

Ground Water Potential Mapping of Tripura Using Analytical Hierarchy Process and GIS

JIMMI DEBBARMA* AND NIBEDITA DAS (PAN)

Department of Geography and Disaster Management, Tripura University, Suryamani Nagar, Tripura-West, 799022, India

E-mail: jimmigeo@tripurauniv.ac.in, nibeditadaspan@gmail.com

*Corresponding author

ABSTRACT

For both the rural and urban environment, groundwater is a key source of water supply and particularly significant due to its consistent supply at times when the supply of surface water becomes deficit. The present study area also has certain pockets experiencing water scarcity both seasonal and non-seasonal due to its physiographic setting. Therefore, locating possible areas of groundwater is of immense significance in managing the groundwater through recharge for securing the continuous availability of this resource. In the present study, Multi-criteria decision analysis (MCDA) such as Analytical Hierarchy Process (AHP) technique was applied along with Geographical Information System (GIS) technique to identify the groundwater prospective zones. The results of the study reveal that the flood plains and intermontane synclinal trough exhibit huge potential for groundwater. However, very low to low potential for groundwater is observed in the anticlinal hill ranges and terraces and tillas. The potential for groundwater decreases as one progress towards the north of the state. The areas which show low and moderate potential for groundwater may be recharged artificially or naturally.

Key words: Groundwater, groundwater parameters, multi-criteria decision analysis, weighted overlay, groundwater potential zones

INTRODUCTION

Groundwater is a natural and dynamic resource on which the needs of domestic, agriculture and industrial usages are met. This dynamic resource, can however, become obsolete in its utility when the quality as well as quantity is jeopardized. Groundwater is unstable as compared to surface water which is almost always present and renewable (Krishnamurthy et al. 2000, Ardakani and Ekhtesasi 2016). The potential of an aquifer is determined by the characteristics of rocks and the amount of space available in rocks for water storage (Kebede 2013). Several factors such as rock types, nature of permeability, transmissibility, porousness and storage capacity determine groundwater availability (Sharma and Kujur 2012, Ardakani and Ekhtesasi 2016).

The enormous pressure for groundwater because of population growth, better irrigation practices and industrial uses has been a cause of serious worry about the sustainable supply of groundwater resource for long-term use (Jha et al. 2010, Andualem and Demeke 2019). As a result, depiction of groundwater potential areas is necessary for efficient and optimal use of water resource in order to meet community

needs (Etikala et al. 2019, Allafta et al. 2021).

Recently, the advancement of space technology has provided affordable and quick satellite data in identifying areas with groundwater prospects when integrated in GIS environment. Prospective groundwater zones were studied using a combination of remote sensing and GIS approaches. In recent years incorporating remote sensing and GIS into groundwater resource discoveries has become one of the techniques that aids in giving early information on observing, evaluating and preserving groundwater resource (Magesh et al. 2012). When multi-criteria decision analysis and geoinformatics tools are integrated to investigate groundwater resource, a qualitative estimate of groundwater resource can be achieved.

GIS provides a unique platform for rapidly analysing and documenting georeferenced information gathered from multiple sources (Lillesand et al. 2015). As a result of its ability to handle large amount of geographical data, GIS is a valuable tool frequently employed in the judgement process for management of hydrological and environmental aspects (Jha et al. 2010, Magesh et al. 2012, Rahmati et al. 2015). Remote sensing and

GIS are widely utilized to identify groundwater potential zones (Andualem and Demeke 2019) through the integration of AHP (Chenini et al. 2010, Rahmati et al. 2015). In the current study, demarcation of prospective groundwater zones was investigated by combining AHP (Saaty 1980), and GIS technique through analysis of various parameters like geology, hydrogeomorphology, lineaments, land use/land cover, slope, drainage and rainfall maps.

MATERIALS AND METHODS

Study area

The study area extends from 22°56' N to 24°32' N latitude and 91°10' E to 92°21' E longitude (Fig. 1). It is a landlocked state covering an area of 10,492 km² with a total population of 36,71,803 persons (350 persons/km²) as per 2011 Census. The State is bounded on the north, west, south and south-east by international boundary of Bangladesh which is 84% (839 km) of its total border. Hills and piedmonts, intermontane synclinal troughs, terraces and tillas,

