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Groundwater Potential Zones Using Multi – Criteria Decision Making for Mirzapur, District, U.P, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Groundwater is one of the most prominent fresh water sources and is under significant threat due to numerous factors such as growing population, rapid urbanization, multiple cropping practices and utilizing by the major water intensive industries. The quality and quantity of groundwater sources are both affected by climate change. Climate variability also has a significant impact on the parameters that influence groundwater recharge. The fall in groundwater levels is worsened by erratic monsoon with deficit amount of rainfall occurring in combination with high heat-flow and over-exploitation of groundwater which contributes stress on the water resources. This study was conducted for Mirzapur district where the groundwater serves as the main source for domestic and agricultural purposes rather than the other sources of water. To delineate the potential groundwater zones, the following parameters were used i.e. geology, drainage density, slope, geomorphology, soil, land use and land cover and lineament density (an area can indirectly reveal the groundwater

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potential) are constructed as separate layers in the GIS (Geographic Information System) background. Thereafter, a weighted overlay analysis was carried out to achieve the graded potential zones using the weights computed for each layer by AHP (Analytical Hierarchy Process) method. In addition, the GWP map has been divided into four categories using multi criteria decision analysis (MCDA): excellent, good, moderate, and poor. The results of the study revealed that the excellent potential zone comprises of 24.4 % (1101 km^2), good 40.07% (1840 km^2), moderate 29.8% (1347 km^2), and poor 5.1% (228 km^2) of the total geographical area. Future management plans, including natural and artificial recharge practices, may be made effectively in these locations because the approach used yielded reliable data.

Keywords: AHP; groundwater potential zonation; GIS; multi criteria decision analysis; weighted overlay.

1. INTRODUCTION

Groundwater is a vital, renewable, and dynamic resource used for drinking, irrigation, and industry [1]. In India, 80–90% of rural and urban populations rely on groundwater for domestic purposes. However, excessive groundwater removal often exceeds natural recharge, leading to aquifers drying up and reducing fresh groundwater supply globally [2]. Uttar Pradesh, which covers 28.68% of the Ganga basin, is a rich and productive region with vast water resource potential. Groundwater accounts for 70% of irrigated agriculture, rural housing needs, urban water consumption, and industrial demands. Over 37 lakh shallow tube wells drain more than 41 billion cubic meters of groundwater per year (state-of-ground-water-2021report). Mirzapur district, covering 4516 sq. km, is characterized by hillocks, plateaus, and plains formed by alluvium. Rainfall run-off is significant in hilly areas, with the Ganga and Belan being the main drainage systems. Ground water is found in porous, fractured, and weathered zones. Well yields range from 30 to 3100 lpm with a 30m drawdown. From 2001 to 2011, water level data showed long-term fluctuation between 0.79 and 4.00 m, indicating negligible base flow of ground water. The district's long-term water level trend shows a fall in ground water levels. However, chemical analysis of ground water samples shows fresh and potable water quality (Groundwter Brochure of Mirzapur District,u.p.).To combat the district's decreasing water levels, it is crucial to find buried and paleo-channels for potable ground water. Artificial recharge procedures and water-shed management are necessary. Quality assessment of shallow and deeper groundwater is essential, and lithological behavior should be considered. Remote Sensing, satellite imagery analysis, and resistivity surveys can be used to investigate potential groundwater withdrawal sites. The statistical method, expert evaluation and deterministic method can be used to determine the groundwater potential zone [3]. The groundwater potential index method is the most popular and reliable method; [4]. Groundwater recharge potential zones need to be identified and planned effectively to meet rising demand [5,2]. Traditional methods like test drilling and stratigraphic analysis are time-consuming and costly [6]. Remote sensing and GIS technology have been used to identify these zones, providing a definitive answer through multidisciplinary data sets [7 and 8]. The multi-criteria decision analysis (MCDA) technique is frequently used to designate these zones [5,9] [10,11 and 12]. Saaty introduced the Analytical Hierarchy Process (AHP) in 1980, a multi-criteria decision-making approach with mathematical qualities and simplicity [13,14]. It uses a hierarchical structure with objectives, criteria, sub-criteria, and options. Relevant data is extracted through pairwise comparisons, determining relative performance measures and weights of decision criteria [15]. If comparisons aren't consistent, the AHP provides a technique to improve consistency [13 and 16].

The Mirzapur district faces increased water supply demand due to exploitation of groundwater resources, leading to ecological issues like decreased groundwater levels, water exhaustion, pollution, and water quality deterioration. This research supports the delineation of groundwater potential zones based on factors like rainfall constraints and drought-like conditions [17 and 18]. A sustainable groundwater management strategy is required, which includes the use of remote sensing and GIS to efficiently identify potential zones [19,20 and 21]. The number of thematic layers required for prospective groundwater mapping varies depending on site characteristics and data availability [22,23 and 24].

2. METHODOLOGY

2.1 Study Area

Mirzapur district, Uttar Pradesh has been selected as a study area in this research work. It lies in the state's south-eastern region and has an area of 4,516 km^2. The location of Mirzapur is 23°52´ to 25°32´ North latitude and 82°07´ to 83°33´ East longitude. It is 80 meters above sea level on average (265 feet). The district of Mirzapur is located between the latitudes of 23.52 and 25.32 North and the longitudes of 82.7 and 83.33 East. It shares border with Varanasi district on the north and north-east, Sonbhadra district on the south, and Allahabad district on the north-west. Chunar, Marihan, Lalganj, and Mirzapur Sadar are the administrative divisions of the district, which are further divided into 12 development blocks. Mirzapur had a population of 234,871 people in 2011, according to Census India's provisional data, with 125,601 men and 109,270 women. Mirzapur has a population of 234,871 people, but its urban/metropolitan population is 246,920, with 132,055 men and 114,865 women. The sex ratio in the municipality was 876 females per1,000 males. The district's climate is mainly mild temperate, where temperature ranges between $5^{o}C$ to $46^{o}C$, maximum in the month of June and minimum in the month of December. Mirzapur receives roughly 80 to 85 percent of its rainfall from the Bay of Bengal monsoon branch during the monsoon season (June to September). The average annual rainfall for the district is around 990 millimeters. The Indian Meteorological Department (IMD) provided monthly meteorological variables such as rainfall and temperature.

2.2 Software Used

ArcGIS serves as the cornerstone for making maps and geographic data accessible across organizations, communities, and on the Internet, facilitating effective decision-making and resource management [19, and 21]. The version employed, ArcGIS 10.4 offers a comprehensive suite of tools for map creation, data compilation, spatial analysis and data sharing [20]. It enables users to leverage geographic information in various applications and manage spatial data within a database [22 and 25]. The thematic maps were prepared like geology, drainage density, slope, geomorphology, soil, land use and land cover

