www.czasopisma.pan.pl PAN www.journals.pan.pl

Arch. Min. Sci. **69** (2024), 1, 77-88

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI: https://doi.org/10.24425/ams.2024.149828

RUKAIYA KAUSHER[1*], ANAND KUMAR SINHA[1],
RAMBABU SINGH[2]

# DELINEATION OF GROUNDWATER POTENTIAL ZONES FOR SUSTAINABLE DEVELOPMENT AND PLANNING USING AHP AND GIS TECHNIQUES IN THE COAL MINING PROVINCE OF MAHAN RIVER CATCHMENT AREA

The present research aims to address the drinking water crisis in the Mahan River catchment area resulting from the disruption of groundwater availability due to extensive coal mining. The study uses GIS-based Multi-Criteria Decision Analysis (MCDA) to map the groundwater potential of the area by analysing several factors that affect groundwater availability, including rainfall, water depth, geomorphology, geology, soil, land-cover/land-use, and topographic characteristics derived from DEM. The groundwater potential map created using the MCDA technique classified the area into low, moderate, and high groundwater potential zones. The map was validated and verified using water table depth and electrical conductivity values available in the region, indicating that it can be used to identify groundwater recharging sites. The study's results show that about 30% of the area has high groundwater potential, and more than 45% of the area has moderate groundwater potential. The information derived from the study can be used for sustainable management and proper planning of groundwater resources in the Mahan River catchment area. Overall, the study presents a useful approach to address the groundwater depletion problem resulting from coal mining activities in the Mahan River catchment area.

**Keywords:** Mining activities; Groundwater potential; AHP; MCDA; Thematic layers

## 1. Introduction

Groundwater is a crucial resource for fulfilling individual basic needs. In India, over 30% and 90% of urban and rural populations rely on it for domestic and drinking purposes. Unfortunately, many regions in India are facing over-exploitation and severe water scarcity of groundwater

[1] CENTRAL MINE PLANNING AND DESIGN INSTITUTE LIMITED, BILASPUR, INDIA
[2] BIRLA INSTITUTE OF TECHNOLOGY, MESRA, INDIA

* Corresponding author: rukaiyakausher@gmail.com

resources due to the depletion of groundwater levels and deterioration of groundwater quality, especially in coal mine areas. The adverse impacts of coal mining on groundwater resources in India have been widely reported. The agricultural and industrial activities, global climate change and urbanisation, along with mining, exacerbate the pressure on groundwater resources, contributing to the declining water levels in coal mine areas. Therefore, management of groundwater resources in a sustainable manner is crucial to ensure the availability of safe and adequate water for present and future generations.

Studies by Andualem and Demeke have shown that groundwater consumption in rural areas is increasing, but traditional management practices are still prevalent [1]. However, these traditional hydrogeological studies, such as drilling, can be costly, time-consuming, and provide limited information for groundwater resource management. To better understand the status and features of a watershed, surface water and groundwater models can be useful tools. However, the calibration and validation of watershed-scale models require extensive data and groundwater movement is influenced by various factors, including hydrological, lithological and topographic conditions [2]. Therefore, a multidisciplinary approach is necessary for studying groundwater.

GIS techniques can help process, organise, and quantify large amounts of data with the least error. GIS-based MCDA has been used to map groundwater potential zones (GWPZ) in recent days [3,4]. Employing a spatial context to define the hydrogeological features offers several advantages over traditional approaches [5]. However, previous studies have primarily concentrated on the topographic characteristics, lithology and rainfall distribution [6]. Groundwater recharge, which is influenced by various factors such as geology, soil type, land cover and slope has not been considered in GWPZ mapping [7]. Depending solely on rainfall as the primary factor in mapping groundwater potential may result in inaccurate conclusions, especially in areas with complex topography. In regions where data is scarce, it is crucial to comprehend the spatiotemporal distribution of recharge and mapping groundwater potential zones (GWPZ) to enhance sustainable groundwater resource management.

In this research, the AHP method was used to delineate groundwater potential zones. The Analytic Hierarchy Process (AHP) is widely recognised as a valuable Multi-Criteria Decision Analysis (MCDA) model applicable in the context of environmental management [8]. Hajkowicz and Higgins emphasised the importance of constructing decision problems that incorporate criteria and decision options [9]. The integration of geospatial technology plays a crucial role in generating a variety of thematic layers. These layers include factors, such as lithology, terrain slope, soil texture, drainage density, lineament density, rainfall, and land use. When combined with the proper assignment of weights using the AHP methodology, this approach has proven effective in identifying regions with significant groundwater resources.

Chenini et al. demonstrated the effectiveness of GIS-based multi-criteria analysis in mapping groundwater recharge zones, highlighting its strong functionality [10]. Adiat et al. applied the AHP to map groundwater potential in the Kedah Peninsula, Malaysia, stressing the importance of using pairwise comparison ratings and expert knowledge for weight assignment in thematic layers [11].