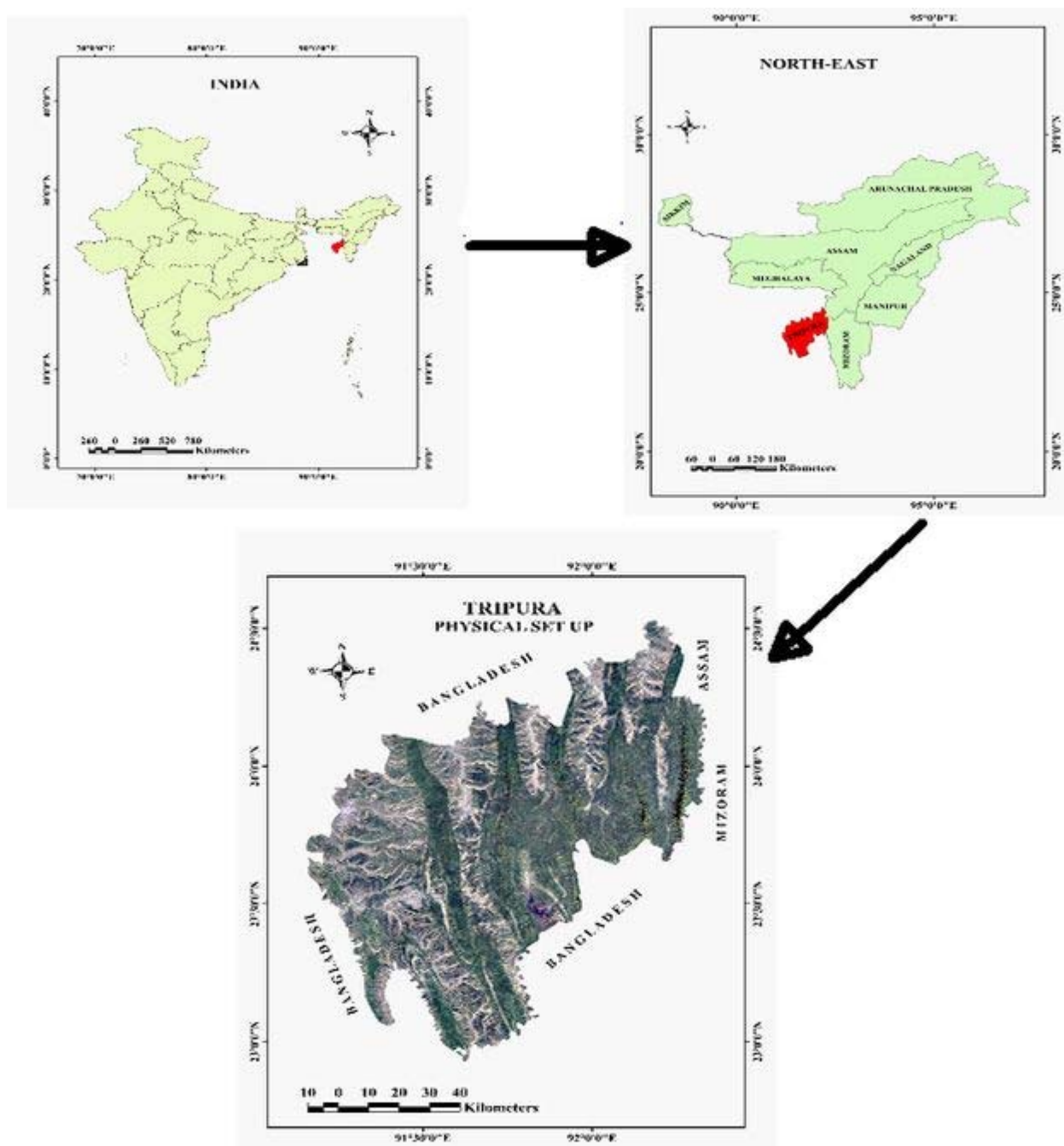


Figure 1. Study area map

and flood plains are the four main physical units that define the study region. The State's hill ranges run parallel to one another in a north-south direction dividing the State into wide valleys with intermittent rivers, stream and undulating tillas (hillocks). The hill ranges in the eastern and southern regions of Tripura are an extension of the folded tertiary topography and a plain that is a component of the Bangladesh plain. The State has three different seasons, including summer, monsoon and winter and known for its warm humid tropical climate. Rainfall in the State is brought on by the south west monsoon, which starts in May and last until September. There are basically four different types of geological formations, including the Surma group, Tipam group, Dupitila group, and Recent group. The State's aquifer is primarily made up of sandstone and shale, from which a significant amount of groundwater was extracted.

Database and methodology

The mapping of groundwater potential areas in the present research was prepared using the application of AHP and GIS techniques. Geology, hydrogeomorphology, lineament density, rainfall, land use/land cover, slope, drainage density and soil type were among the eight selected criteria that provide useful information on groundwater potentiality. The Analytical Hierarchy Process (AHP) technique and weighted overlay in the GIS environment were used to accomplish this.

The geology map was acquired from the Geological Survey of India's Tripura-Mizoram Division in Agartala, while the soil map came from the Government of Tripura. Using information from the Shuttle Radar Topographic Mission (SRTM) digital elevation model, which has a resolution of 30 m, the drainage density and slope map was created. Tripura's published Hydrogeological Atlas, Govt. of India was used to prepare the hydrogeomorphology map. NRSC Bhuvan website, Govt. of India provided the land use land cover map. Rainfall data was collected from Tripura Government's Department of Agriculture and Farmers Welfare. Drainage and lineament density were created in ArcGIS 10.3 application using the spatial analyst tool. Rainfall map was produced through interpolation technique by applying Inverse Distance

Weighted (IDW) method. Thereafter, Saaty's (1980), multi-criteria decision analysis utilising the Analytical Hierarchy Process (AHP) was combined with weighted overlay in a GIS platform. This technique has been extensively used in delineating groundwater potential zones. Each parameter was given a weight of relevant scale of 1-9, popularly known as Saaty's scale. The matrix was compared pair-wise to differentiate the thematic layers with each other. A parameter with a high weight indicates a layer that has a considerable impact on groundwater potential, while a parameter with a low weight indicates a layer that has a modest impact. Further, the features of thematic maps were re-classified in GIS platform. The sub-classes were assigned rank ranging from 1-5. One represents a very minimal influence on groundwater potential whereas five suggests a very high influence.