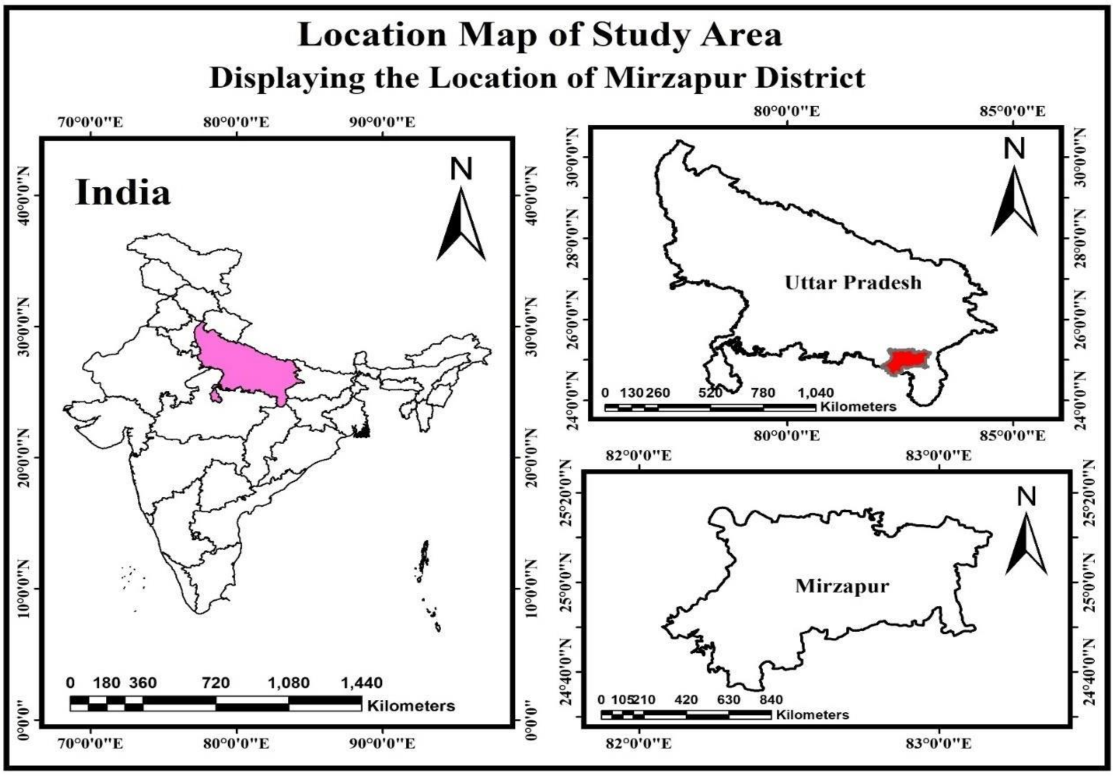

Fig. 1. Location map of study area

and lineament density, base map and elevation by using ArcGIS 10.4. Image classification was also done that Image categorization produces a raster that can be used to build thematic maps [7]. There are two types of classification: supervised and unsupervised, based on the interaction between the analyst and the computer during categorization. The goal of classification is to connect the image's spectral properties to a meaningful information class value that can be shown as a map, allowing resource managers and scientists to assess the terrain in an accurate and cost-effective manner [7,26].

2.3 Satty's Analytical Hierarchical Process (AHP)

The Analytic Hierarchy Process (AHP), pioneered by Thomas Saaty in 1980, stands as a powerful tool for navigating complex decision-making processes, aiding decision-makers in setting priorities and identifying optimal choices [13,14,27 and 16]. AHP facilitates the evaluation of a set of criteria and a range of alternative options to determine the most favorable course of action [28,29, and 30]. Through pairwise comparisons of criteria, the AHP assigns weights to each criterion, reflecting its relative importance. These weights guide the decision-making process, with higher weights indicating greater significance. Additionally, AHP assigns scores to each option based on pairwise comparisons made by the decision-maker regarding the options' performance against each criterion [31,32 and 33]. These scores are then aggregated to derive a global score for each option, resulting in a ranking [34]. The overall score of a particular option represents a weighted average of its performance across all evaluated criteria. Thus, the AHP provides a structured framework for decision-making by systematically integrating criteria weights and option scores to facilitate informed choices [35]. The various AHP parameters to check the consistency of weightage assigned to each thematic layer is given in table.1a.

The consistency of inverse second-order symmetrical matrices is guaranteed. Consistency relationship refers to the relationship between a matrix's calculated Consistency Index CI and the average Random Index value CR. Random Index (RI) values (Table.1b) used to calculate the consistency ratio [3,36], which measures the degree of matrix consistency:

Consistency Ratio (CR) = CI/RI.

A CR of less than or equal to 0.1 is considered acceptable, indicating that the matrix is consistent [37].

2.4 Weighted Overlay Analysis

The Weighted Overlay tool is a commonly used methodology for solving multi-criteria problems like site selection and suitability models through overlay analysis [38]. In this approach, each criterion layer is assigned preference values on a common scale, typically ranging from 1 to 10, with 10 representing the most favorable condition. These preference values are crucial for merging the input criteria layers into a single analysis. It's important that these values not only reflect the relative importance of criteria within a layer but also maintain consistent meaning across layers. For instance, assigning a preference of 5 to a location for one criterion should have a similar impact as assigning a preference of 5 to a location for another criterion.

Table 1a. Parameters of AHP to check consistency of weightages assigned to thematic layers

AHP parameters	Formula	Remarks
ConsistencyMeasures	(Row of comparison Matrix) × (Eigen Vector)/Corresponding Eigen Vector of the row	Last column of the Normalized Matrix
Principal Eigen Value	Λmax	Average of thecolumn of Consistency Measures
ConsistencyIndex (CI)	λmax – n/n-1	n is number ofthematic layers
ConsistencyRatio (CR)	CI/RI	RI is Random Index

Table 1b. Values of Random Index (RI) for number of thematic layers (n)

n	1	2	3	4	5	6	7	8	9	10

RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

The Weighted Overlay program streamlines various overlay analysis processes into one application, allowing users to efficiently integrate multiple criteria. The program only accepts integer raster inputs, necessitating the conversion of continuous raster data to integer format before use. Moreover, in scenarios like estimating potential groundwater recharge, where factors vary in their influence and interdependence, weight buildup techniques are employed to derive a composite recharge potential score, considering the complex relationships among different parameters.

2.5 Identification of Ground Water Potential Zones

For the definition of groundwater potential zones in the research region, thematic layers on geomorphology, geology, soil, slope, elevation, drainage density, lineament density, land use land cover, and ground water level analysis were employed [39]. All of these thematic layers were combined (overlayed) to demarcate possible zones using Arc GIS 10.4 software's Modeler features. On a scale of 1 to 1/9, the weights of various themes were assigned depending on their influence on groundwater potential. On a scale of 0 to 100, different aspects of each topic were given weights based on their impact on groundwater potential. The weights were then completed by considering the weights provided by numerous specialists, as well as the weights utilized in previous studies and local experience.

Then, using Saaty's Analytical Hierarchy Process (AHP) to produce normalized weights for individual themes, a pairwise comparison of the choice based on the criterion is performed [13 and 23].

$$\textbf{Groundwater Potential Zones (GWPI)} = G_r G_w + D_r D_w + L_r L_w + Sl_r Sl_w + Ge_r Ge_w + S_r S_w + Lu_r Lu_w$$

Where,

GWPI is Groundwater Potential Index,

G is geomorphology, D is drainage density, L is lineament density, Sl is slope, Ge is geology, Lu is land use and land Cover, S is soil.
The suffix r and w represent the rank and weight of each layer.

3 RESULTS AND DISCUSSION

3.1 Base Map

The base map was selected as reference map to prepare all other thematic maps. The United States Geological Survey (USGS) was processed to create a base map of the Mirzapur District, which was then rectified by overlaying on Toposheet scale (1:50,000) Google Earth Pro. After that, the toposheet was geo-referenced (Projection and Coordinate System) with the UTM WGS-43 Geographic Coordinate System (GCS) India 1986 and WGS 1984. The base map of Mirzapur is shown in Fig. 2.

Within Geographic Information Systems (GIS), basemaps act as the essential foundation for thematic maps [22]. These basemaps provide the critical geographic context that allows users to understand the spatial relationships within the thematic data they're analyzing. They're built upon various data and imagery layers, including transportation networks (roads, highways, etc.) for understanding movement across an area, boundaries (land ownership or political divisions) for orientation and scope, and terrain representation (digital elevation models or shaded relief) to visualize the Earth's surface features [21]. Additionally, waterways (rivers, streams, lakes) are incorporated to depict drainage patterns, and imagery (aerial photography or satellite) offers a realistic backdrop for further spatial understanding. The specific combination of these elements is tailored to the thematic map's purpose. For instance, a map highlighting foreclosed properties might focus on clear street labels and parcel lines for location purposes, while a hiking trail map would benefit from detailed elevation data to depict trail difficulty. In essence, basemaps are the cornerstone of effective GIS maps, providing the crucial foundation for users to interpret and analyze the thematic information displayed.