Manap et al. emphasised that a GIS-based multi-criteria decision analysis framework provides a swift and comprehensive means of assessing groundwater potential, which applies to diverse regions and is particularly valuable in areas with limited data [12].

Coal mining regions in India face significant water scarcity, worsened by population growth, resource stress, and historical mining activities. Changes in land use patterns and high groundwater abstraction result in a water crisis during the summer when groundwater levels are low. Effective management of groundwater resources, particularly in coal mining areas, is essential due to the inadequate availability of surface water for domestic purposes. A study in the Mahan River catchment area of Central India integrated the Analytical Hierarchy Process (AHP), Remote Sensing (RS), and GIS techniques to create a groundwater potential zone map. This map assists decision-makers in selecting suitable drilling sites for productive wells and analysing spatial factors influencing groundwater accumulation.

The significance of this study lies not only in its focus on groundwater potential but also in the exploration of correlations between terrain characteristics, hydrological parameters, and groundwater potential in the study area. Given the absence of prior research in this particular region, the findings of this study carry substantial relevance and timeliness. The implementation of the MCDA-based AHP method demonstrated in this study showcases its efficiency and cost-effectiveness, making it a promising approach for groundwater management.

## 2. Materials and methods

### 2.1. Study area

The present research was done in the Bishrampur coalfield region of the Surguja district in Chhattisgarh, India, as shown in Fig. 1. The area covers approximately 717 $km^2$ (23° 00' N–23° 30' N, 83° 00' E–83° 45' E) latitudes and longitudes. The region experiences a tropical monsoon climate with temperatures ranging from 17.8°C in winter to 30.1°C in summer, with maximum temperatures reaching 42.7°C and minimum temperatures dropping to 4.4°C. The yearly rainfall

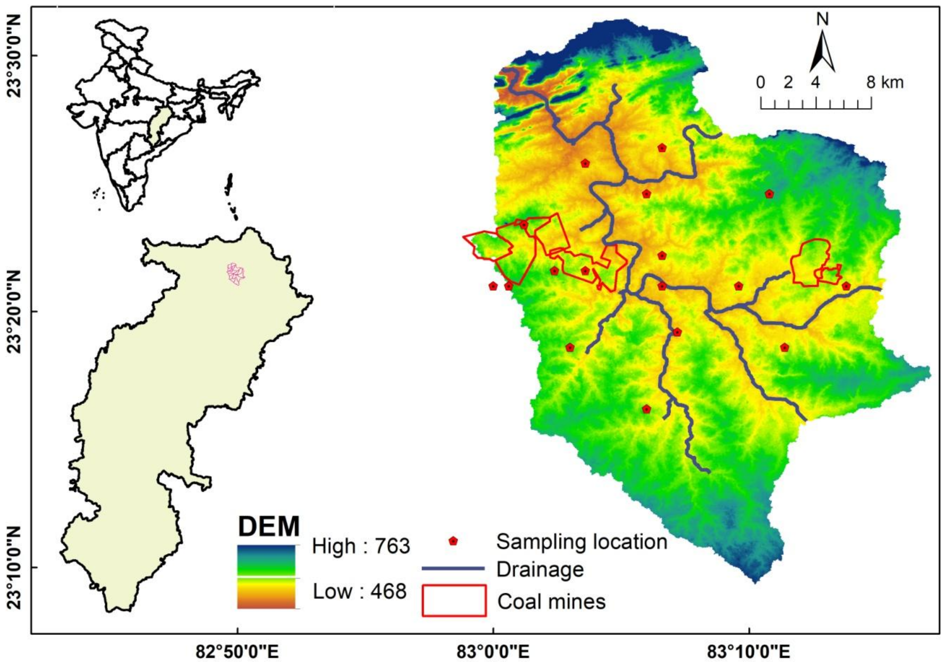



Fig. 1. Study area of Mahan River catchment

varies from 1100-1270 mm, with around 80% of the yearly rainfall occurring from 15th June to 15th October during the Southwest monsoon. The drainage area is controlled by the Mahan River and its branches, which have an undulating geography with elevations ranging from 468-763 m above MSL (mean sea level).

In terms of the hydrogeology of the study area, a significant portion is characterised by the Barakar Formation, which consists of a soil cover and sandstone with varying grain sizes intermingled with shale beds and coal seams. The Barakar Formation exhibits a multi-layered aquifer system with medium to very coarse-grained sandstone, along with intermittent gritty pebbly conglomerate horizons serving as aquifers. In contrast, the shale beds and coal seams act as aquicludes, impeding the flow of groundwater between these layers. The layer immediately above the working seam primarily comprises alluvium and sandstone, with an average thickness of approximately 15 m, behaving as an unconfined aquifer. In contrast, the lower formations consist of compact sandstone with secondary porosity, creating semi-confined to confined aquifers.

