Original Research Article

Groundwater potential zones using multi – criteria decision making for Mirzapur, District, U.P, India

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, and industry. 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 and poor-quality surface water resource. As a result, necessity has been realized to identify Groundwater Potential Zones (GWP) that can supplement the groundwater supply. This study was conducted for Mirzapur district where the groundwater serves as the main source for domestic and agricultural purposes rather than the surface water. To delineate the potential groundwater zones, the parameters namely: geology, drainage density, slope, geomorphology, soil, land use and land cover, and lineament density 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 km2), good 40.07% (1840 km2), moderate 29.8% (1347 km2), and poor 5.1% (228 km2) 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: Groundwater Potential Zonation, GIS, Weighted Overlay, Multi Criteria Decision Analysis (MCDA), AHP

1. Introduction

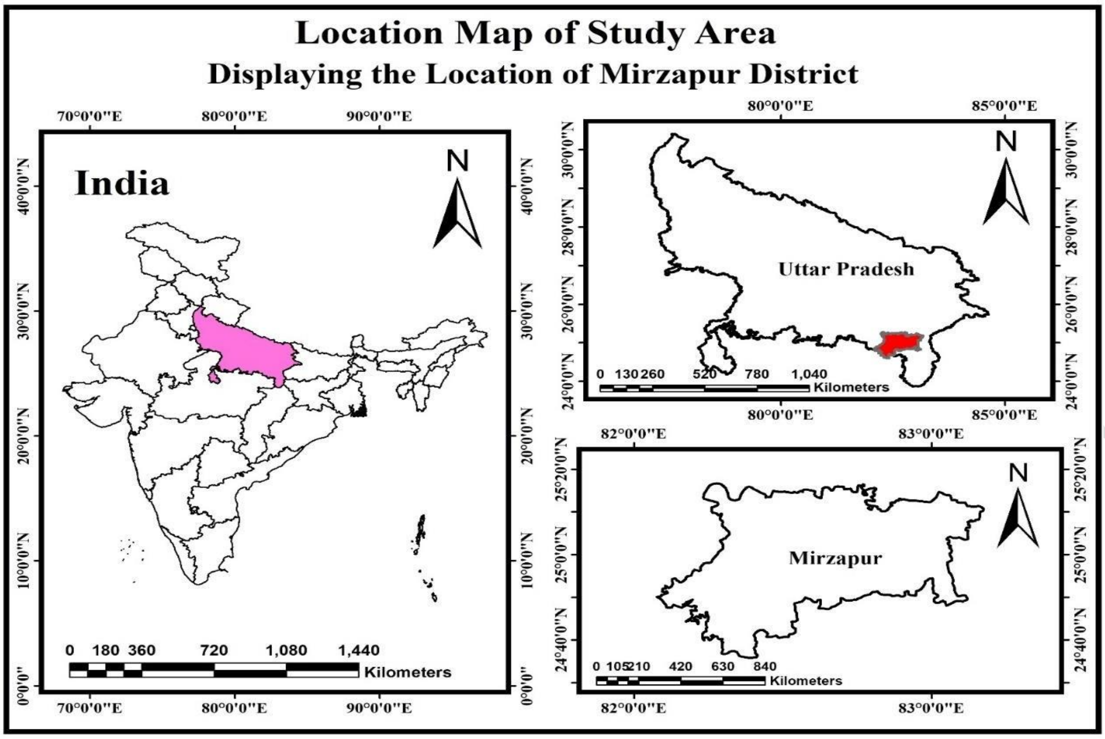
Groundwaterisoneoftheworld'smostimportantsourcesofwater.It'sa natural resource that's both dynamic and renewable (Gebrie and Getachew, 2019).Groundwater is an essential natural resource on the earth that is used fordrinking,irrigation,and industry,among otherthings (Sharmaand Kujur,2012).In India, 80–90 percent of the rural population and 50 percent of the urbanpopulationrelyongroundwaterfordomesticpurposes,whilenearlyhalfoftheirrigated land is reliant on groundwater. In manyareas,excessivegroundwaterremovalsurpassesnaturalrecharge, and aquifers are drying up as a result of this imbalance between recharge and extraction. In most places of the world, the amount of fresh groundwater supply is reducing overtimeowing to over-exploitation (Kaliraj *et al.* 2014). It isalsoworthnotingthatUttarPradesh aloneaccountsfor28.68percentof thewhole Ganga basin, which spans 11 states and includes some of the country's mostfertileandproductiveterritory,aswellastremendouswaterresourcepotential.Currently, groundwater supplies 70 percent of the state's irrigated agriculture, as wellas 90 percent of rural home needs, more than 75 percent of urban water usage, and 95percent of industrial, infrastructure, and commercial needs. Irrigation supplies in thestate are heavily reliant on groundwater, with over 37 lakh shallow tube wells drawingover 41 bcm of groundwater yearly, accounting for roughly 90% of total groundwaterabstraction in the state. This is made more essential by the fact that this state is hometo35-40%ofall irrigation wellsin thecountry(State-of-ground-water-2021report). Mirzapur district covers an area of 4516 Sq. km. and falls in the VindhyanSupergroup rocks. Hillocks, plateaus, and plains formed by alluvium characterize thedistrict. In the district's hilly areas, rainfall run-off is considerable. Apart fromlesser streams in the district, the Ganga and Belan are the main drainage systems.Groundwaterisfoundinporous,fractured,andweatheredzones,accordingtodata fromCGWB'sexploratorydrillinginthedistrict.Inthedistrict,wellyieldsrangefrom30 to 3100 lpm with a 30m drawdown. In the pre-monsoon period, the depth to waterlevelrangesfrom5.00to45.00mbgl.Thewaterlevelinthepost-monsoonrangesfrom 3.30to16.75mbgl.From2001to2011,waterleveldataforallNHS(National Hydrograph Stations) inthedistrictwere reviewed, revealing that the long-term fluctuation spans between 0.79 and 4.00 m,indicating a negligible base flow of ground water in the area. The district's long-termwater level trend has showed a fall in ground water levels. Except for a few villages in Marihanblock,wheresignificantironconcentrationingroundwaterhasbeendetected,chemicalanalysisofgroundwatersamplesfromthedistrictshows thatthewaterquality isfresh and potable(GroundwaterBrochureofMirzapurDistrict, U.P.). It is possible to seek for buried and paleo-channels for potable ground water.Artificialrechargeproceduresandwater-shedmanagement(fromhilltovalleyapproach)shouldbeusedonabigscaletocombatthedistrict'sdiminishingwater level trend. The quality assessment of shallow and deep groundwater, aswell as its relationship to lithological behavior, is urgent. The use of Remote Sensing,Satellite Imagery Analysis, and Resistivity Surveys should be used to investigatepossibleground waterwithdrawal sites. Thestatisticalmethod,expertevaluation,anddeterministicmethodcanbeused to determine the groundwater potential zone. The groundwaterpotential index method is the most popular and reliable method of identifying thepotentialzone(Gebrie and Getachew, 2019).

Identifying groundwater recharge potential zones is crucial for effective water resource management, particularly as demand continues to rise (Chowdhury et al., 2010). While traditional methods like test drilling are time-consuming and costly, recent decades have seen the adoption of remote sensing and GIS technologies for this purpose, offering a more efficient and comprehensive approach (Das & Pal, 2019). Multi-criteria decision analysis (MCDA), often employing techniques like the Analytical Hierarchy Process (AHP) introduced by Saaty (1980), has become popular for categorizing groundwater potential zones due to its mathematical robustness and ease of data integration (Machiwal et al., 2011). The Mirzapur district, facing increased water demand, primarily from groundwater exploitation, highlights the urgency of sustainable groundwater management strategies to address ecological concerns such as declining groundwater levels and water pollution (Chowdhury et al., 2010). Remote sensing and GIS techniques offer valuable tools for delineating groundwater potential zones, leveraging various thematic layers such as geomorphology, geology, land use/land cover (LULC), and drainage density (Chowdhury et al., 2010). Consequently, studies like "Assessment of groundwater potential zones using RS and GIS" are essential for informed decision-making and resource allocation, adapting the number and type of thematic layers according to site characteristics and data availability (Chowdhury et al., 2010).