3.2 Drainage Density

Drainage density is a valuable tool for understanding how effectively stream channels drain a particular watershed. It's calculated by dividing the total length of all streams and rivers within a drainage basin by its total area. Several factors influence drainage density, including climate and the physical characteristics of the basin itself. For example, areas with impermeable soil or exposed bedrock will have higher surface water runoff, leading to more streams and thus a higher drainage density. Similarly, landscapes with high relief or rugged topography will tend to have higher drainage density compared to flatter areas [40]. Conversely, drainage basins with thick vegetation cover, highly permeable subsurface materials, and low relief are more likely to exhibit low drainage density. In simpler terms, a high drainage density indicates a fine drainage texture, meaning water flows readily through the system. Low drainage density suggests a coarse texture, where water infiltration is slower. Drainage density also plays a role in groundwater recharge [23]. As drainage density increases, the time it takes for surface water to penetrate the ground decreases, potentially limiting groundwater replenishment.

Aster-GEO-DEM was used for generating drainage map of Mirzapur District's. The spatial resolution of Aster-GEO-DEM is 30 m, and ArcGIS 10.4 software was used to fill up the data maps in the DEM. The technique for creating stream order was then followed by flow direction (Fig.3), flow accumulation (Fig.4), and raster calculation (Fig.5). The total length of all streams and rivers in a drainage basin divided by the drainage basin's total area is known as drainage density. It's a measure of how well a watershed is drained by the stream channels. The drainage network in this work was built using ASTER/GDEM and a command sequence in ArcMap 10.4 and its density (Fig.6) was calculated using the 'Line Density' command.

The prepared map and the areal distribution of different classes of drainage density have been presented in Fig. 6 and Table 2 respectively. The drainage system was primarily dendritic, with most drainage lines running parallel to the lineaments. The Northwest side plains have a high drainage density (>2.1 km/sq km). Permeability is inversely proportional to drainage density. Rainfall infiltration is reduced as a rock becomes less permeable, resulting in a concentration of surface runoff. Groundwater shortage areas with a density of (>1 km/sq km) covered over 57.71 percent of the total area, rendering it impervious to groundwater recharge.

3.3 Elevation Map

Earth Explorer was downloading a DEM of the research region. Using ArcGIS 10.4, various satellite pictures 30m of the surrounding areas were mosaiced and then trimmed to the appropriate extent. The lowest point measured 31 m above sea level. The elevation of the Mirzapur district is less than 272 m above sea level. The highest elevation on the Mirzapur is roughly 465 m above mean sea level. The basin's average elevation is around 224 m above sea level. The slope of basin is towards the north. The DEM of the study region is shown in Fig. 7 [41,42].