Based on the hydrogeological assessment in the study area, the aquifer parameters have been determined as Hydraulic conductivity (K) = 0.63 m/day and Transmissivity (T) = 13 $m^2$/day. Storage coefficient (S) = $3.7\times10^{-2}$. It is important to note that in specific locations, the permeability is notably higher due to the presence of localized gritty or pebbly conglomeratic beds.

## 2.2. Data collection and handling

Groundwater potential zone mapping requires a significant amount of data, including time-series and spatial data. Data obtained from various sources are outlined in TABLE 1 A 30-meter resolution Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM) was used in this study. The DEM was acquired from the USGS Earth Explorer and covered an elevation range from 463 metres to 763 metres above mean sea level. The land use and land cover map was created using supervised classification [13], with LANDSAT data sourced from the USGS Earth Explorer. To enhance data accuracy and reliability, a validation and refinement process was conducted by cross-referencing this information with LULC maps from BHUVAN and by incorporating ground truth observations. All maps were transformed to UTM zone 44N before being incorporated into the GWPZ.

TABLE 1

Data acquisition and description for the study area

| SI. No. | Data type | Source |
|---|---|---|
| 1. | Digital Elevation | USGS (Date: March 2023) |
| 2. | LULC | Global Land Cover Facility website, Landsat (Sensor-ETM+, Path/Row-140/43) |
| 3. | Soil map | FAO |
| 4. | Rainfall | crudata |
| 5. | Geomorphology | Bhuvan (https://bhuvan app1.nrsc.gov.in/thematic/thematic/index.php) |
| 6. | Geology | Bhukosh (https://bhukosh.gsi.gov.in/Bhukosh/MapViewer.aspx) |
| 7. | Water depth | Field survey |
| 8. | Electrical conductivity | Field survey |

## 2.3. Multi-Criteria Decision Analysis

GIS techniques and multi-criteria decision analysis (MCDA), particularly the Analytical Hierarchy Process (AHP), are valuable tools for water resources management. AHP, when combined with GIS, allows for the integration of various factors affecting water storage and flow, aiding decision-making [14]. Previous research has shown the superiority of AHP over alternative techniques in mapping groundwater potential. By using AHP and GIS, water resource managers can make informed decisions based on accurate assessments and prioritise actions accordingly.

The AHP technique is a robust methodology that combines both empirical data and expert subjective opinions to facilitate a well-informed decision-making process [15]. It encompasses the consideration of both substantial and insubstantial factors to establish a meaningful ratio and an abstract priority scale, which is essential for making intricate decisions [16,17]. AHP plays a pivotal role in the identification and the assignment of weights to selection criteria and the analysis of collected data.

To determine the significance of each class within each thematic layer and assign rankings, an AHP-based pairwise comparison matrix is used (TABLE 2). The matrix considers the number of parameters assessed for groundwater potential. Saaty's 1-9 significance scale is employed to allocate weights to the classes (TABLE 3). Rankings are determined based on expert opinions and literature reviews [18]. The assigned ranks and corresponding weights for each parameter are listed in TABLE 4. In the second step of the AHP method, normalised weights are generated using the geometric mean [19].

$$W = \frac{G_m}{\sum_{i-1}^{n} G_m} \tag{1}$$

Where: $W$ – the eigen vector and $G_m$ – the geometric mean of the $i^{\text{th}}$ row of the judgement.

In the AHP method, the last step involves evaluating the consistency of the normalised criteria weights (as shown in TABLE 4). This is done by calculating the consistency ratio (CR)

TABLE 2

Pairwise comparison matrix and normalised weight of influencing parameters

| | Rainfall | Water Depth | Geomor-phology | Soil | Geology | Slope | Drainage Density | LULC | Weight |
|---|---|---|---|---|---|---|---|---|---|
| **Rainfall** | 1 | 1 | 3 | 5 | 7 | 7 | 9 | 9 | 0.31 |
| **Water Depth** | 1 | 1 | 2 | 3 | 4 | 5 | 7 | 9 | 0.23 |
| **Geomor-phology** | 0.33 | 0.5 | 1 | 4 | 5 | 6 | 8 | 9 | 0.20 |
| **Soil** | 0.2 | 0.33 | 0.25 | 1 | 4 | 5 | 7 | 9 | 0.12 |
| **Geology** | 0.14 | 0.25 | 0.2 | 0.25 | 1 | 2 | 5 | 7 | 0.06 |
| **Slope** | 0.14 | 0.2 | 0.16 | 0.2 | 0.5 | 1 | 4 | 7 | 0.05 |
| **Drainage Density** | 0.11 | 0.14 | 0.12 | 0.14 | 0.2 | 0.25 | 1 | 3 | 0.02 |
| **LULC** | 0.11 | 0.11 | 0.11 | 0.11 | 0.14 | 0.14 | 0.33 | 1 | 0.01 |