RESULTS AND DISCUSSION

Remote sensing and GIS have been widely employed for the generation of various sorts of thematic layers and blended together for various applications throughout the last two decades (Sharaf and Choudhury 1998). The combination of these two technologies has shown to be a useful tool for determining groundwater potential. Groundwater flow and occurrence are governed by various parameters, including rock type and structural attributes, topography, land use/land cover, landform pattern, drainage network and weather conditions (Jaiswal et al. 2003, Ali et al. 2015, Yeh et al. 2016, Thapa et al. 2017, Golla et al. 2018). For assessing the Groundwater Potential Zones (GWPZs) in Tripura, eight thematic maps were evaluated in the current study.

Geology

Geology plays a vital influence in the prevalence and circulation of groundwater in any area. Groundwater occurrence and flow are influenced by the character of the rocks, with factors such as porosity and permeability varying depending on the kind of rock (Ghasemizadeh et al. 2012, Etikala et al. 2019). Geologically, the study area is underlain by quaternary and Upper Tertiary group of sedimentary rocks. The four types of geological formations found

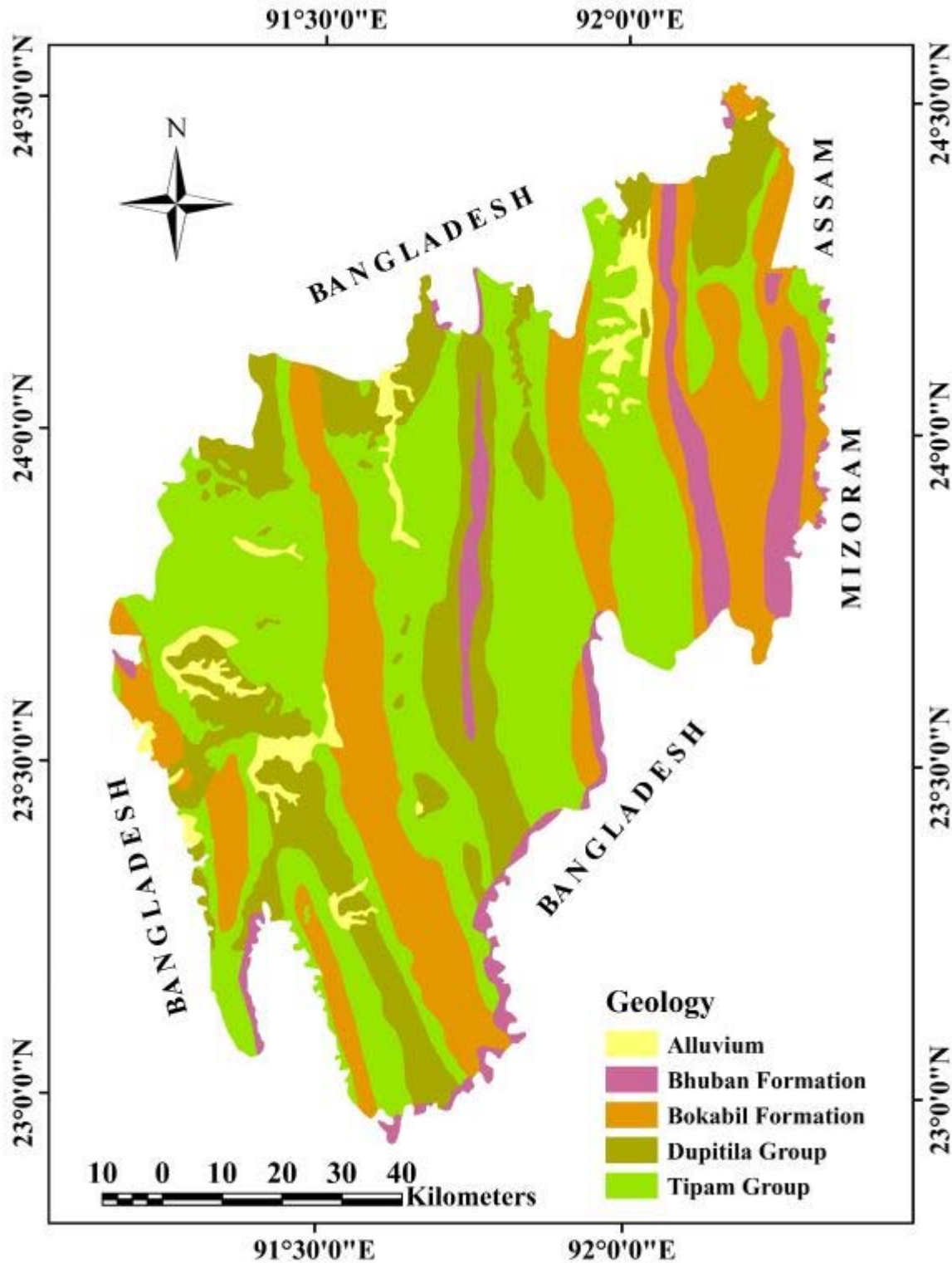


Figure 2. Geological map

in the State are Dupitila Group, Tipam Group, Surma Group and recent formations (Fig. 2). The Bhuban and Bokabil formations form the Surma Group of rocks. Groundwater mostly occurs in Tipam and

Dupitila formations in rocks of sandstone and shale.