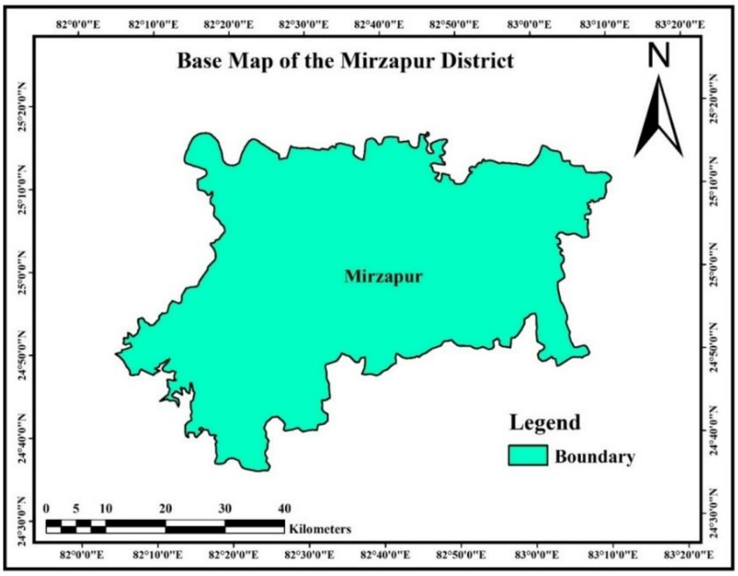

Fig. 2. Base map of the Mirzapur

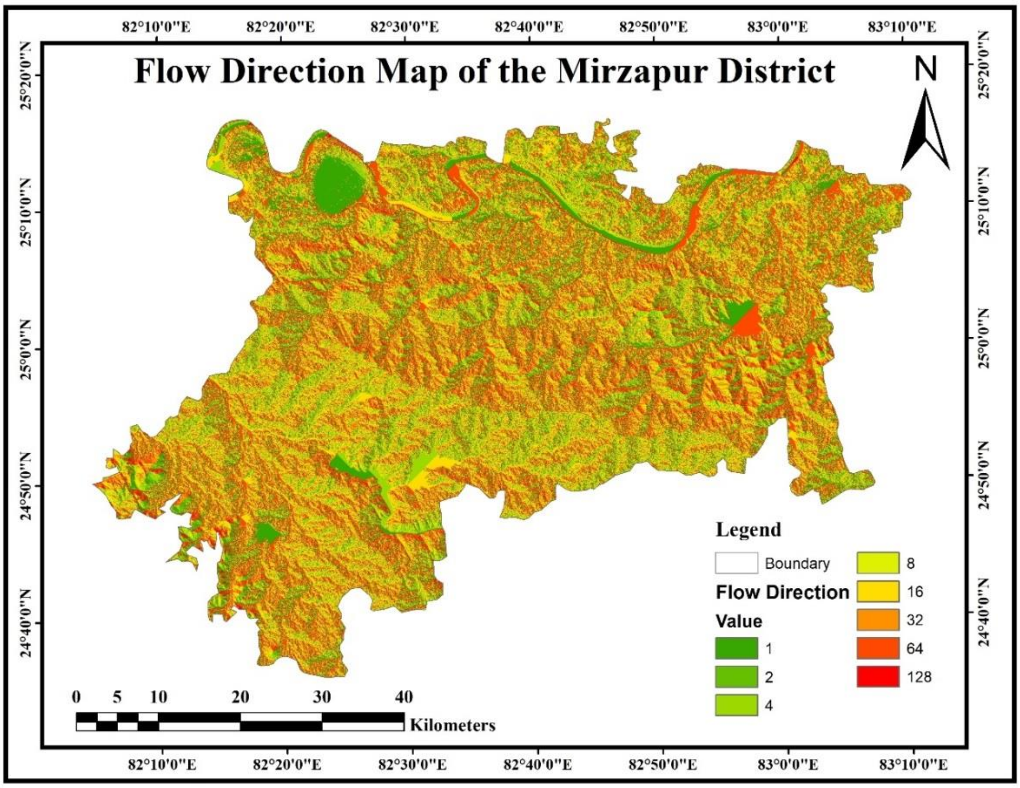

Fig. 3. Flow Direction map of the Mirzapur District

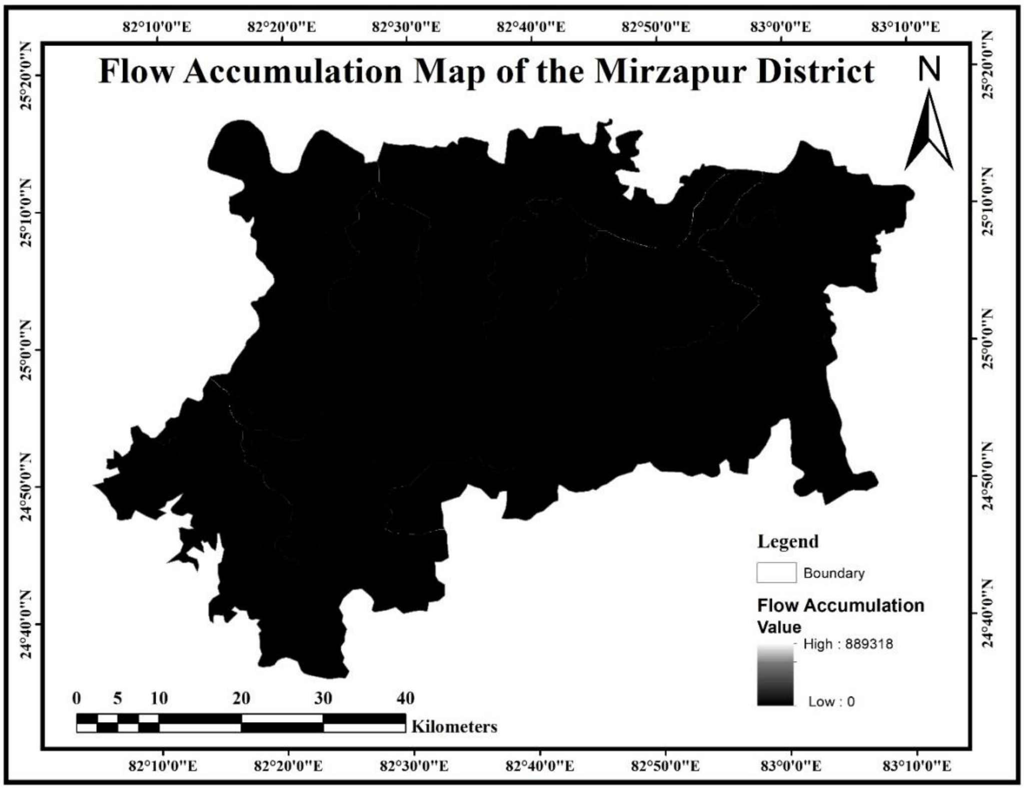

Fig. 4. Flow Accumulation map of the Mirzapur District

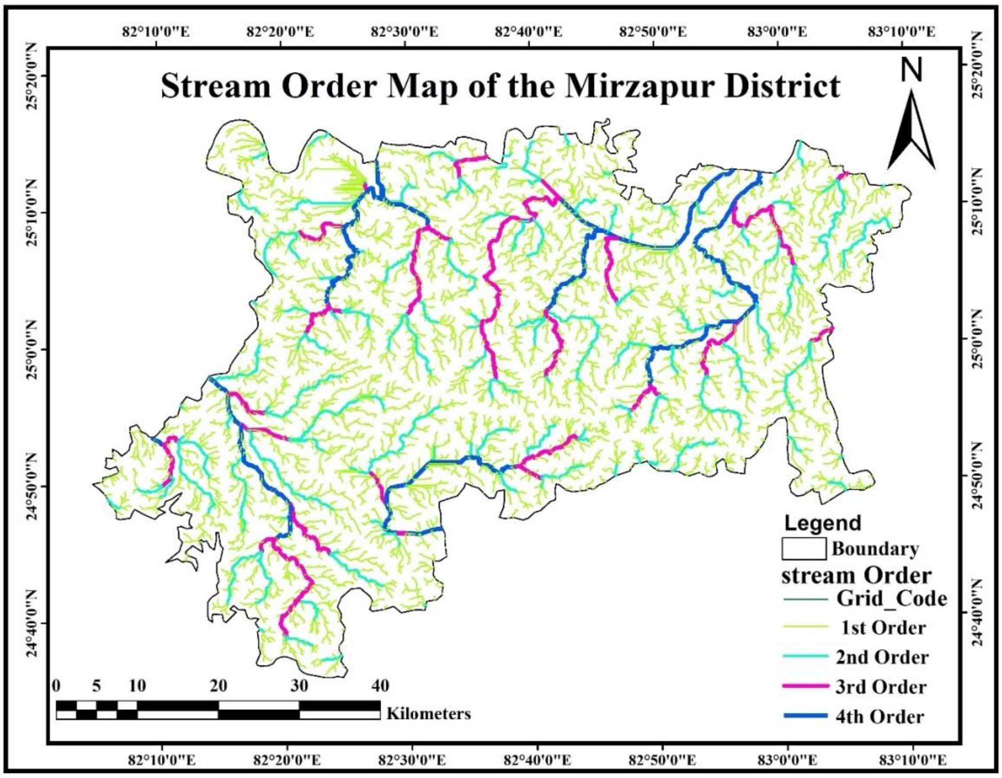

Fig. 5. Stream Order map of the Mirzapur District

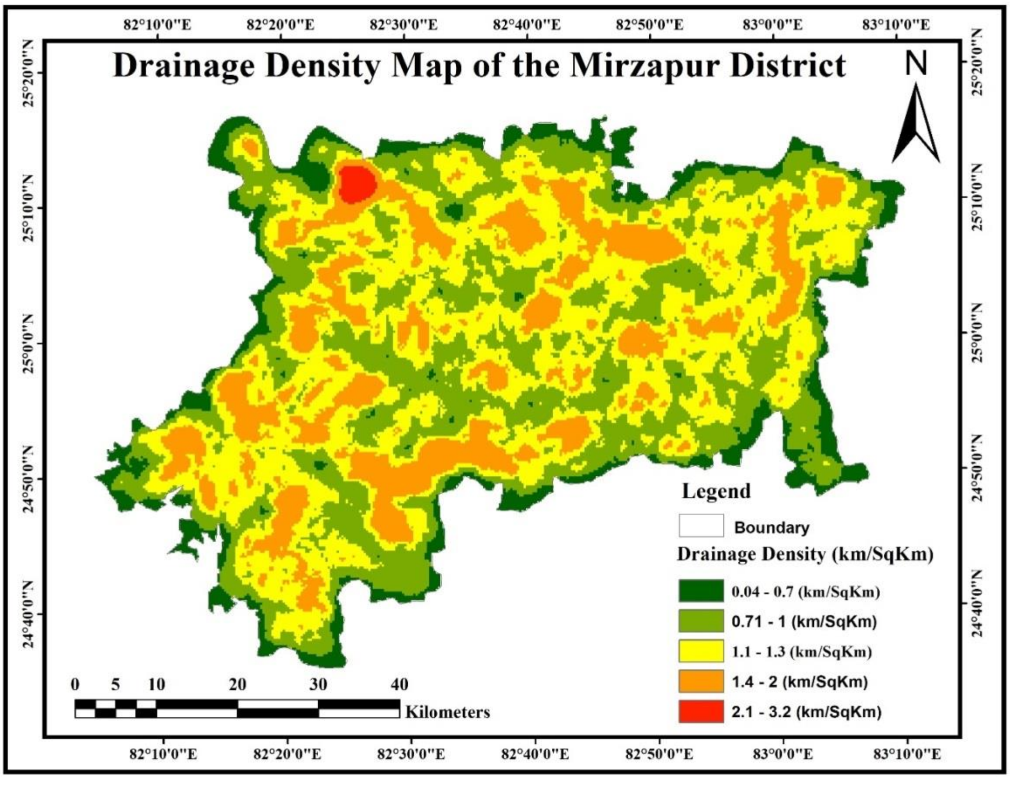

Fig. 6. Drainage Density map of the Mirzapur District

Table 2. Drainage density area distribution table

Sr. No.	Drainage density (km/sq km)	Area (sq.km)	Percentage of total area
1	0.04-0.7	464	10.27
2	0.71-1	1446	32.02
3	1.1-1.3	1714	37.96
4	1.4-2	871	19.28
5	2.1-3.2	21	0.47
Total		4516	100