TABLE 3

Scale of Intensity for Pair-wise Comparison in Multi-criteria Decision Analysis (MCDA) [20]

| Intensity Importance | Description |
|---|---|
| 1 | Equal significance |
| 2 | Equal to moderate significance |
| 3 | Moderate significance |
| 4 | Moderate to the strong significance. |
| 5 | Strong significance |
| 6 | Somewhat more important |
| 7 | Very strong significance |
| 8 | Very to the extremely strong significance |
| 9 | Extreme significance |

using Eq. 2. The value of CR must be less than 0.10 for the weights to be considered consistent. If the CR value exceeds 0.10, then it is necessary to reassess the pairwise comparisons [21].

$$CR = \frac{CI}{RI} \tag{2}$$

Where: *CR* – consistency ratio, *CI* – consistency index (Eq. 3), and *RI* is the random consistency index (TABLE 4)

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{3}$$

Where $\lambda_{\max}$ is the judgement matrix's highest eigen value, as determined by Eq. 4.

$$\lambda_{\max} = \frac{1}{n}\sum_{i-1}^{n}\frac{(A_w)i}{w_i} \tag{4}$$

TABLE 4

Assigned and computed normalised weights of the eight thematic layers
for the AHP-based MCDA approach

| | Rainfall | Water depth | Geomor-phology | Soil | Geology | Slope | Drainage density | LULC |
|---|---|---|---|---|---|---|---|---|
| **Rainfall** | 0.33 | 0.28 | 0.44 | 0.36 | 0.32 | 0.27 | 0.22 | 0.17 |
| **Water depth** | 0.33 | 0.28 | 0.29 | 0.22 | 0.18 | 0.19 | 0.17 | 0.17 |
| **Geomorphology** | 0.11 | 0.14 | 0.15 | 0.29 | 0.23 | 0.23 | 0.19 | 0.17 |
| **Soil** | 0.07 | 0.09 | 0.04 | 0.07 | 0.18 | 0.19 | 0.17 | 0.17 |
| **Geology** | 0.05 | 0.07 | 0.03 | 0.02 | 0.05 | 0.08 | 0.12 | 0.13 |
| **Slope** | 0.05 | 0.06 | 0.02 | 0.01 | 0.02 | 0.04 | 0.10 | 0.13 |
| **Drainage density** | 0.04 | 0.04 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.06 |
| **LULC** | 0.04 | 0.03 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 |
| $\lambda_{\max}$ | 8.7 | | | | | | | |
| ***CI*** | 0.1 | | | | | | | |
| ***CR*** | 0.07 | | | | | | | |

### 2.4. Deriving groundwater potential zones

To generate the groundwater potential zones (GWPZs) for the Mahan River catchment area, the multi-influencing factors of groundwater potential are superimposed on the GIS platform and classified based on their assigned ranks and weights. After ensuring consistency in the assigned ranks and weights, a weighted overlay approach is used to generate the GWPZs. To obtain the groundwater potential index, a weighted linear sum combination algorithm is employed, as shown in Eq. 5.

$$GWPI = (RF_w \times RF_{iw}) + (WL_w \times WL_{iw}) + (GM_w \times GM_{iw}) + (ST_w \times ST_{iw}) + \\ + (GG_w \times GG_{iw}) + (SL_w \times SL_{iw}) + (DD_w \times DD_{iw}) + (LULC_w \times LULC_{iw}) \tag{5}$$