Lineament

The faulting and fracturing zones that result in

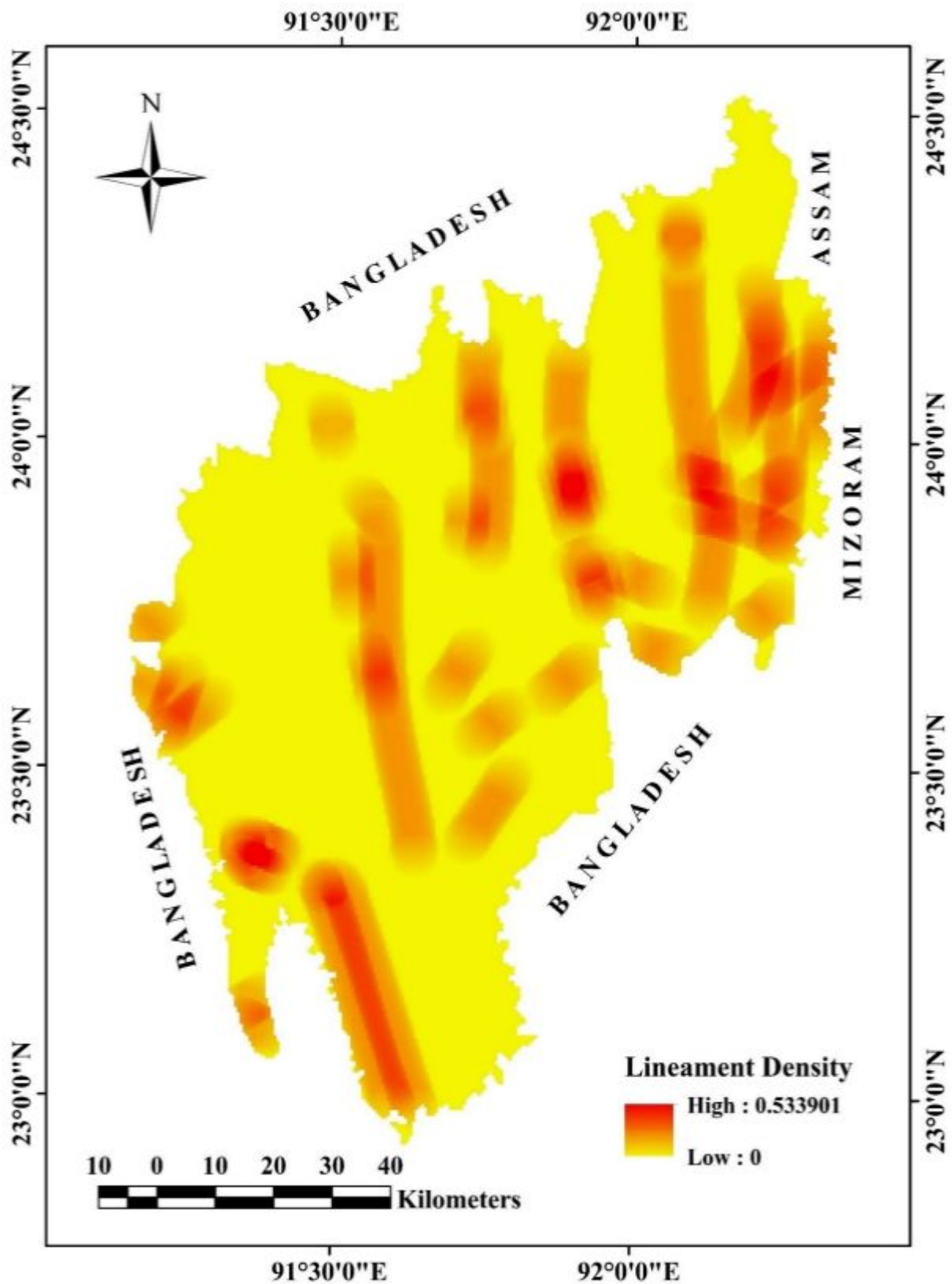


Figure 3. Lineament density map

increased secondary porosity and permeability are represented by the lines formed by tectonic activity

(Aryanto and Hardiman 2018). Lineaments influence the percolation of surface runoff into the sub-surface and are crucial to groundwater storage and