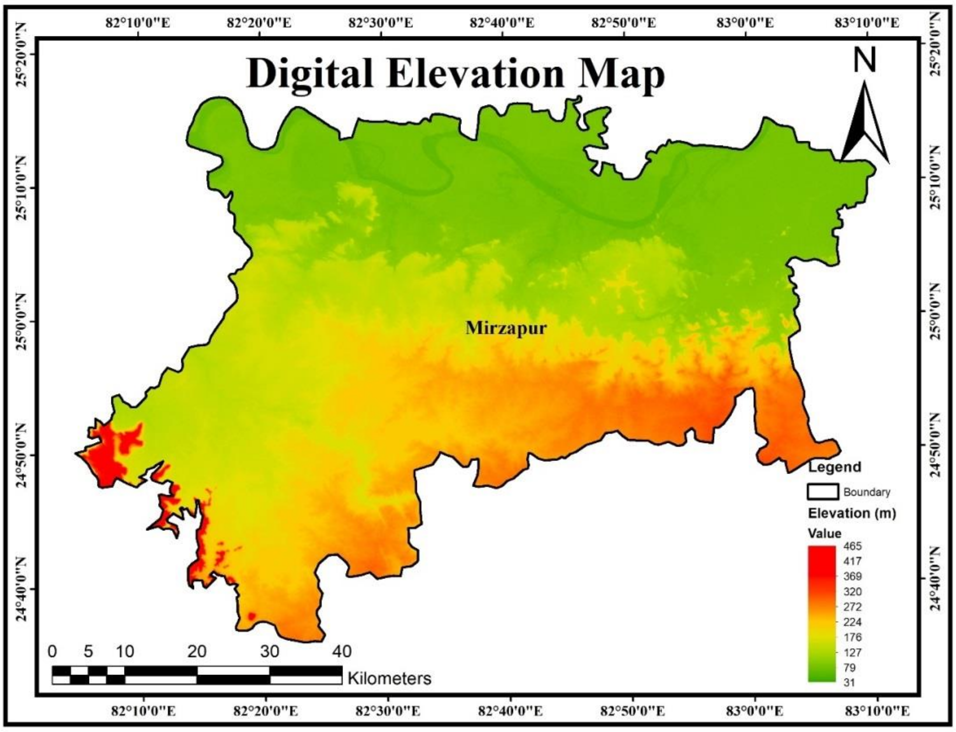

Fig.7. Digital Elevation of the Mirzapur District Slope

The maximum rate of change in height across a portion of a surface is referred to as the slope. The run-off rate increases as the slope increases since the opportunity time to infiltrate down reduces. As shown in Fig.8.the slope map was created using elevation profile derived from ASTER 30 m DEM of the study area. The slope in the study area was divided into five classes (Table 3)

3.4 Soil

The soil map of the Mirzapur District was collected from the Food and Agriculture Organization (FAO). The soil map of the study area is shown in Fig 9, Table 4.

3.5 Geology

The study area's geology map, displayed in Fig.10, was created using data from the Geological Survey of India. There are five types of geology in the area: (1) alluvium, (2) sandy silt – clay, (3) hard rock, (4) sandstone, and (5) fine grained sand stone. The studied area's geology is characterized by alluvium units, which cover 1825 km2 (40.41%), sandy silt – clay 1162 km2 (25.73%), hard rock 773 km^2 (17.12%), sandstone 545 km^2 (12.07%), and fine grained sand stone 211 km^2 (4.67 percent). The different geology classes and area distribution have been shown in table 5.

3.6 Geomorphology

The research area's geomorphology map, shown in Fig.11, was obtained from the Geological Survey of India. The area's geomorphological features can be divided into seven categories: alluvial plain, dam and reservoir, flood plain, low dissected plateau, moderate dissected plateau, pediment pediplain, and water body - river area.

The study area's geomorphology is dominated by an alluvial plain unit covering 678 km^2 (15.01%), a dam and reservoir covering 90 km^2 (2%), a flood plain covering 406 km^2 (9%), a low dissected plateau covering 160 km^2 (3.5%), a moderate dissected plateau covering 1693 km^2 (37.48%), a pediment pediplain covering 1374 km^2 (30.42%), and a water body - river area 115 km^2 (2.59%). The different geomorphological classes and its area distribution have been shown in Table 6.

3.7 Lineament Density

The length and number of lineaments inside Upper Mirzapur are derived using the Landsat 8 OLA images' digital processing technique, which provides more detailed structural and geological information [31]. The application of directional filtering on a continuous linear pattern resulted in enhanced linear features in a specific direction.

Because a high lineament density area indicates good water infiltration, lineaments are an essential hydrogeological component [26]. According to [7], groundwater potential zones benefit from high lineament density.

In the study area, lineament density ranged between 0 and 0.63 km/km^2, as depicted in Fig.12. A high lineament density value of 0.63 km/km^2 was deemed indicative of a good potential zone for groundwater. Conversely, areas with low lineament density were considered unsuitable for groundwater extraction. Specifically, within the study area, 78.63% had a lineament density of less than 0.084 km/km^2, while 16.43% fell within the range of 0.085-0.26 km/km^2, and only 4.95% had a lineament density between 0.27 and 0.63 km/km^2, as detailed in Table 7.

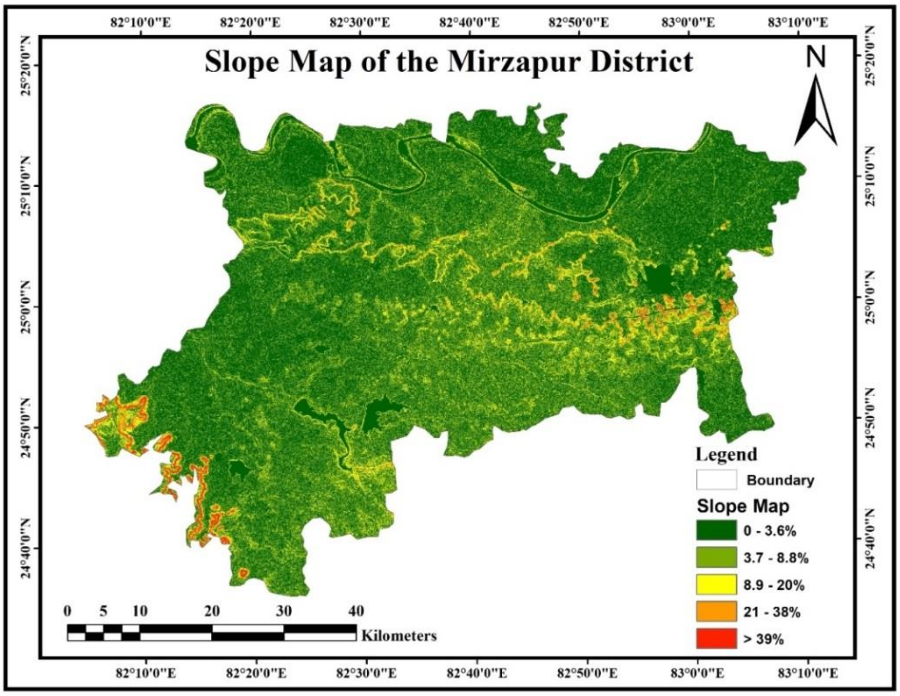

Fig. 8. Slope map of the Mirzapur District

Table 3. Slope classes distribution table

Sr. No.	Slope category	Slope (%)	Area(km^2)	Percentage of total area
1	Very low Slope	0-3.6	2436	53.94
2	Low Slope	3.7-8.8	1688	37.37
3	Moderate Slope	8.9-20	300	6.64
4	High Slope	21-38	65	1.41
5	Very high Slope	>39	27	0.64
Total			4516	100

3.9 Weights of Different Parameters-Based MCDA Tool

After determining the behavior and contribution of various thematic features to groundwater occurrence and control in the study area, appropriate weights were assigned to the various themes and individual features of various themes. Table 9 illustrates how the Continuous Rating Scale allocated weights to the specific features of each theme. These weights were established following consultations with prior researchers, such as [6] [8,10]. Threating scale used in the Multi-Criteria Decision Analysis (MCDA) assigned weights for different features and different themes of all the thematic layers for groundwater potential zones, as presented in Table 10.