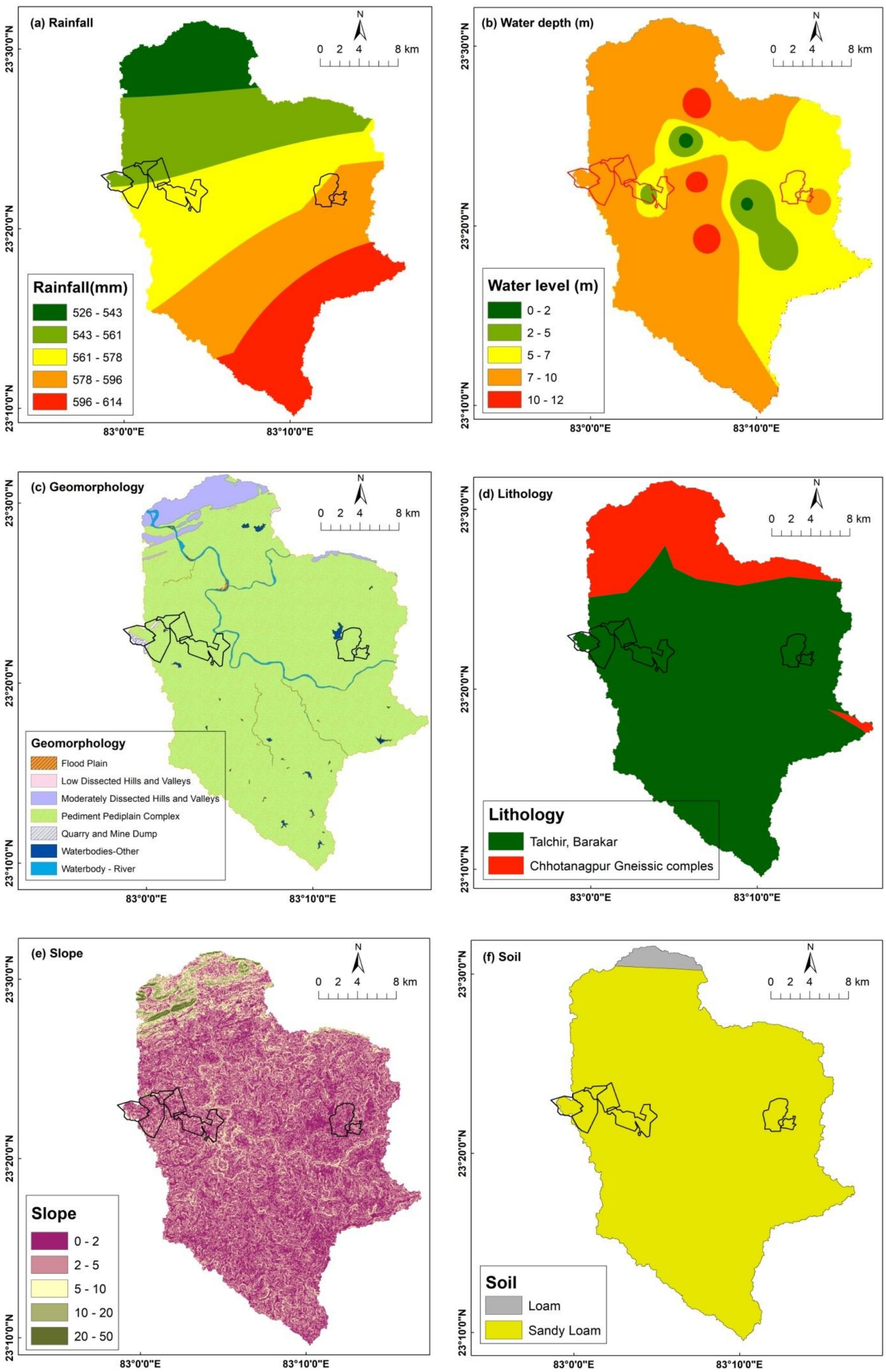
Where: *GWPI* – groundwater potential index; *RF* – rainfall; *WL* – water level; *SL* – slope; *GM* – geomorphology; *ST* – soil texture; *LULC* – land use/land cover; *GG* – geology; *DD* – drainage density.

The subscripts "*w*" and "*iw*" represent the normalised weights of each criterion or thematic layer and the normalised weights of individual classes within a layer, respectively. Based on the *GWPI* (Groundwater Potential Index) values, groundwater potential zones (GWPZs) are determined for the Mahan River catchment area. These zones are classified as low, moderate, and high groundwater prospective zones.

## 3. Result and discussion

### 3.1. Preparation of thematic layers

The Mahan River catchment relies heavily on monsoonal rainfall for aquifer recharge. To analyse the rainfall distribution, data was obtained from https://crudata.uea.ac.uk/cru/data/hrg/, and a map was prepared in Fig. 2(a). The average annual rainfall in the catchment was categorised into five levels: very low (526-543 mm), low (543-561 mm), moderate (561-578 mm), high (578-596 mm), and very high (596-614 mm). During the study, the water level in the area was evaluated by conducting field visits and measuring the levels of 21 observation wells. The depth of the water table below the ground surface ranged from 0.7 to 12 metres, as shown in Fig. 2(b). Fluctuations in groundwater levels can be influenced by factors such as rainfall and variations in groundwater recharge and discharge. Groundwater occurrence in the study area is influenced by its geomorphological setting. Different hydrogeomorphologic units, including the Flood Plain, Low and Moderately Dissected Hills and Valleys, Quarry/Mine Dump, Pediment Pediplain Complex, and Water bodies-Other, control the flow and storage of groundwater as shown in Fig. 2(c). The floodplain has a high potential for groundwater occurrence, while other units have a moderate impact. According to Hema et al., groundwater flow and occurrence are highly influenced by permeable and porous hydrogeological zones that can easily transmit and store water [22]. The Bishrampur coalfield is part of the Lower Gondwana formations, which include Talchirs, Karharbaris, Barakars, and Kamthis. The Talchir rocks are exposed along the western and eastern peripheries, whilst the Gondwana sediments (Lower) are adjacent to Slates, Archaean gneisses, and quartzites towards the north and south Fig. 2(d). A slope map of the area