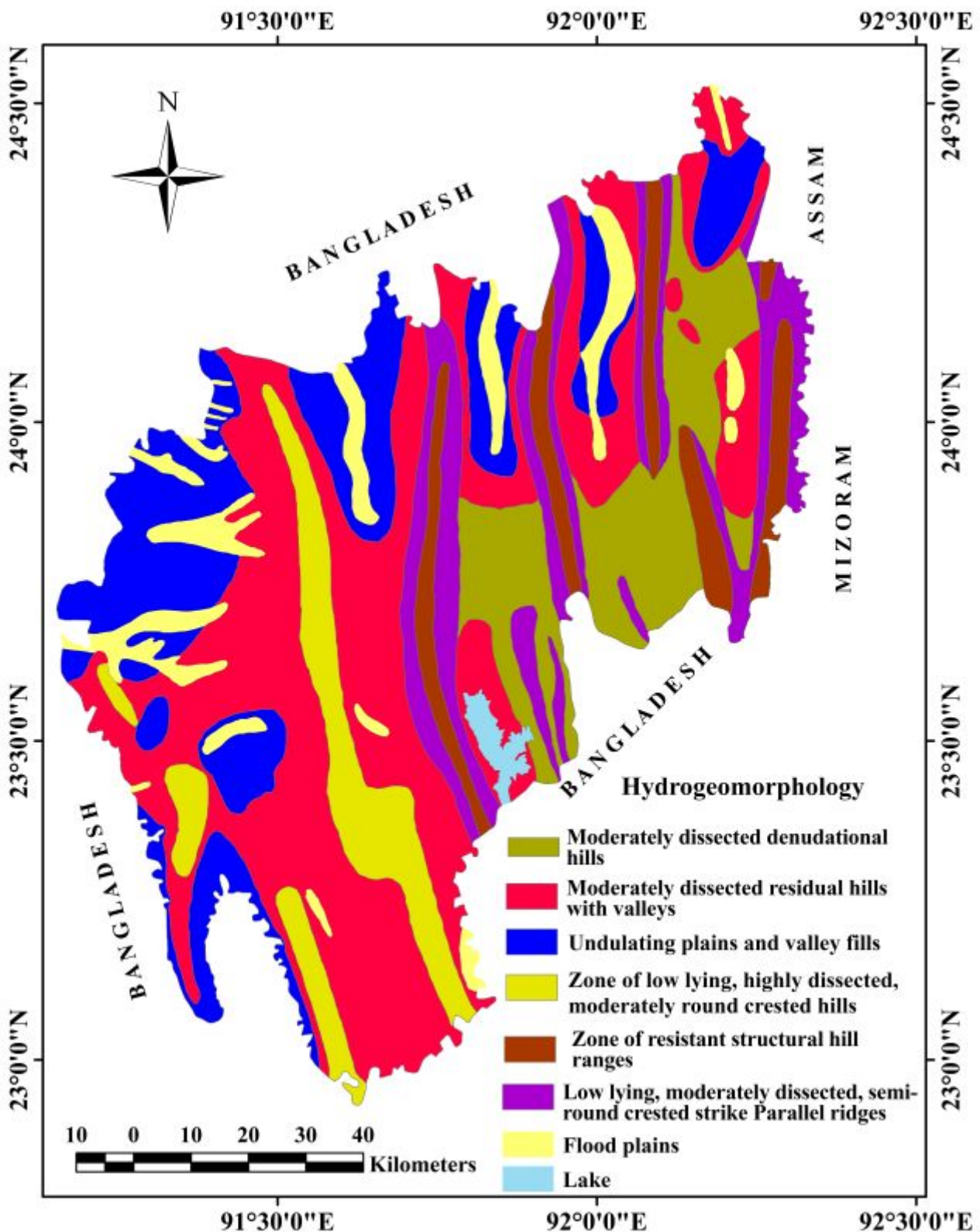


Figure 4. Hydrogeomorphology map

circulation. Areas with high density of lineaments are likely to have good groundwater possibilities. Lineament density in this investigation ranges from 0-0.534 km/km². Due to the presence of linear

structural elements, lineament density indirectly depicts the zone of groundwater recharge and storage offering optimal routes for groundwater recharge and storage (Ahirwar et al. 2020). In most cases, high