2. StudyArea

Mirzapur district, Uttar Pradesh has been selected as a study area in this researchwork. 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´ Eastlongitude.Itis80metersabovesealevelonaverage(265feet).ThedistrictofMirzapur is located between the latitudes of 23.52 and 25.32 North and the longitudes of 82.7and 83.33 East. It shares border with Varanasi district on the north and north-east, Sonbhadradistrict on the south, and Allahabad district on the north-west. Chunar, Marihan,Lalganj, and Mirzapur Sadar are the administrative divisions of the district, which arefurther divided into 12 development blocks. Mirzapur had a population of 234,871people in 2011, according to Census India's provisional data, with 125,601 men and109,270women.Mirzapurhasapopulationof234,871people,butitsurban/metropolitan population is 246,920, with 132,055 men and 114,865 women. The sexratioin themunicipality was 876 females per1,000males.

Fig.1:LocationMap ofStudyArea



2.1 ClimaticCondition

Thedistrict'sclimateismainlymildtemperate,where temperatureranges between 5^{o}C to 46^{o}C, maximum in the month of June and minimum in the month ofDecember. Mirzapur receives roughly 80 to 85 percent of its rainfall from the Bay ofBengalmonsoonbranchduringthemonsoonseason(JunetoSeptember).The averageannualrainfallforthedistrictisaround990millimeters.TheIndianMeteorological Department (IMD) provided monthly meteorological variables such as rainfall andtemperature.

2.2 Software Used

ArcGIS, a Geographic Information System (GIS) program utilized in this project, facilitates the manipulation, preparation, and analysis of maps and geographic data. The version employed, ArcGIS 10.4, offers a comprehensive suite of tools for map creation, data compilation, spatial analysis, and data sharing. It enables users to leverage geographic information in various applications and manage spatial data within a database. 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 (ArcGIS, version 10.4).

This image processing program is well-known and widely used. Image interpretation, classification, and subsequent analysis have all been done using the same method.

2.3 Georeferencing

The goal of georeferencing is to connect a map's or aerial photo image's internal coordinate system to a ground system of geographic coordinates. Georeferencing is the process of assigning coordinates to a map that lacks geographic coordinates by using four or more well-known landmarks. The word is often used in the field of geographic information systems to describe the process of linking spatial places with a physical map or raster image of a map.

Though there are several different techniques for achieving georeferencing, the appropriate coordinate transforms are often contained within the picture file (for example, GeoPDF and GeoTIF).

2.4 Mosaic

A combination or merger of two or more images is termed as mosaic. In mosaic two or more neighboring datasets which are merged in order to make one object. While mosaicking there could be sudden changes along the overlapping raster boundaries and such overlapping could be reduced by variety of ways. For example, the tool could be set to keep only the first raster dataset's data or overlapping cell values could be blended. In case a raster dataset uses one full stop, several options could be used to determine how to develop a colour map. In such case colour map of the latest raster dataset, which is used in the mosaic, could be kept.

2.5 Clip

Clipping is a tool to create subset of a raster dataset. This is done for generating a new feature class which could be geographic subset of a larger feature class. In clip tool a slice of one feature class is cut out by utilizing one or more feature classes as cookie cutters. Clip features could be points, lines and polygons depending upon the input features. In the output feature, all the attributes of input features are included. For handling large number of datasets, clip uses tiling approach.

3. Preparation of Various Thematic Maps

Thematic maps, such as groundwater potential zones and artificial recharge zones, are used to assess groundwater potential zones and artificial recharge zones. According to the requirements, geology, geomorphology, soil, slope, land use and land cover, drainage network, drainage density, lineament, and water map were created using both satellite photos and traditional data.

*3.1*Base Map

The map was opened in ArcGIS 10.4 program for the preparation of the Mirzapur district boundary and registered by four-pint georeferencing procedure. The district administrative map was registered using an image-to-image registration procedure. The district border was digitize using the GIS software's on-screen digitization features. The limits of digitized boundaries were scoured for use in this study.

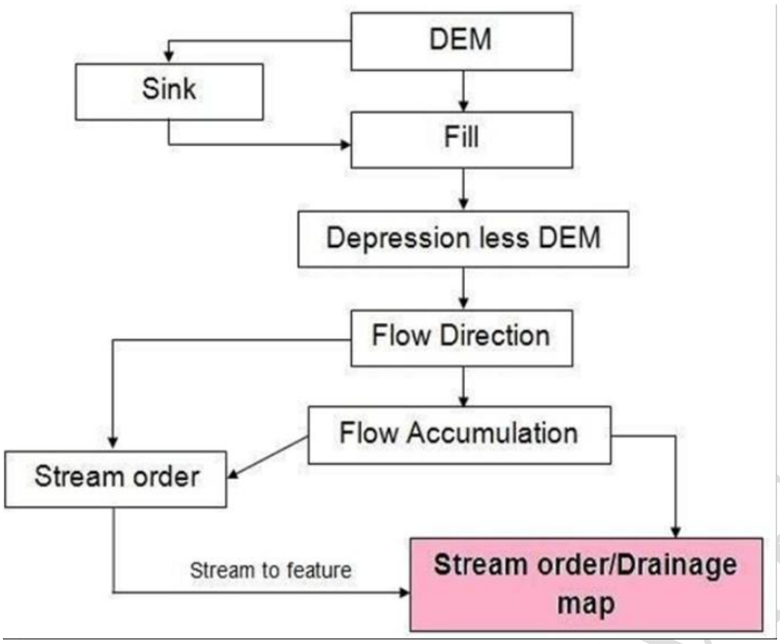
The Digital Elevation Model (DEM) was processed to create a base map, which was then corrected by overlaying it on the Google Earth interface.

*3.2*Elevation

Water prefers to travel to lower elevations rather than higher elevations. The ground water potential decreases as elevation rises, and vice versa. For this investigation, a 30m spatial resolution ASTER DEM was used to create an elevation map.

*3.3*Drainage Map

The drainage map is a map that depicts all types of stream networks. DEM was used to create the drainage network for the study region. Using ArcGIS 10.4 software, stream segments of various orders were digitized, and a drainage map was then processed using standard commands in ArcGIS 10.4 to create a drainage density map (flow chart .1). The steps used to prepare drainage map. Slope, characteristics of bed rock, and fracture patterns are explained here and all have a role in the drainage system. Drainage networks, which are plainly apparent on remote sensing image, reflect the lithology and structure of a specific location to varied degrees. As a result, it is critical for assessing groundwater supplies.



Flow Chart 1: Drainage Density

*3.4*Drainage density

The ratio of the total length of a stream segment to the basin area projected on a horizontal surface is known as drainage density.

$$\mathrm{Dd} = \frac{Lu}{\mathrm{A}}$$

Where,
Dd = Drainage density (m/Sq. M)
Lu = Total stream length of all orders (m)
A = Area of the watershed (m)

The ratio of total stream length of all orders per unit basin area is known as drainage density (Horton, 1945). Dd is a numerical measure of dissection and runoffpotential in the landscape.It depicts the catchment's infiltration capacity and vegetation cover.

Drainage was investigated using two parameters: the first is drainage pattern, which is linked to the substratum's nature and structure. The second factor is drainage texture, which is affected by rock/soil permeability as well as the kind of rock/soil. In fact, the less permeable a rock is, the less rainfall penetration occurs, which is therefore concentrated in surface runoff. This is where a well-developed and excellent drainage system emerges. In Karst environments, on the other hand, where underground water circulation is far more developed than surface water circulation, drainage is less developed or non-existent (Krishnamurty *et al*. 1996).

*3.5*Slope

In groundwater research, terrain slope plays a crucial role in determining water accumulation rates at specific sites. The slope gradient directly influences rainwater infiltration, with lower slopes resulting in reduced runoff and increased infiltration and recharge. Consequently, flat terrain is more favorable for groundwater availability due to its higher potential for infiltration. The creation of slope maps utilizes datasets such as the SRTM DEM 30m to accurately depict terrain gradients and inform groundwater studies.The tool Arc GIS 10.4 Analyst was used to create it. An examination of the surface slope percentage is a function that calculates the slope.