(a) Rainfall
Rainfall(mm)
526 - 543
543 - 561
561 - 578
578 - 596
596 - 614
(b) Water depth (m)
Water level (m)
0 - 2
2 - 5
5 - 7
7 - 10
10 - 12
(c) Geomorphology
Geomorphology
Flood Plain
Low Dissected Hills and Valleys
Moderately Dissected Hills and Valleys
Pediment Pediplain Complex
Quarry and Mine Dump
Waterbodies-Other
Waterbody - River
(d) Lithology
Lithology
Talchir, Barakar
Chhotanagpur Gneissic comples
(e) Slope
Slope
0 - 2
2 - 5
5 - 10
10 - 20
20 - 50
(f) Soil
Soil
Loam
Sandy Loam
N
0 2 4 8 km
23°30'0"N
23°20'0"N
23°10'0"N
83°0'0"E
83°10'0"E

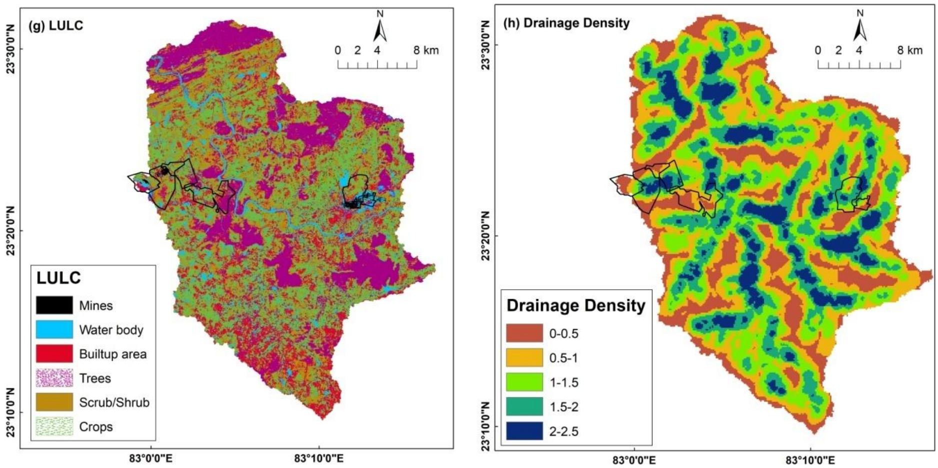



Fig. 2. Thematic maps of the Mahan River catchment area (a) Rainfall (b) Water level (c) Geomorphology (d) Lithology (e) Slope (f) Soil (g) LULC (h) Drainage Density

was created using a digital elevation model (DEM) generated from SRTM data with a resolution of 30 m Fig. 2(e). Greater weight was assigned to moderate and low slope areas, while steep slope regions were given less weight to identify groundwater potential zones. Five categories were used to classify the slope of the basin: 0-2 (very low), 2-5 (very low), 5-10 (moderate), 10-20 (high) and 20-50 (very high). Loam and sandy loam are two major soil types identified in the Mahan River catchment area, as shown in Fig. 2(f). Loam soil is highly fertile and has good nutrient-holding capacity, making it suitable for agriculture. Sandy loam soil, on the other hand, has a higher proportion of sand particles compared to silt and clay. It has a coarser texture and a lower water-holding capacity than loam soil, making it more prone to drought. However, sandy loam soil has good drainage and aeration, making it suitable for crops that require sufficient soil drainage [23]. A LULC map was created using remote sensing on Landsat-8 imagery, as shown in Fig. 2(g). Vegetation areas are suitable for groundwater exploration, while aquatic bodies facilitate aquifer recharge. Categories include plantations, built-up land, agricultural land, mines/quarries, and water bodies. Intensive irrigation areas have high aquifer potential, but mines/quarries can deplete aquifers. The drainage map of the terrain is an essential tool in hydrogeological studies as it provides valuable information on the porosity of rocks and groundwater availability. In this study, the drainage density of the study area was categorised into five classes, ranging from very high (2-2.5 km/km$^2$) to very low (0-0.5 km/km$^2$), as illustrated in Fig. 2(h). According to Todd and Mays 2005, regions characterised by a high density of drainage are not favourable for groundwater occurrence. Conversely, moderate drainage density suggests a moderate potential for groundwater, while low drainage density implies a high likelihood of groundwater occurrence.

## 3.2. Demarcation of groundwater potential zones

When mapping GWPZs using GIS-based MCDA, the most crucial step is determining the weight of each layer. After ranking the thematic layers (TABLE 4), a pairwise matrix was constructed, which generated several parameters, such as $\lambda_{max} = 8.7$, $CR = 0.07$, $CI = 0.1$, and normalised weight. The AHP analysis yielded a ranking of thematic layers along with their normalised weights, as shown in TABLE 4. These normalised weights are then utilised by the WLC method to combine the layers and create maps of the GWPZs.

According to the study's results, more than 45% of the land surface area had moderate aquifer potential, while about 30% of the area had high groundwater potential. The downstream side showed a recharge rate of 400-450 mm, which was also evident in the GWPZ map Fig. 3(a).