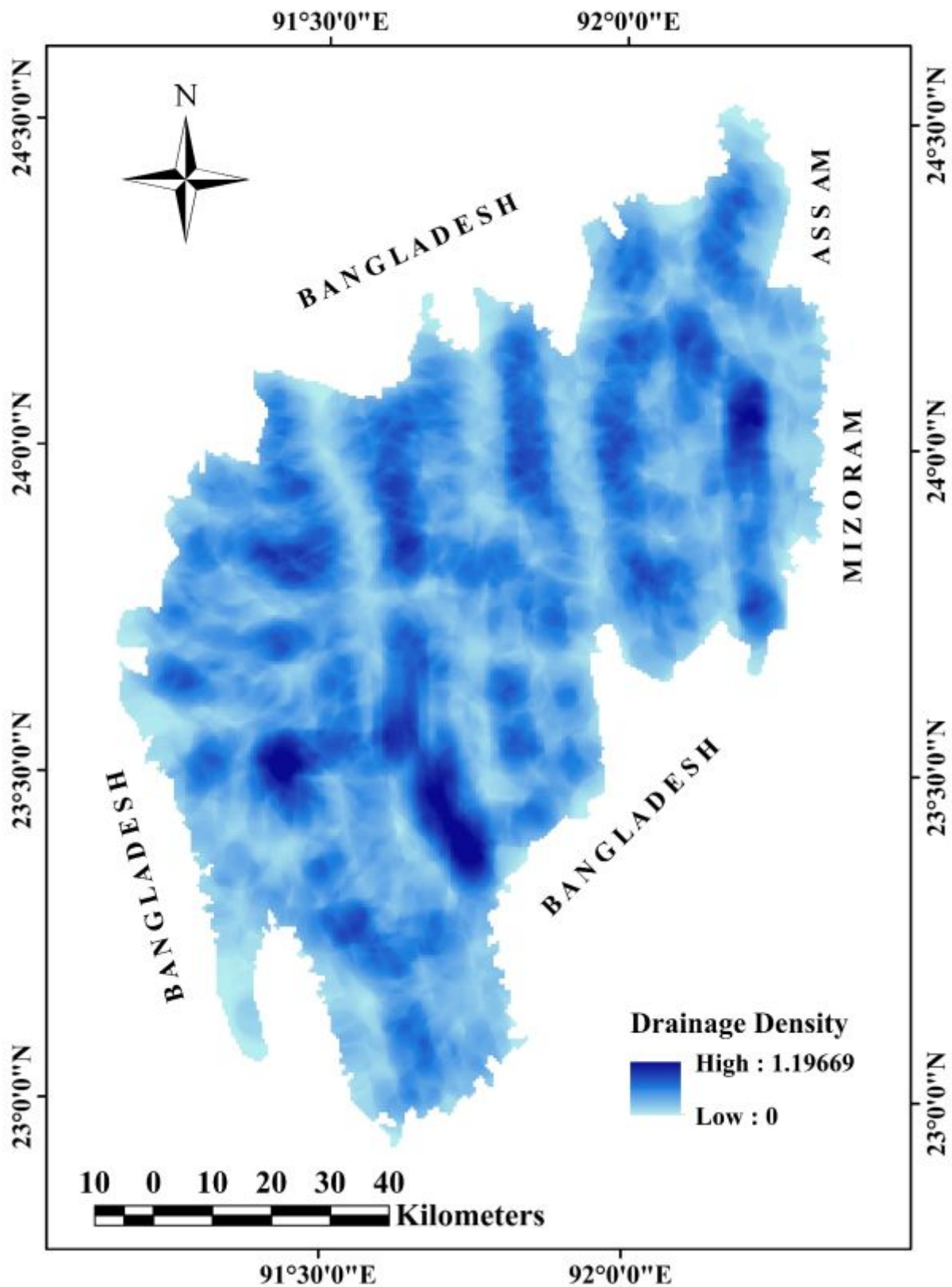


Figure 5. Drainage density map

lineament density was found in locations near watersheds. It was observed that the lineaments are orientated in the north-south, south-west and north-east directions (Fig. 3).

Hydrogeomorphology

The landform and topography of an area are represented by hydrogeomorphology which offers

information on the presence of groundwater based on the landform types observed in the study area (Arulbalaji et al. 2019). Seven geomorphic features identified from Hydrogeological Atlas of Tripura published by Central Ground Water Board, Govt. of India (1990), were (i) moderately dissected denudational hills; (ii) moderately dissected residual hills with valleys; (iii) undulating plains and valley fills; (iv) zone of low lying, highly dissected moderately round crested hills; (v) zone of resistant structural hill ranges; (vi) low lying, moderately dissected, semi-round crested strike parallel ridges; (vii) and flood plains (Fig. 4). In the study area, moderately dissected residual hills with valleys and undulating plains and valley fills represent areas of maximum potential for development of groundwater.

Drainage density

The density of drainage performs a critical function in the passage of water into the earth (Etikala et al. 2019). Low drainage density induces higher infiltration and less surface runoff making it appropriate for groundwater replenishment. However, high drainage density generates less infiltration and so does not favour much on groundwater potential. High drainage density was mostly observed in the anticlinal hill ranges, but lowlands and flood plains have low drainage density indicating a strong potential for groundwater development (Fig. 5). The drainage density in the studied region ranges from 0-1.197 km/km².

Land use land cover

Land use land cover information is critical for assessing the effects of various land uses on water infiltration capacity. It is also one of the most important governing variables in the process of groundwater recharge (Kaliraj et al. 2014). The land use land cover in the research area was classified into six types, such as agricultural land, barren land, built area, evergreen forest, forest plantation and lake (Fig. 6). Water bodies, agricultural lands and forests have high infiltration capacities and are considered as good areas for groundwater potential. Infiltration capacity is low in built-up areas as the concrete structures impede the permeability of water and in barren land, the devoid of vegetation makes it unable to hold water, thereby, reducing infiltration of water and offer poor sites for groundwater potential. Forests

and agricultural lands in the study area offer substantially high prospect of groundwater. The study area is widely occupied by evergreen forests which provide good scope for flow and recharge of groundwater. However, the hill ranges covered by forests do not indicate potential for groundwater because of faster surface runoff and thus, poor water holding capacity.