3.6 Geology

Geology is one of the most important determining elements in the occurrence and transport of groundwater in each area. The thematic layer on geology was created using the Arc GIS 10.4 software using a map from the Geological Survey of India. The Geology of Mirzapur District resource map was scanned, corrected, and georeferenced.

3.7 Geomorphology

Geomorphology (Gregory and Goudie, 1986) is the science of landforms, and it has a direct link to the presence and flow of groundwater. The geomorphology of a certain place deals with rock type, soil type, drainage pattern, and so on, and so geomorphic units and associated features indirectly govern an area's groundwater prospect. The data collected from the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP), Mirzapur, was classed in ArcGIS 10.4 program for thisstudy. The reclassification was carried out to ensure that the obtained data was compatible and easy to understand for future research. To reclassify the collected data, “classify tool” of spatial analyst, ArcGIS 10.4 was taken into use.

*3.8*Soil

Soil, as defined by Johnson et al. (1980), refers to the residual material shaped by physical, chemical, and biological processes. Its impact on groundwater occurrence is primarily dictated by its retention capacity, often correlated with its texture. Soil texture is characterized by the relative proportions of silt, sand, and clay. Clay soil, with its smaller pores, tends to promote runoff and hinder infiltration, while sandy soil, featuring larger pores, facilitates greater infiltration and subsequently recharges groundwater reserves (Johnson et al., 1980).

As previously stated, the study area's soil map was received from the Food and Agriculture Organization (FAO). Using Arc GIS 10.4 software, the map was scanned, corrected, and georeferenced.

3.9 Land Use Land Cover Map

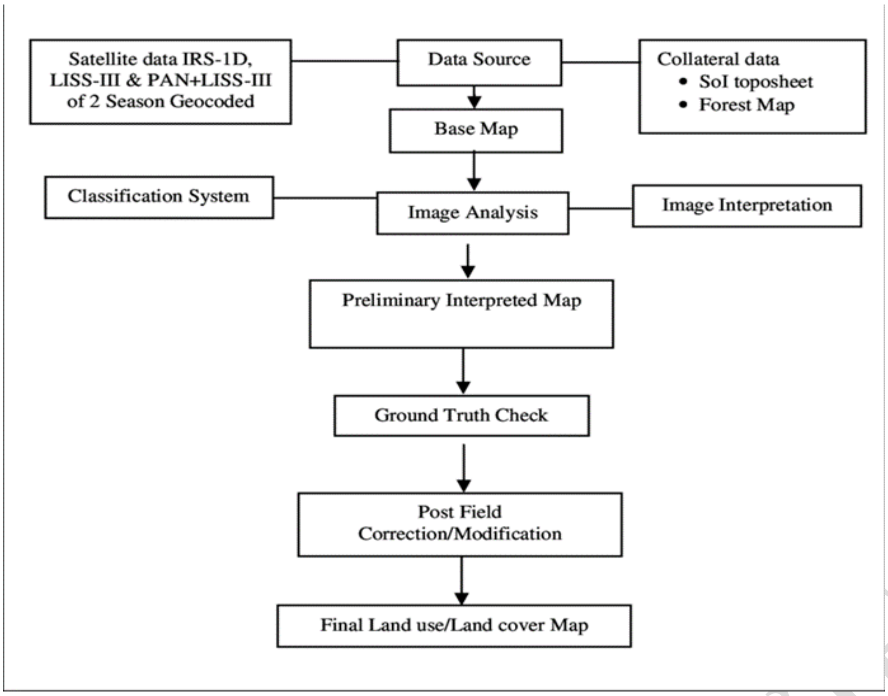
“Human activities and diverse uses carried out on land” are referred to as “land use”, “Vegetation, water bodies, rocks/ soil, artificial cover, and others originating from transformations” are all examples of land cover. The research area's land use/land cover classification was done using Sentinel satellite images.

There are two methods for categorizing pixels into distinct groups. A supervised classification approach is the first technique. This is an interactive method in which the operator builds a training data set of pixels that belong to one or more land use/land cover categories. The unsupervised classification approach is the other classification strategy. In this strategy, the operator selects how many different classes are desirable and then uses a complex set of algorithms to classify the data into the statistically created

3.10 Image classification

Image classification involves extracting information classes from multiband raster images to generate thematic maps. This task can be performed through supervised or unsupervised methods. In supervised classification, the analyst guides the computer by providing training samples, while unsupervised classification relies on algorithms to group similar pixels without prior training. These methods are essential for various applications, including land cover mapping and environmental monitoring.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 (Weber and Dunno, 2001). To classify the area into several land use classifications in this study, a hybrid classification strategy (supervised, unsupervised, and NDVI threshold) was used. The distinction between supervised and unsupervised classification is based on the fact that the majority of remotely sensed images are composed of spectral classes that are reasonably homogeneous in terms of reflectance throughout one or more spectral channels, and so can be defined and mapped (Tou and Gonzalez, 1974).

In this study, the ArcGIS 10.4 program was employed to classify land use and cover (flow chart .2). Visual supervised classification, also known as pixel-based classification, was employed as the most prevalent land use classification approach.



Flow Chart .2: Land Use and Land Cover

3.11 Lineament

Lineaments, which are linear or curved features found on the Earth's surface, serve as indicators of underlying geological characteristics such as weak zones in bedrocks and secondary aquifers, particularly in hard rock regions. These lineaments often correlate with geological structures like faults, fractures, joints, bedding planes, and lithological boundaries. Utilizing satellite data, researchers and geologists employ various techniques to map these lineaments effectively. By analyzing satellite imagery, patterns of lineaments can be identified and studied, providing valuable insights into the geological makeup and hydrogeological properties of an area. Lineament mapping contributes significantly to geological studies, groundwater exploration, and natural hazard assessments by revealing subsurface features and potential pathways for fluid movement. Therefore, understanding and mapping lineaments play a crucial role in comprehending the Earth's subsurface processes and geological hazards. The intersection of lineaments is thought to be a favorable location for groundwater potential zones to arise. Groundwater potential zones benefit from areas with dense lineaments (Haridas *et al*., 1998). Thus, Lineaments play an important role in groundwater potential zoning. In this work, Lineaments were identified using satellite Landsat 8 OLI data collection.

3.12 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. AHP facilitates the evaluation of a set of criteria and a range of alternative options to determine the most favorable course of action. 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. These scores are then aggregated to derive a global score for each option, resulting in a ranking. 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.The various AHP parameters to check the consistency of weightage assigned to each thematic layer is given in table 1.

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

AHP parameters	**Formula**	**Remarks**
ConsistencyMeasures	(RowofcomparisonMatrix) × (Eigen Vector)/Corresponding Eigen Vector ofthe row	*Last column of theNormalizedMatrix*
PrincipalEigenValue	Λmax	*Averageofthecolumnof ConsistencyMeasures*
ConsistencyIndex (CI)	λmax– n/n-1	*nisnumberofthematic layers*
ConsistencyRatio (CR)	CI/RI	RIisRandomIndex

Table 2: ValuesofRandom Index(RI)fornumberofthematiclayers(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 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 2) used to calculate the consistency ratio (Saaty 1980), 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(1986, Saaty).

3.13 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. 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.

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.

3.14 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. All of these thematic layers were combined (overlayed) to demarcate possible zones using Arc GIS 10.4 software's Modeller 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.

$$\mathbf{GroundwaterPotentialZones\ (GWPI)} = \mathbf{G_rG_w + D_r\,D_w + L_r\,L_w + Sl_r\,Sl_w + Ge_rGe_w + S_r\,S_w + Lu_r\,Lu_w}$$

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.

4. Result and Discussion

4.1 Preparation of Thematic Maps

4.1.1 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. 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. 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.