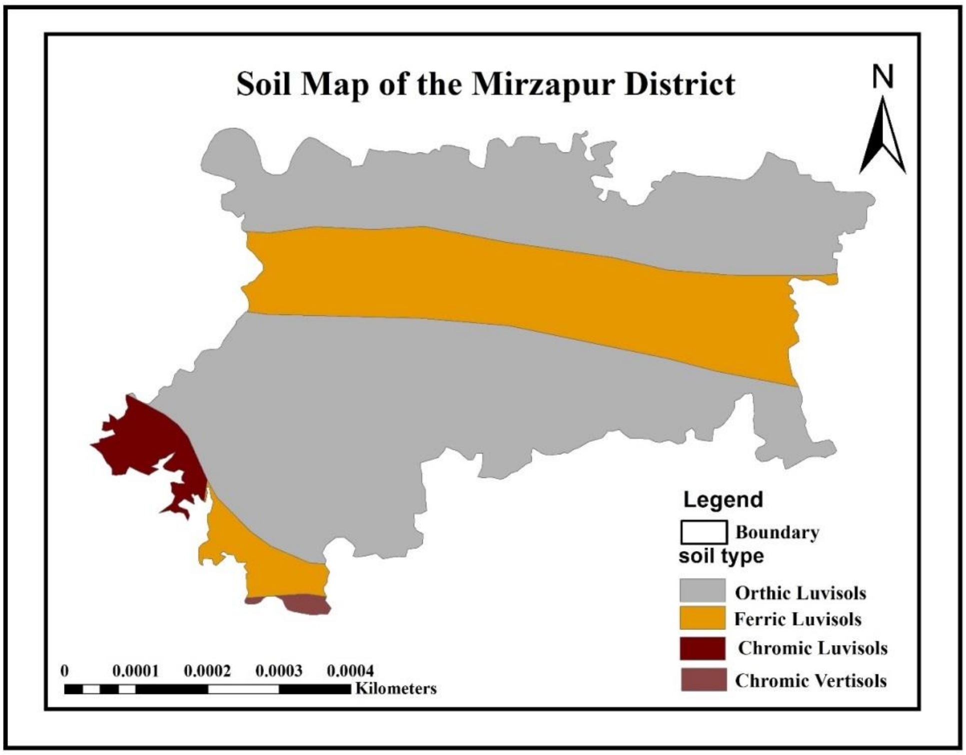

Fig. 9. Soil map of the Mirzapur District

Table 4. Soil classes area distribution table

Sr. No.	Soil Class	Area(km^2)	Percentage of total area
1	Orthic luvisols	3045	67.42
2	Ferric luvisols	1065	23.59
3	Chromic luvisols	340	7.53
4	Chromic vertisols	66	1.46
Total		4516	100

Table 5. Geology area distribution table

Sr. No.	Geology Class	Area(km^2)	Percentage of total area
1	Alluvium	1825	40.41
2	Sandy Silt -Clay	1162	25.73
3	Hard Rock	773	17.12
4	Sand Stone	545	12.07
5	Fine Grained Sand Stone	211	4.67
Total		4516	100

A pairwise comparison of the option based on the criterion using the Saaty's analytical hierarchy process to calculate normalized weights for individual themes shown in Table 11. Groundwater Potential Zones = (Geomorphology) x (38) + (Lineament Density) x (19) + (Geology) x (12) + (Slope) x (10) + (Soil) x (8) + (Land Use Land Cover) x (7) + (Drainage Density) x (6)

After that, an overlay analysis was performed using the tool 'Weighted Overlay' from the Overlay Toolset, which is part of the Spatial Analyst Tools in ArcGIS. The weighted overlay system layers numerous raster's using a standard estimation scale and loads each one according to its importance (ESRI).

3.10 Groundwater potential zone

All the thematic maps were connected with one another based on their value, using a weighted overlay. The sequence adopted in present study was a) Geomorphology, b) Lineament Density, c) Geology, d) Slope, e) Soil, f) Land use Land Cover and g) Drainage Density. As indicated in Fig.14, Gound water potential zones are divided into four categories: poor, moderate, good, and excellent. According to the classification, 1101 km^2 (24.4%) has excellent groundwater potential, 1840 km^2 (40.7%) has medium groundwater potential, 1347 km^2 (29.8%) has moderate groundwater potential, and 228 km^2 (5.1%) has low groundwater potential. The different ground water potential zones and its area distribution have been shown in Table 12.

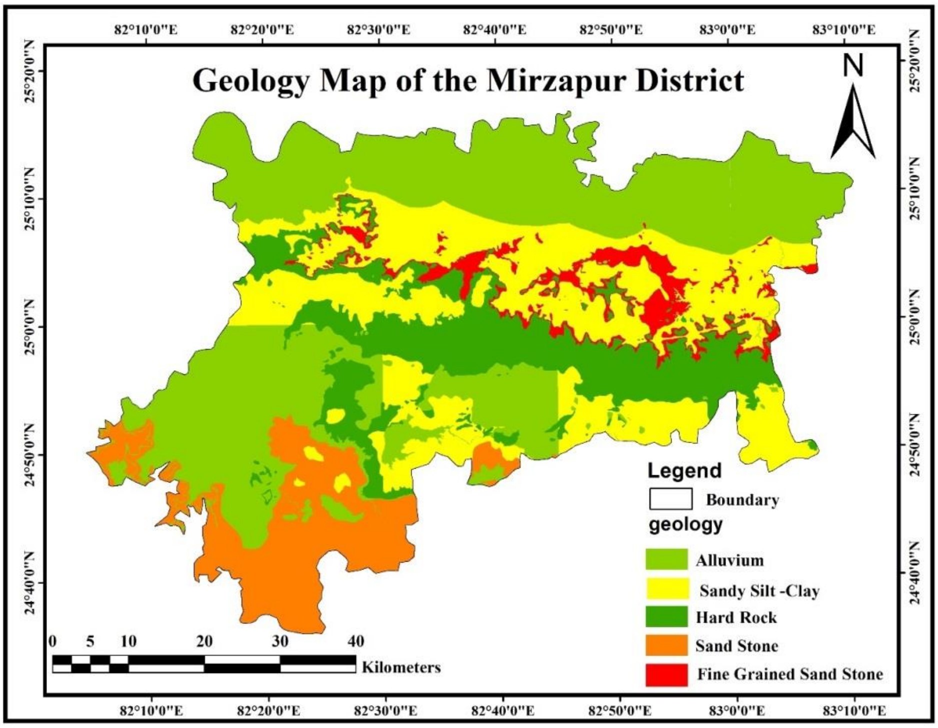

Fig. 10. Geology map of the Mirzapur District

Table 6. Geomorphology area distribution table

Sr. No.	Geomorphology Class	Area(km^2)	Percentage of total area
1	Alluvial Plain	678	15.01
2	Dam and Reservoir	90	2
3	Flood Plain	406	9
4	Low Dissected Plateau	160	3.5
5	Moderate Dissected Plateau	1693	37.48
6	Pediment pediplain	1374	30.42
7	Waterbody – River	115	2.59
Total		4516	100

