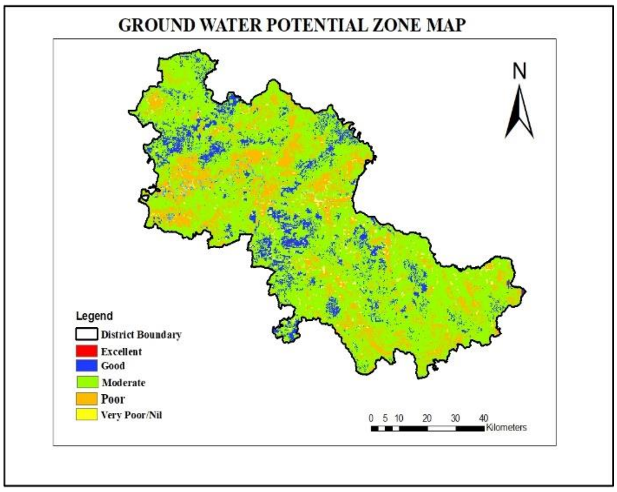


Fig 10. Ground water potential map

Conversely, the 'Poor' classification, covering 19.97% of the map, denotes areas with limited groundwater resources, potentially requiring careful management strategies for sustainable use. Lastly, the 'Very Poor/Nil' category, though representing a small fraction at 0.17%, highlights regions where groundwater availability is extremely scarce or virtually non-existent, posing significant challenges for any utilization. Overall, this map offers valuable insights into the spatial distribution of groundwater potential, aiding planners, policymakers, and stakeholders in making informed decisions regarding water resource management and conservation efforts. Map shows the potential of ground water.

VI. CONCLUSION

This study plays a crucial role in achieving several interconnected objectives vital for sustainable water resource management. Firstly, it facilitates the identification of water resource-rich areas. However, only around 9.79% of the area exhibits rich water resources, indicating a scarcity of water resources in the region. Secondly, by assisting in optimizing water resource management, it aids in the equitable distribution and sustainable exploitation of groundwater, crucial for meeting various societal needs, from agriculture to urban supply. Moreover, it plays a pivotal role in planning strategies to mitigate water scarcity by identifying areas prone to depletion or contamination, allowing for proactive measures to safeguard against shortages. Additionally, by informing infrastructure development, such as the construction of wells or water supply networks, it ensures that investments are directed towards areas with the greatest potential for sustaining reliable water sources. Ultimately, by enhancing decision-making through comprehensive data analysis and visualization, groundwater potential zone mapping empowers stakeholders to make informed choices, fostering long-term resilience and sustainability in water management practices.

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