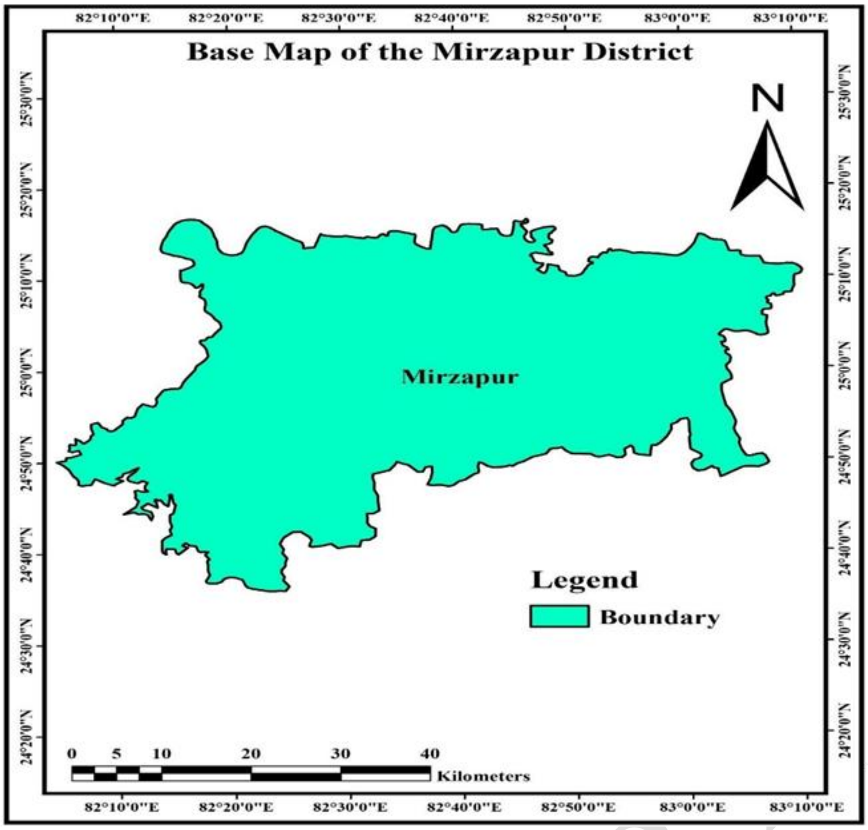


Fig. 2: Base map of the Mirzapur

4.1.2 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. 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. 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 generatingdrainage 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.