Rainfall

The recharge of groundwater is dependent on rainfall. In the study area, the mean annual rainfall is 268 cm. The average low and maximum are 209 and 452 cm, respectively. The rainfall ranged from 208.98 to 451.87 cm (Fig. 7). Higher weightage was allotted to high rainfall and vice-versa. The study area receives rainfall from south-west monsoon. Rainfall with a high intensity and a short duration has a negative impact on infiltration and increases surface run-off. Low intensity and long duration rain, on the other hand, leads to higher infiltration and less surface runoff.

Slope

Slope refers to local and regional relief that has a significant impact on groundwater circulation and recharge into the aquifer (Gupta and Srivastava 2010). It is an important indicator for identification of groundwater conditions. The degree of slope influences surface run-off and infiltration rates. Areas with steeper slopes have poor groundwater prospects compared to areas with gentler slope due to increased surface runoff. The northern and central parts of the study area that are occupied by hill ranges have very steep and steep slopes (Fig. 8). In these parts of the study area, very low to low groundwater potential zone was found.

Soil

Soil is one of the influencing factors that determines the infiltration and percolation of surface water into aquifers, and hence, influences groundwater storage (Anbhazagan et al. 2005). The permeability of soils and their ability to hold water determines an area's water holding capacity. The red loam and sandy loam soil cover the major portion of the State (Fig. 9). Areas with younger alluvial soil generally have high potential for groundwater recharge due to high

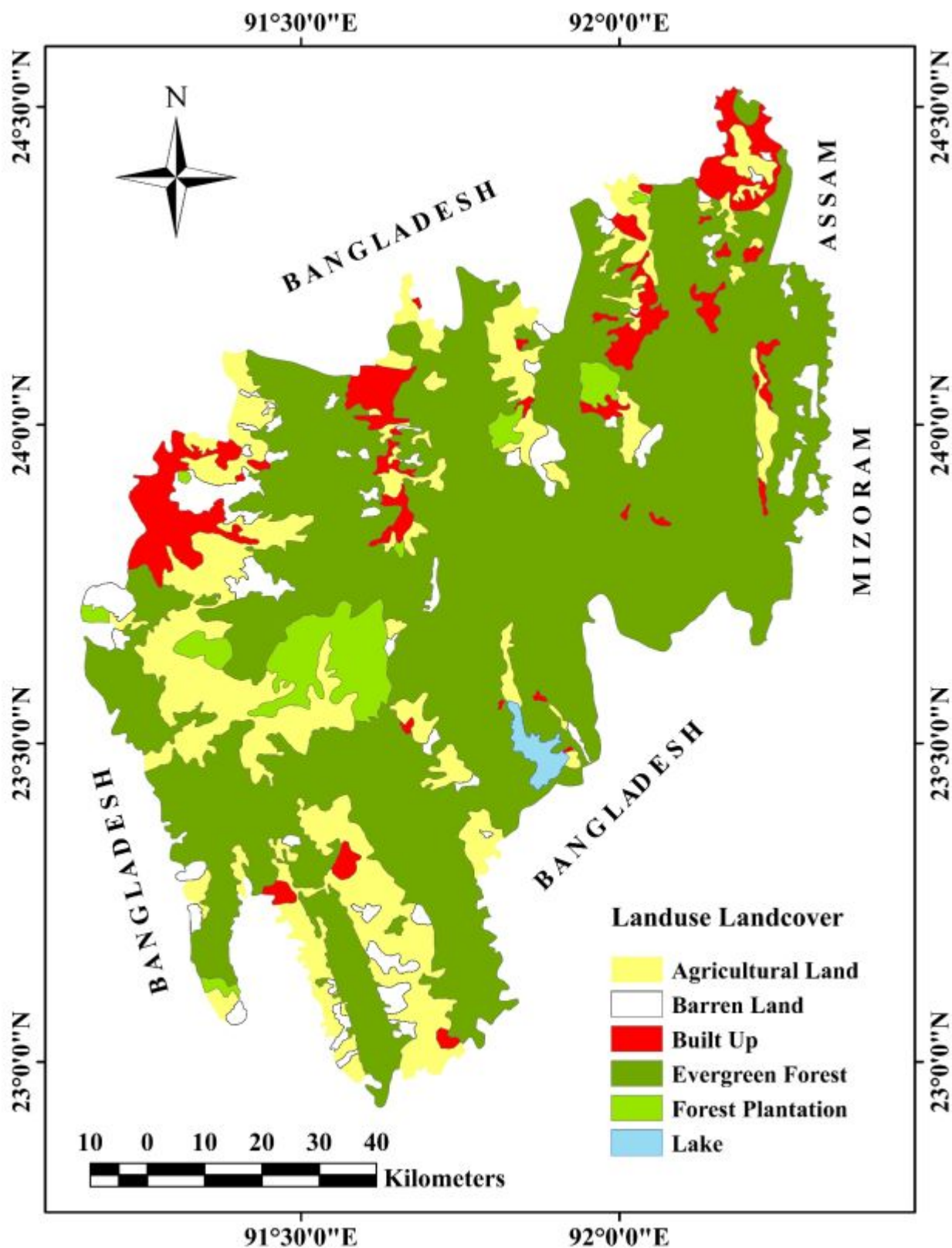


Figure 6. Land use land cover map

infiltration and percolation.