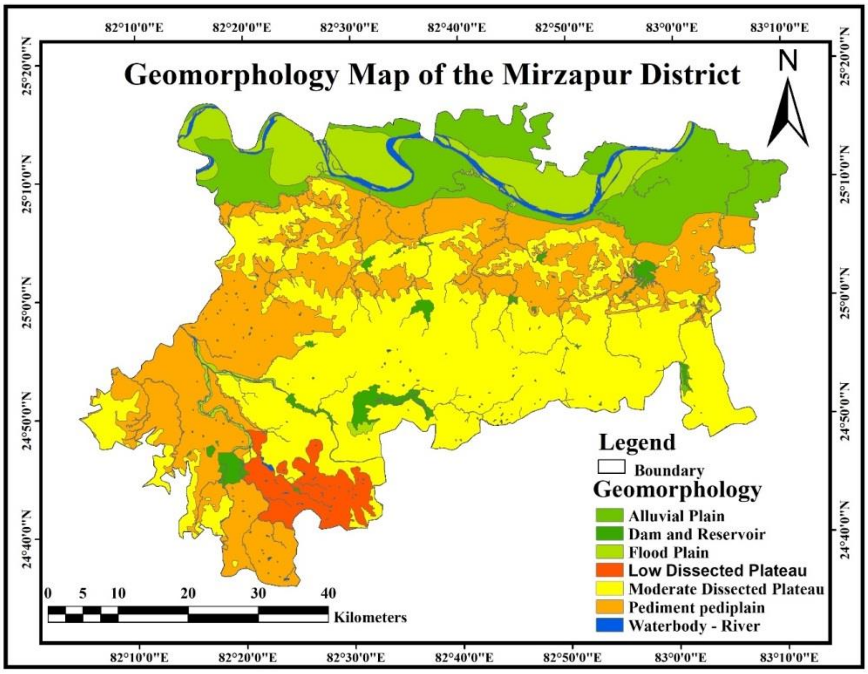

Fig. 11. Geomorphology map of the Mirzapur District

Table 7. Lineament density area distribution table

Sr. No.	Lineament density (km/km^2)	Area(km^2)	Percentage of total area
1	0-0.084	3506	78.63
2	0.085-0.26	719	16.43
3	0.27-0.63	291	4.94
Total		4516	100

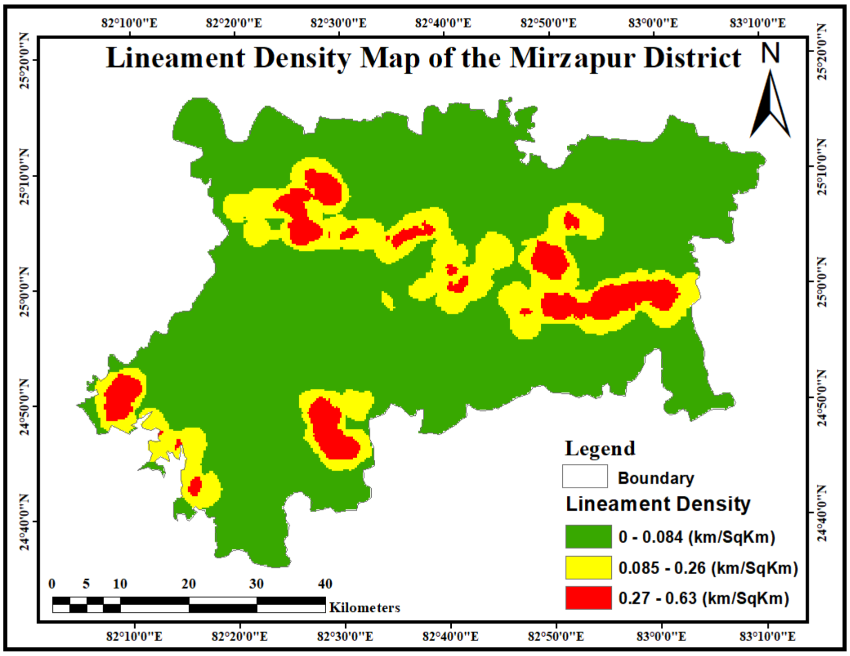

Fig. 12. Lineament density of the Mirzapur District

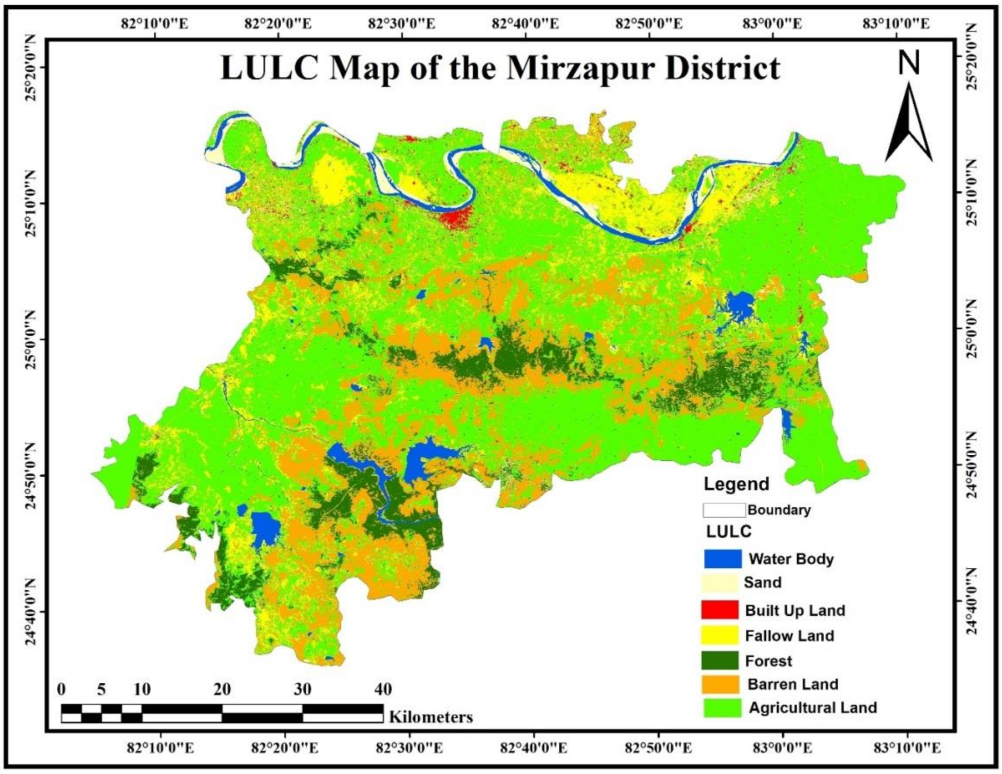

Fig. 13. LULC Map of the Mirzapur District

Table 8. Land use Land cover area distribution table

Sr. No.	Land use Land cover type	Area(km^2)	Percentage of total area
1	Water Body	163	3.61
2	Sand	118	2.61
3	Built Up Land	151	3.34
4	Fallow Land	625	13.83
5	Forest	439	9.72
6	Barren Land	917	20.33
7	Agricultural Land	2103	46.56
Total		**4516**	**100**

Table 9. Pair wise comparison of thematic layers

Layer	Geomorphology	Lineament Density	Geology	Slope	Soil	LULC	Drainage Density	Weight
Geomorphology	7	6	5	4	3	2	1	0.38
LineamentDensity	7/2	6/2	5/2	4/2	3/2	2/2	1/2	0.19
Geology	7/3	6/3	5/3	4/3	3/3	2/3	1/3	0.12
Slope	7/4	6/4	5/4	4/4	3/4	2/4	1/4	0.10
Soil	7/5	6/5	5/5	4/5	3/5	2/5	1/5	0.08
LULC	7/6	6/6	5/6	4/6	3/6	2/6	1/6	0.07
Drainage Density	7/7	6/7	5/7	4/7	3/7	2/7	1/7	0.06
Total								1

Table 10. Weights for thematic layers

S. No.	Influencing factor	Value	Eigen Value	% Weightage
1	Geomorphology	High	0.38	38
2	Lineament Density		0.19	19
3	Geology		0.12	12
4	Slope		0.10	10
5	Soil		0.08	08
6	Land Use Land Cover		0.07	07
7	Drainage Density		0.06	06
		Low		
Total				100