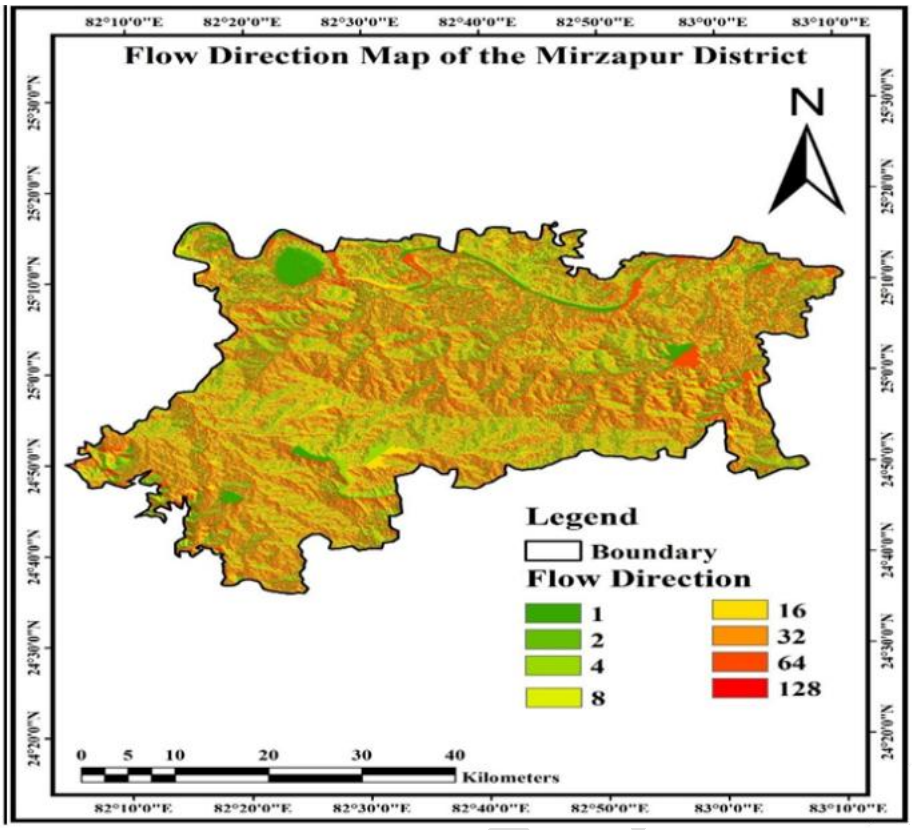


Fig. 3: Flow Direction map of the Mirzapur District

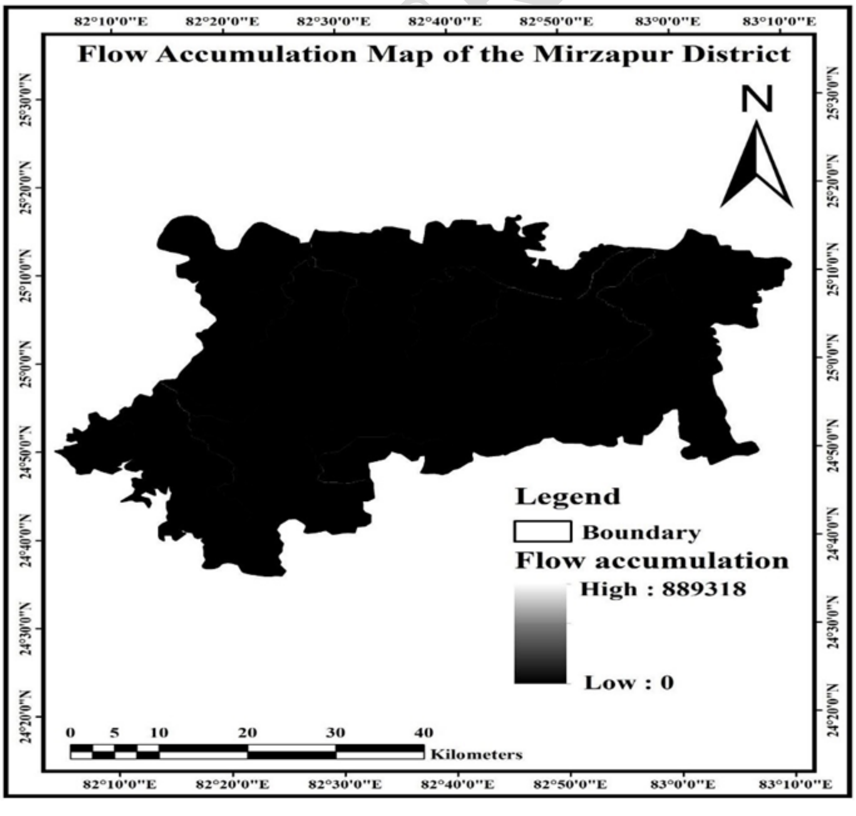


Fig. 4: Flow Accumulation map of the Mirzapur District

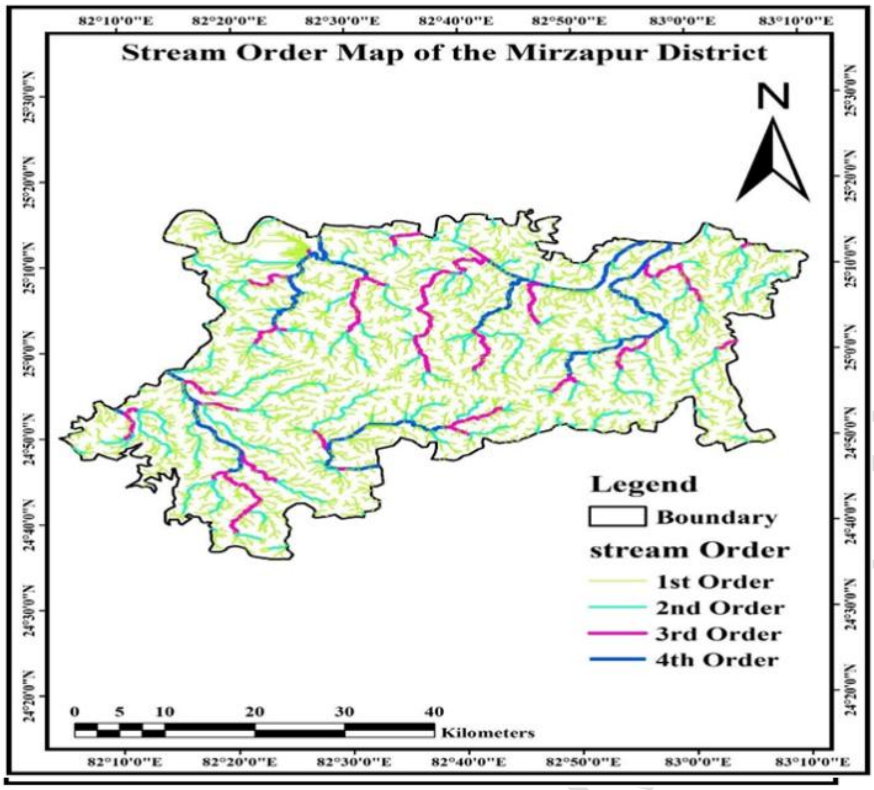


Fig. 5.: Stream Order map of the Mirzapur District

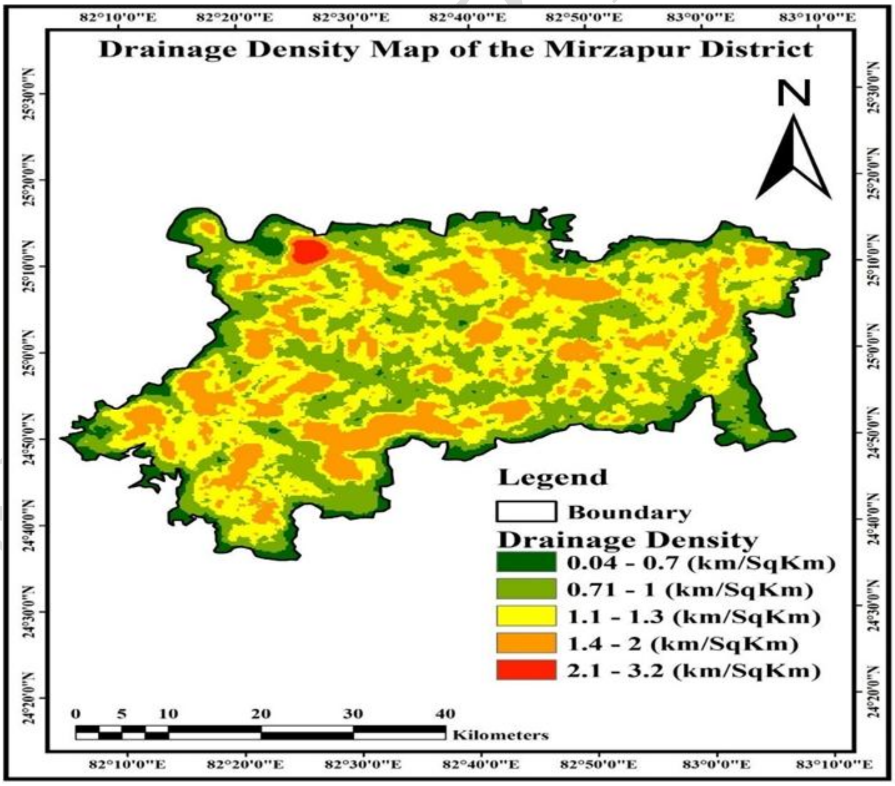


Fig. .6: Drainage Density map of the Mirzapur District

The prepared map and the areal distribution of different classes of drainage density have been presented in Fig 5 and Table 3 respectively. The drainage densities were divided into 5 groups, i.e., very low (0.04 – 0.7 km/sq km), low (0.71 – 1 km/sq km), average (1.1 – 1.3 km/sq km), high (1.4 – 2 km/sq km) and very high (2.1-3.2 km/sq km). 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.

Table 3: Drainage density area distribution table

Sr.No.	*Drainagedensity(km/sqkm)*	*Area(km^2)*	*Percentageoftotalarea*
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*

4.1.3 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. .6.

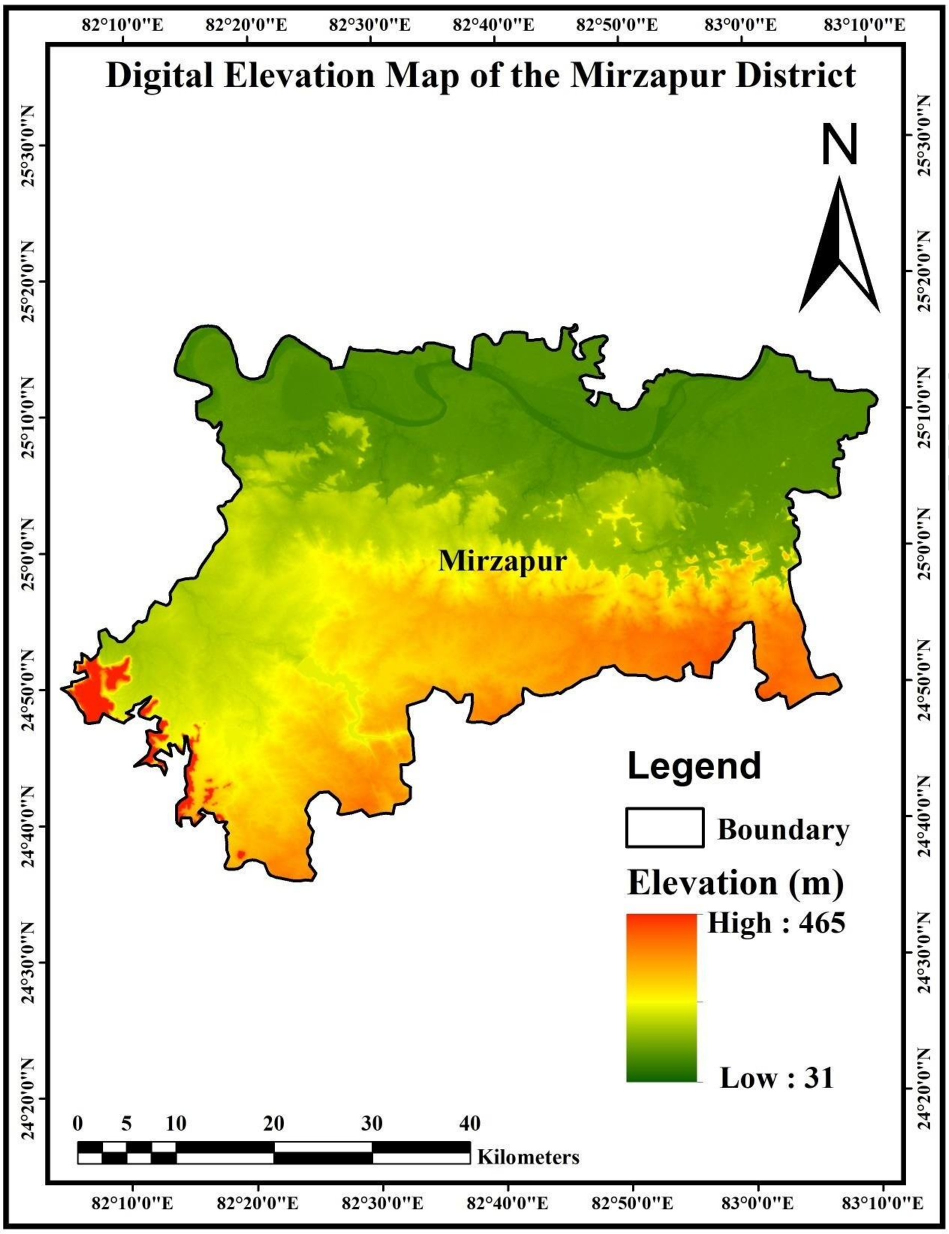


Fig. 7: Digital Elevation of the Mirzapur DistrictSlope

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. .7.the slope map was created using elevation profile derived from ASTER 30m DEM of the study area. The slope in the study area was divided into five classes (Table 4.) viz: "Very low slope (0-3.6 percent)", "low slope (3.7-8.8 percent)", "moderate slope (8.9-20 percent)", "high slope (21-38 percent)", "Very high slope (>39 percent)". With very low runoff, 53.94 percent of the area falls between 0-3.6 percent; low runoff, 37.37 percent of the area falls between 3.7-8.8%, Land slope with moderate runoff, 6.64% of the area falls between 8.9-20% with high runoff, 1.41% of the area falls between 21-38% with very high runoff, 0.64 of the area falls under >39%.