## 3.3. Validating the results

The groundwater potential zone map was validated using the electrical conductivity (EC) values of the study area. A total of 26 wells were sampled to collect groundwater from the study area. EC values were measured using a Consort C-831 portable conductivity metre in the field. A spatial distribution map has been prepared using the IDW tool in Arcmap; the electrical conductivity values ranged from 90 to 600 µS/cm with an average value of 216 µS/cm.

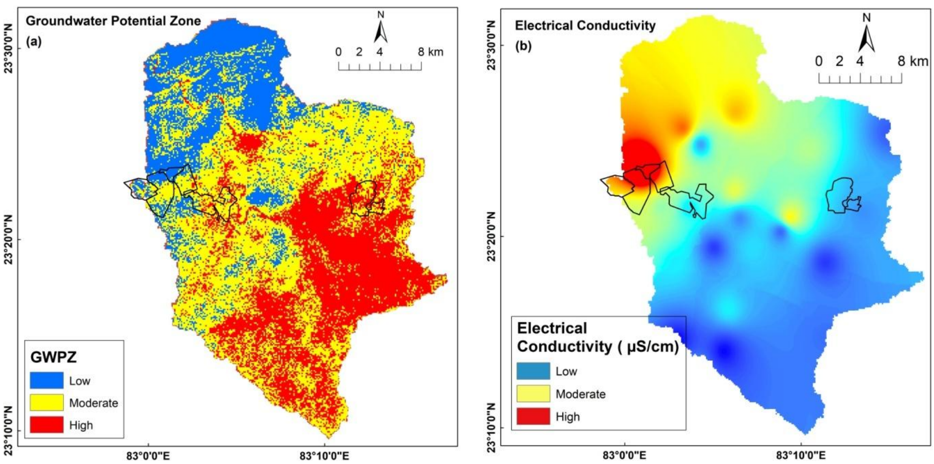



Fig. 3. (a) Groundwater Potential zone map (b) Spatial distribution map of Electrical conductivity

In most instances, the trends observed in the electrical conductivity (EC) values closely corresponded, as depicted in Fig. 3(b). However, a few disparities were detected in certain areas. With the exception of a few areas, the groundwater samples with high electrical conductivity (EC) values were predominantly located in the moderate-to-unsuitable zone. Conversely, the low EC values of the water samples were found to extend to the very suitable to suitable recharging zone. These findings indicate that electrical conductivity validation can be used to identify suitable groundwater recharging sites. Therefore, the GIS-based MCDA technique plays a vital role in ensuring a suitable equilibrium between the quantity of groundwater and its utilisation.

# 4. Conclusions

This study aimed to estimate recharge and assess groundwater potential in a coal mine region with limited data using the GIS-based MCDA. Thematic maps of rainfall, water depth, geomorphology, lithology, LULC, digital elevation, and soil model-derived major water flows controlling topographic attributes were analysed to map GWPZs in the coal mines. The results were categorised into high, moderate, and low GWPZs, with over 45% of the area having moderate groundwater potential and approximately 30% having high potential. The assessment results were cross-validated using water level and electrical conductivity data from dug wells and tubes in the watershed, showing a 91% match. This study focuses on examining the negative impact of mining and its associated activities on the groundwater potential within the designated study area. The results obtained from this research have the potential to provide valuable insights into the sustainable management of water resources in mining regions.

### Acknowledgements

The researchers express their appreciation for the support received from Birla Institute of Technology, Mesra, Ranchi, India, which greatly contributed to the progress of this research.

### Conflict of Interest

There is no conflict of interest.

### References

[1] T.G. Andualem, G.G. Demeke, Groundwater potential assessment using GIS and remote sensing: A case study of Guna tana landscape, upper blue Nile Basin, Ethiopia. J. Hydrol.: Reg. Stud. **24**, 100610 (2019). DOI: https://doi.org/10.1016/j.ejrh.2019.100610

[2] J. Mallick, R.A. Khan, M. Ahmed, S.D. Alqadhi, M. Alsubih, I. Falqi, M.A. Hasan, Modeling groundwater potential zone in a semi-arid region of Aseer using fuzzy-AHP and geoinformation techniques. Water **11** (12), 2656 (2019). DOI: https://doi.org/10.3390/w11122656

[3] M.K. Jha, A. Chowdhury, V.M. Chowdary, S Peiffer, Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. Water Resour. Manage. **21**, 427-467 (2007).