Table 11. Assigned weights of different features of all the thematic maps

S.No.	Influencingfactors	Class Interval	Weight	Rank	Over all Weight
		0.04-0.7 km/sq km		7	42
1	DrainageDensity	0.71-1 km/sq km	6	5	30
		1.1-1.3 km/sq km		4	24
		1.4-2 km/sq km		2	12
		2.1-3.2 km/sq km		1	6
		Alluvium		5	60
		Fine Grained Stone		4	48
		Hard Rock		1	12
2	Geology	Sand Stone	12	3	36
		Sandy Silt Clay		4	48
		Alluvial Plain		5	190
		Dam and Reservoir		6	228
		Flood Plain		4	152
		Low DissectedPlateau		1	38
		Moderate Dissected Plateau		2	76
3	Geomorphology	Pediment Pediplain	38	3	114
		Waterbody- River		7	266
		Water Body		8	56
		Sand		7	49
		Built Up Land		3	21
		Fallow Land		4	28
	Land use Landcover	Forest		6	42
4		Barren Land	7	2	14
		Agricultural Land		5	35
		Orthic Luvisols		3	24
		Chromic Luvisols		2	16
5	Soil	Ferric Luvisols	8	1	8
		Chromic Vertisols		4	32
		0-3.6%		7	70
		3.7-8.8%		6	60
		8.9-20%		3	30
6	Slope	21-38%	10	2	20
		>39%		1	10
		0-0.84 km/km^2		6	114
	Lineament Density	0.085-0.26 km/km^2		4	76
7		0.27-0.63 km/km^2	19	1	19

Table 12. Ground water potential zones area distribution table

Sr. No.	GW Potential Zones	Area(km^2)	Percentage of total area
1	Excellent	1101	24.4
2	Good	1840	40.7
3	Moderate	1347	29.8
4	Poor	228	5.1
Total		**4516**	**100**

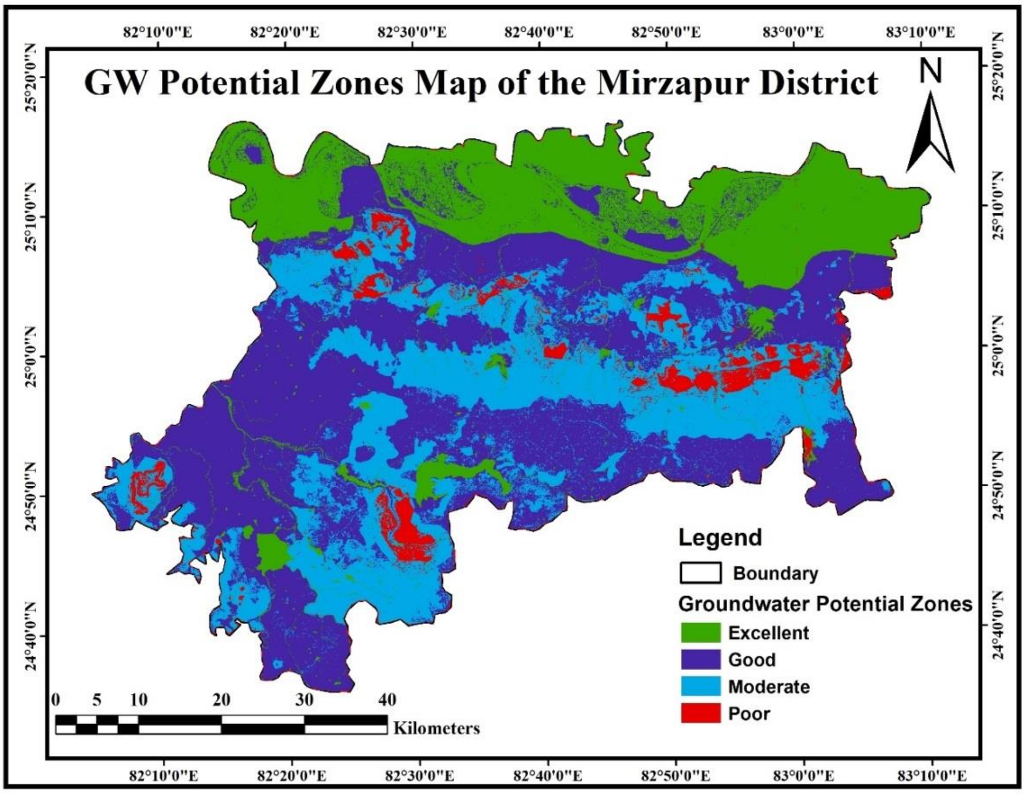

Fig. 14. GW Potential Zone Map of the Mirzapur District

4. CONCLUSION

Groundwater studies hold paramount importance in optimizing groundwater usage across various sectors, spanning agriculture, domestic, and industrial needs. Throughout human history, groundwater has been crucial in meeting water demands, and its role continues to evolve amidst climate variability, increasing demands, and catchment degradation. Addressing these challenges necessitates understanding groundwater potential zones and recharge mechanisms. Artificial groundwater recharge, a key aspect of integrated water resource management, involves replenishing groundwater tables by introducing water into permeable formations. Perspective zoning aids in identifying areas with readily available groundwater and those experiencing stress in terms of water potential. Modern techniques such as remote sensing and GIS play pivotal roles in studying groundwater availability and recharge potential.

In the case of the Mirzapur district, situated between 23°52´ to 25°32´ north latitude and 82°07´ to 83°33´ east longitude, covering an area of 4516 km², the elevation ranges from 31m to 465m above sea level. Groundwater recharge potential zones were estimated by analyzing various parameters including geology, geomorphology, drainage density, lineament density, slope, land use land cover, soil, and elevation. The AHP MCDM method was employed to rank these factors, followed by weighted overlay analysis to delineate groundwater potential zones. The resulting recharge potential zone map integrates thematic layers using remote sensing and GIS techniques. Through a weighted Multi-Criteria Decision Analysis (MCDA) process, different groundwater potential zones were assigned based on interpreted layers, resulting in four classes: excellent, good, moderate, and poor. These zones provide insights into the relative roles of different areas within the district.

In the study, agriculture land cover is 2103 km^2 which accounts 46.56% of the total area, 917 km^2 area (20.33%) is under Barren lands, 625 km^2 area (13.83 per cent) is under fallow land, 151 km^2 (3.34 per cent) under built up land, 439 km^2 area (9.72 per cent) is under forest and 163 km^2 area (3.61 per cent) is of water bodies. Very high drainage density (2.1-3.2 km/km^2) is founded in the Mirzapur District and density covered 0.47%. Very low slope (0 - 3.6 %) was observed in study area which cover 53.94 % of the total area indicating that the opportunity time of water infiltration is high. The higher lineament density (0.27 to 0.63 km/km^2) observed in the Mirzapur district and it covered almost 4.94 percent of the total area. The groundwater potential map groundwater recharge map demonstrates potential water extraction and recharge zones in the district. In the study, the poor ground water recharge area is about 228 Km^2 which constitute 5.1% of total area and 1347 Km^2 which is nearly 29.8% of the total area fallen in moderate ground water zone which is basically in the hilly terrain. Therefore, this area may be restricted for ground water exploration and artificial recharge and surface water supply sources may be developed in this area. Nearly 1840 Km^2, which constitutes 40.7% of total geographical area is being demarcated under good groundwater potential zone because of all favorable features regarding different parameters taken into consideration. In the same way nearly 1101Km^2, which is nearly 24.4% of total area has emerged as excellent groundwater potential zones.

Thus, based on overall analysis groundwater recharge zones must be identified in areas having lack of groundwater potential zone and surface water availability as well as ground water recharge facility must be ensured in this area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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