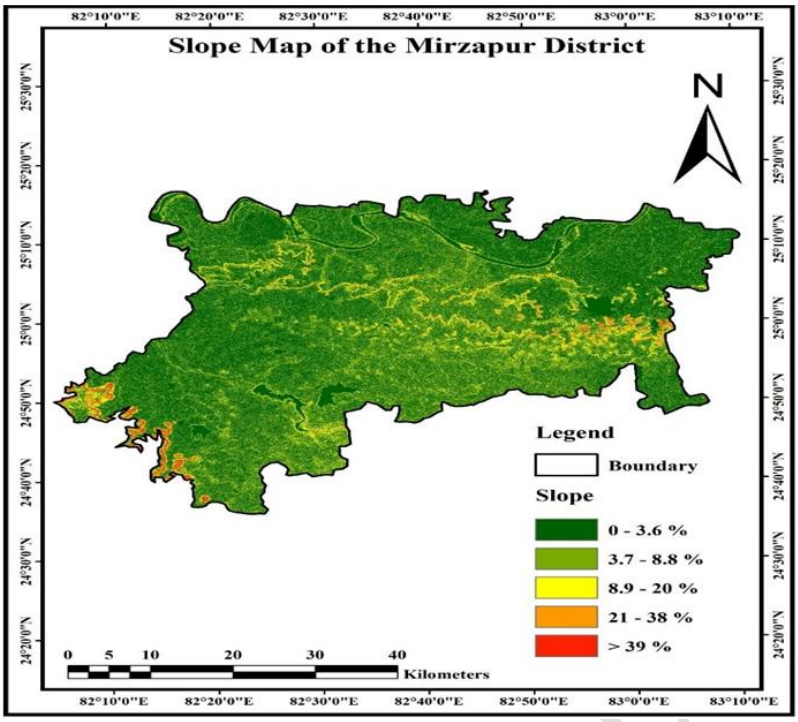


Fig. 8: Slope map of the Mirzapur District

Table 4.: Slope classes distribution table

Sr.No.	***Slopecategory***	***Slope(%)***	***Area(km^2)***	***Percentageoftotalarea***
1	VerylowSlope	0-3.6	2436	*53.94*
2	LowSlope	3.7-8.8	1688	*37.37*
3	ModerateSlope	8.9-20	300	*6.64*
4	HighSlope	21-38	65	*1.41*
5	VeryhighSlope	>39	27	*0.64*
Total			*4516*	*100*

4.1.4 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. The soil Features in the area can be categorized in to four classes (1) orthic luvisols, (2) chromic luvisols, (3) ferric luvisols, (4) chromic vertisols. The soil of the study area orthic luvisols which cover 3045 km2 (67.42%), chromic luvisols 1065 km2 (23.59%), ferricluvisols 340 km2 (7.53%), chromic vertisols 66 km2 (1.46%). The different soil classes and area distribution have been shown in Table 5.

Table 5: Soil Classes area distribution table

Sr.No.	***SoilClass***	***Area(km^2)***	***Percentageoftotalarea***
1	Orthicluvisols	3045	*67.42*
2	Ferricluvisols	1065	*23.59*
3	Chromicluvisols	340	*7.53*
4	Chromicvertisols	66	*1.46*
Total		*4516*	*100*

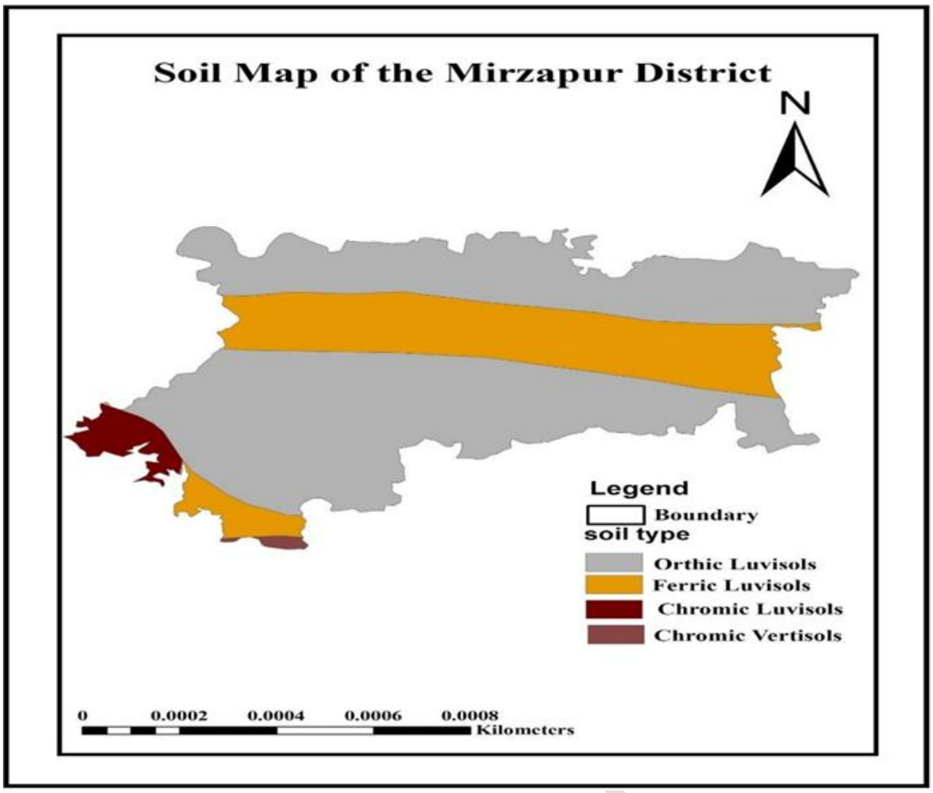


Fig. 9: Soil map of the Mirzapur District

4.1.5 Geology

The study area's geology map, displayed in Fig. 9, 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 km2 (17.12%), sandstone 545 km2 (12.07%), and fine grained sand stone 211 km2 (4.67 percent). The different geology classes and area distribution have been shown in table 6

Table 6: Geology area distribution table

Sr.No.	***GeologyClass***	***Area(km^2)***	***Percentageoftotalarea***
1	Alluvium	1825	*40.41*
2	SandySilt -Clay	1162	*25.73*
3	HardRock	773	*17.12*
4	SandStone	545	*12.07*
5	FineGrainedSandStone	211	*4.67*
Total		*4516*	*100*