[4] P. Arulbalaji, D. Padmalal, K. Sreelash, GIS and AHP tech- niques based delineation of groundwater potential zones: a case study from Southern Western Ghats. India Sci. Rep. (2019). DOI: https://doi.org/10.1038/s4159 8-019-38567-x

[5] H.C. Nair, D. Padmalal, A. Joseph, P.G. Vinod, Delineation of groundwater potential zones in river basins using geospatial tools – an example from Southern Western Ghats, Kerala, India. J. Geovis. Spatial Anal. **1**, 1-16 (2017). DOI: https://doi.org/10.1007/s41651017-0003-5

[6] A. Bera, B.P. Mukhopadhyay, S. Barua, Delineation of groundwa- ter potential zones in Karha river basin, Maharashtra, India, using AHP and geospatial techniques. Arab. J. Geosci. **13**, 693 (2020). DOI: https://doi. org/10.1007/s12517-020-05702-2

[7] K. Ibrahim-Bathis, S.A. Ahmed, Geospatial technology for delineating groundwater potential zones in Doddahalla watershed of Chitradurga district, India. Egypt. J. Remote Sens. Sp. Sci. **19**, 223-234 (2016). DOI: https://doi.org/10.1016/j.ejrs.2016.06.002

[8] O. Rahmati, A. Nazari Samani, M. Mahdavi, H.R. Pourghasemi, H. Zeinivand, Groundwater potential mapping at Kurdistan region of Iran using analytic hierarchy process and GIS. Arab. J. Geosci. **8** (9), 7059-7071 (2015).

[9] S. Hajkowicz, A. Higgins, A comparison of multiple criteria analysis techniques for water resource management. Eur. J. Oper. Res. **184**, 255-265 (2008).

[10] I. Chenini, A.B. Mammou, M.Y. May, Groundwater recharge zone mapping using GIS- based multi-criteria analysis: a case study in central Tunisia (maknassy basin).Water Resour. Manag. **24**, 921-939 (2010).

[11] K.A.N. Adiat, M.N.M Nawawi, K. Abdullah, Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction toola case of predicting potential zones of sustainable groundwater resources. J. Hydrol. **440**, 75-89 (2012).

[12] M.A. Manap, W.N.A. Sulaiman, M.F. Ramli, B. Pradhan, N. Surip, A knowledge-driven GIS modeling technique for groundwater potential mapping at the Upper Langat Basin, Malaysia. Arab. J. Geosci. **6**, 1621-1637 (2013).

[13] H.G. Kuma, F.F. Feyessa, T.A. Demissie, Assessing the impacts of land use/land cover changes on hydrological processes in Southern Ethiopia: The SWAT model approach. Cogent. Eng. **10** (1), 2199508 (2023).

[14] L.K. Singh, M.K. Jha, V.M. Chowdary, Assessing the accuracy of GIS-based multicriteria decision analysis approaches for mapping groundwater potential. Ecol. Indic. **91**, 2437 (2018).
DOI: https://doi.org/10.1016/j.ecolind.2018.03.070

[15] E. Şener, S. Şener, A. Davraz, Groundwater potential mapping by combining fuzzy-analytic hierarchy process and GIS in Beyşehir Lake Basin, Turkey. Arab. J. Geosci. **11**, 1-21 (2018).

[16] M.I. Al Khalil, Selecting the appropriate project delivery method using AHP. International Journal of Project Management **20** (6), 469-474 (2002).

[17] J. Solnes, Environmental quality indexing of large industrial development alternatives using AHP. Environmental Impact Assessment Review **23** (3), 283-303 (2003).

[18] G. Gnanachandrasamy, Y. Zhou, M. Bagyaraj, S. Venkatramanan, T. Ramkumar, S. Wang, Remote sensing and GIS based ground- water potential zone mapping in Ariyalur District, Tamil Nadu. J. Geol. Soc. India **92** (4), 484-490 (2018).

[19] S.I. Ifediegwu, Assessment of groundwater potential zones using GIS and AHP techniques: a case study of the Lafia district, Nasarawa State, Nigeria. Appl. Water Sci. **12** (1), 10 (2022).
DOI: https://doi.org/10.1007/s13201-021-01556-5

[20] T.L. Saaty, How to make a decision: the analytic hierarchy process. Eur. J. Oper. Res. **48** (1), 9-26 (1990).
DOI: https://doi.org/10.1016/0377-2217(90)90057-I

[21] T.L. Saaty, Decision making – the analytic hierarchy and network processes (AHP/ANP). J. Syst. Sci. Syst. Eng. **13**, 1-35 (2004). DOI: https://doi.org/10.1007/s11518-006-0151-5

[22] H.C. Hema, S.S. Vittala, S. Govindaiah, Quantitative morphometric infer in the hard rock Terrain based on SRTM-DEM and GIS-Chintamani Watershed, Chikkaballapur District, Karnataka, India. Sustain. Water Resour. Manag. **7**, 1-12 (2021). DOI: https://doi.org/10.1007/s40899-021-00534-8

[23] J. Wu, H. Zhou, S. He, Y. Zhang, Comprehensive understanding of groundwater quality for domestic and agricultural purposes in terms of health risks in a coal mine area of the Ordos basin, north of the Chinese Loess Plateau. Environ. Earth Sci. **78**, 1-17 (2019). DOI: https://doi.org/10.1007/s12665-019-8471-1