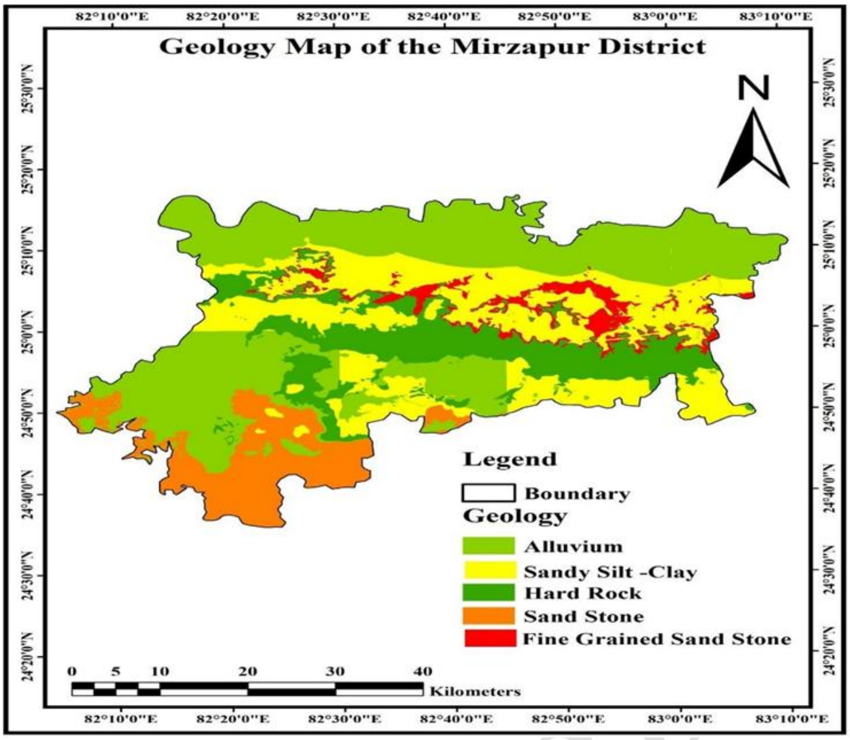


Fig. 10: Geology map of the MirzapurDistrict

4.1.6 Geomorphology

The research area's geomorphology map, shown in Fig. 10, 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 (Fig. .10). The study area's geomorphology is dominated by an alluvial plain unit covering 678 km2 (15.01%), a dam and reservoir covering 90 km2 (2%), a flood plain covering 406 km2 (9%), a low dissected plateau covering 160 km2 (3.5%), a moderate dissected plateau covering 1693 km2 (37.48%), a pediment pediplain covering 1374 km2 (30.42%), and a water body - river area 115 km2 (2.59%). The different geomorphological classes and its area distribution have been shown in Table 7.

Table 7: Geomorphology area distribution table

Sr.No.	*GeomorphologyClass*	*Area(km^2)*	*Percentageoftotalarea*
1	AlluvialPlain	678	*15.01*
2	DamandReservoir	90	*2*
3	FloodPlain	406	*9*
4	LowDissectedPlateau	160	*3.5*
5	ModerateDissectedPlateau	1693	*37.48*
6	Pedimentpediplain	1374	*30.42*
7	Waterbody-River	115	*2.59*
Total		*4516*	*100*

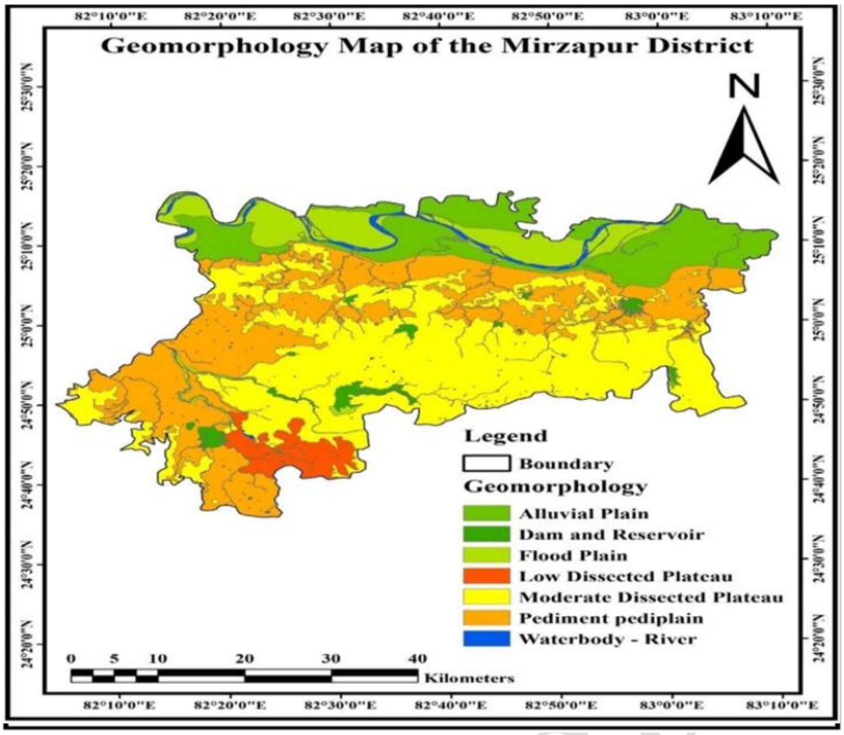


Fig. .11: Geomorphology map of the Mirzapur District

4.1.7 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. 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 (Magesh 2012). According to (Haridas*et al* 1998), groundwater potential zones benefit from high lineament density.

In the study area, lineament density ranged between 0 and 0.63 km/km², as depicted in Fig. .11. A high lineament density value of 0.63 km/km² 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/km², while 16.43% fell within the range of 0.085-0.26 km/km², and only 4.95% had a lineament density between 0.27 and 0.63 km/km², as detailed in Table 8.

Table 8: Lineament density area distribution table

Sr.No.	*Lineamentdensity (km/km^2)*	*Area(km^2)*	*Percentageoftotalarea*
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*

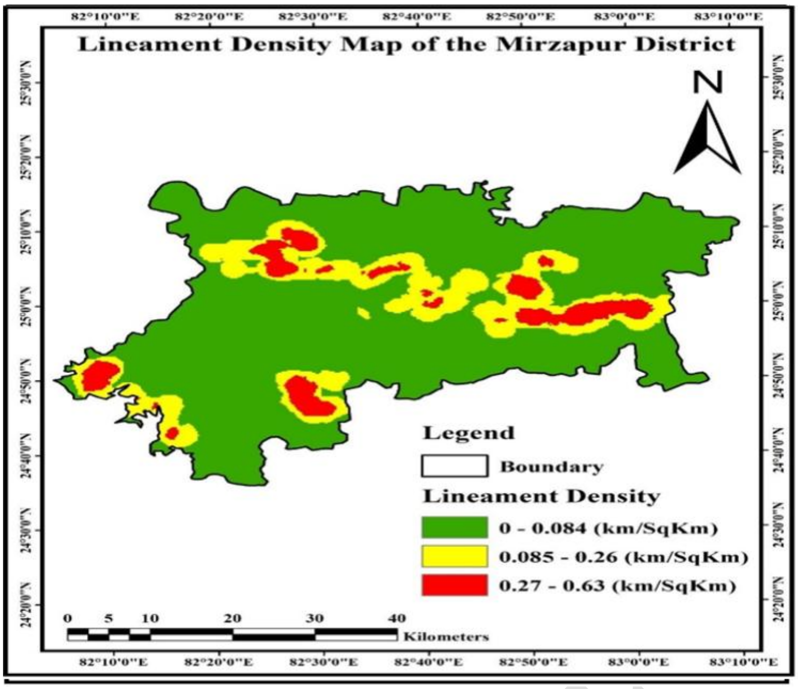


Fig. 12: Lineament Density of the Mirzapur District

4.1.8 Landuseandlandcover(LULC)

Satellite data Landsat 8(acquisition date 24 October 2020) was used to create alanduseandlandcovermapforMirzapur.Eachdatasetwasclassifiedusingsupervisedclassificationtechnique,andafinalmapoflanduseandlandcoverfortheresearchareawas created, as shown in Fig 12. Table 9 shows the area covered by each class,including water bodies, sand areas, built up land, fallow land, woodland, barren land,and agricultural land. Table 9 shows that out of the total area of 163 km2 (3.61percent),118km2(2.61percent)isundersand,151km2(3.34percent)isbuiltupland,and 625 km2 (13.83 percent) is fallow land, 439 km^2 area (9.72%) is under forest, 917km^2 area (20.33%) under barren land and 2103 km^2 area (46.56%) under agriculturalland.Thismeans thatthestudyareahasthe highestareaunder agriculture fields.

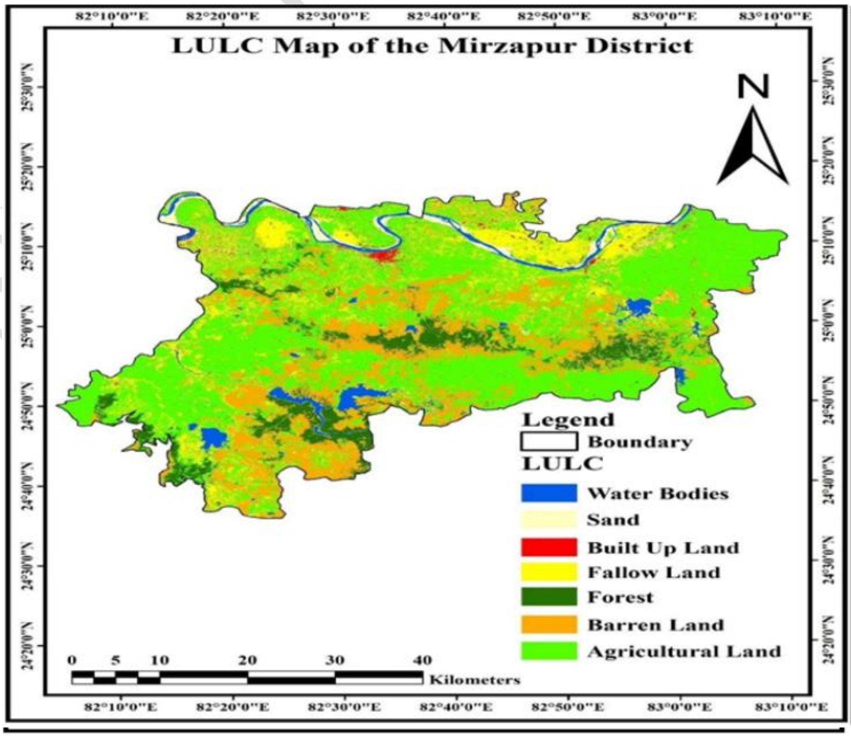


Fig. 13: LULC Map of the Mirzapur District

Table9:LanduseLandcover areadistribution table

Sr.No.	*LanduseLandcovertype*	*Area(km^2)*	*Percentageoftotalarea*
1	WaterBody	163	*3.61*
2	Sand	118	*2.61*
3	BuiltUpLand	151	*3.34*
4	FallowLand	625	*13.83*
5	Forest	439	*9.72*
6	BarrenLand	917	*20.33*
7	AgriculturalLand	2103	*46.56*
Total		*4516*	*100*

4.1.9 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 Machiwal et al. (2010), Ramu et al. (2014), and Harsha et al. (2018). The rating 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.

Table 10: 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*
Lineament Density	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*
DrainageDensity	7/7	6/7	5/7	4/7	3/7	2/7	1/7	*0.06*
Total								*1*

Table .11: Weights for thematic layers

S.No.	*Influencingfactor*	*Value*	*Eigen Value*	*%Weightage*
1	Geomorphology	High	0.38	*38*
2	LineamentDensity		0.19	*19*
3	Geology		0.12	*12*
4	Slope		0.10	*10*
5	Soil	↓	0.08	*08*
6	LandUseLandCover		0.07	*07*
7	DrainageDensity		0.06	*06*
		Low		
Total				*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 12 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 rasters using a standard estimation scale and loads each one according to its importance (ESRI).

Table .12: Assigned weights of different features of all the thematic maps

S.No.	*Influencingfactors*	*ClassInterval*	*Weight*	*Rank*	*Overall Weight*
1	DrainageDensity	0.04-0.7km/sq km	6	7	*42*
		0.71-1km/sq km		5	*30*
		1.1-1.3km/sq km		4	*24*
		1.4-2km/sq km		2	*12*
		2.1-3.2km/sq km		1	*6*
2	Geology	Alluvium	12	5	*60*
		FineGrainedStone		4	*48*
		HardRock		1	*12*
		SandStone		3	*36*
		SandySiltClay		4	*48*
3	Geomorphology	AlluvialPlain	38	5	*190*
		DamandReservoir		6	*228*
		FloodPlain		4	*152*
		LowDissectedPlateau		1	*38*
		ModerateDissectedPlateau		2	*76*
		PedimentPediplain		3	*114*
		Waterbody-River		7	*266*
4	LanduseLandcover	WaterBody	7	8	*56*
		Sand		7	*49*
		BuiltUpLand		3	*21*
		FallowLand		4	*28*
		Forest		6	*42*
		BarrenLand		2	*14*
		AgriculturalLand		5	*35*
		OrthicLuvisols		3	*24*

5	Soil	ChromicLuvisols	8	2	16
		FerricLuvisols		1	8
		ChromicVertisols		4	32
6	Slope	0-3.6%	10	7	70
		3.7-8.8%		6	60
		8.9-20%		3	30
		21-38%		2	20
		>39%		1	10
7	Lineament Density	0-0.84km/km^2	19	6	114
		0.085-0.26km/km^2		4	76
		0.27-0.63km/km^2		1	19

4.1.10 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. .13, Gound water potential zones are divided into four categories: poor, moderate, good, and excellent. According to the classification, 1101 km2 (24.4%) has excellent groundwater potential, 1840 km2 (40.7%) has medium groundwater potential, 1347 km2 (29.8%) has moderate groundwater potential, and 228 km2 (5.1%) has low groundwater potential. The different ground water potential zones and its area distribution have been shown in Table 13.

Table 13: Ground water potential zones area distribution table

Sr.No.	*GWPotentialZones*	*Area(km^2)*	*Percentageoftotalarea*
1	Excellent	1101	24.4
2	Good	1840	40.7
3	Moderate	1347	29.8
4	Poor	228	5.1
Total		4516	100

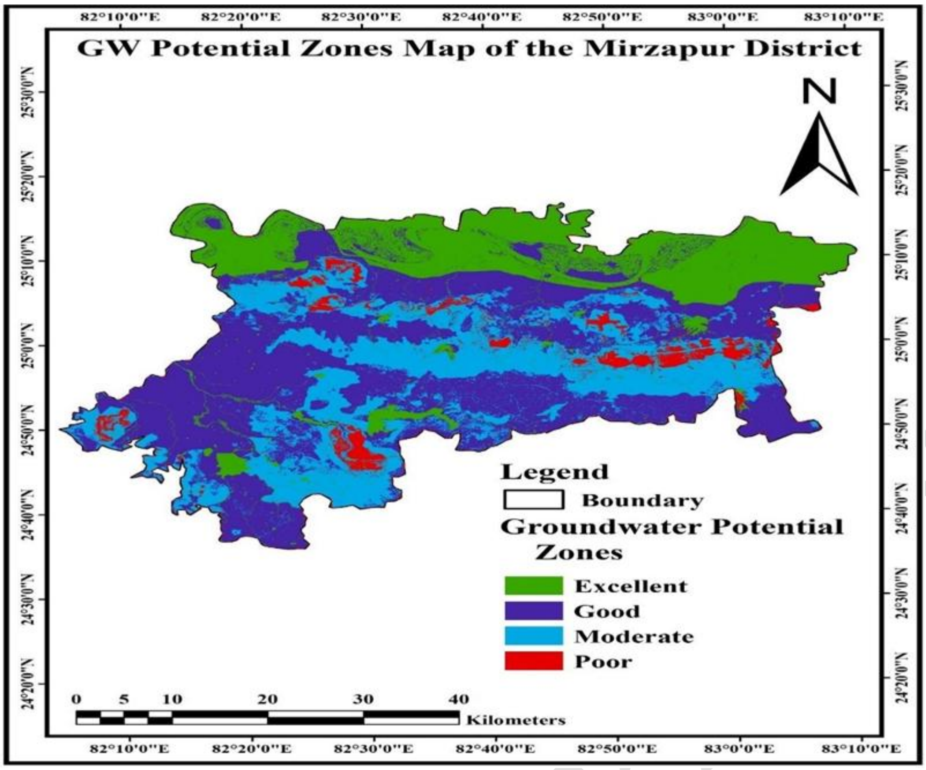


Fig. 14: GW Potential Zone Map of the Mirzapur District

5. Summary and 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 km^2, 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 km2 which accounts 46.56% of the total area, 917 km2 area (20.33%) is under Barren lands, 625 km2 area (13.83 per cent) is under fallow land, 151 km2 (3.34 per cent) under built up land, 439 km2 area (9.72 per cent) is under forest and 163 km2 area (3.61 per cent) is of water bodies. Very high drainage density (2.1-3.2 km/km2) 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/km2) 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 Km2 which constitute 5.1% of total area and 1347 Km2 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 Km2, 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 1101Km2, 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.

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