Assignment of weights

AHP as one of the multi-criteria decision-making

strategies for assessing and organising complex issues was proposed by Saaty (1980). On the basis of Saaty’s 1-9 scale, weights were assigned to each of the thematic parameters according to their

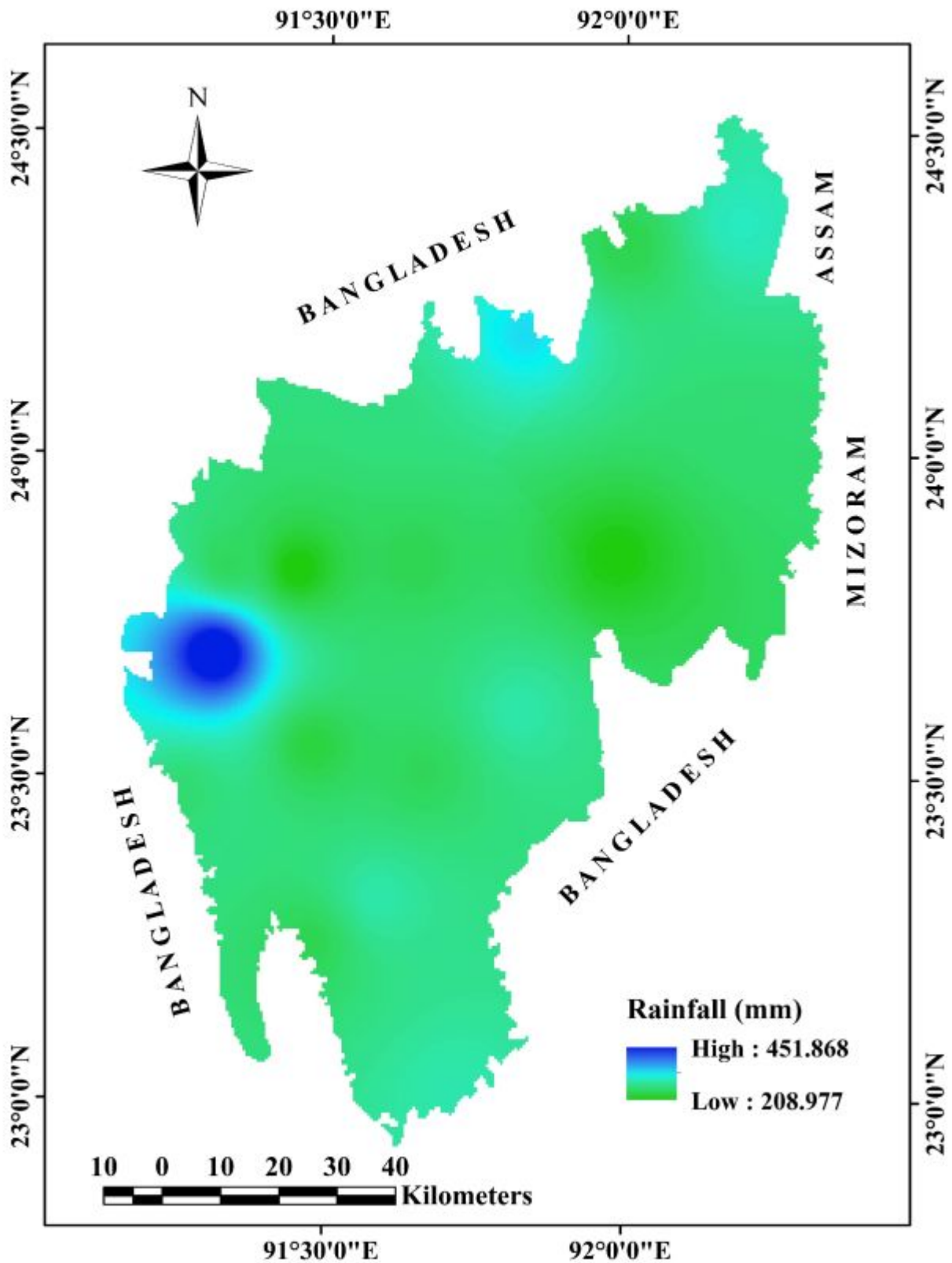


Figure 7. Rainfall distribution

influence on groundwater potential (Table 1) where one (1) represents similar effect of the two layers and nine (9) represents the greatest impact of a row layer compared to a column layer. The weights of

each of the respective thematic parameters were computed using AHP method and then normalized weights were obtained. Therefore, a pair-wise comparison matrix of the eight thematic layers was

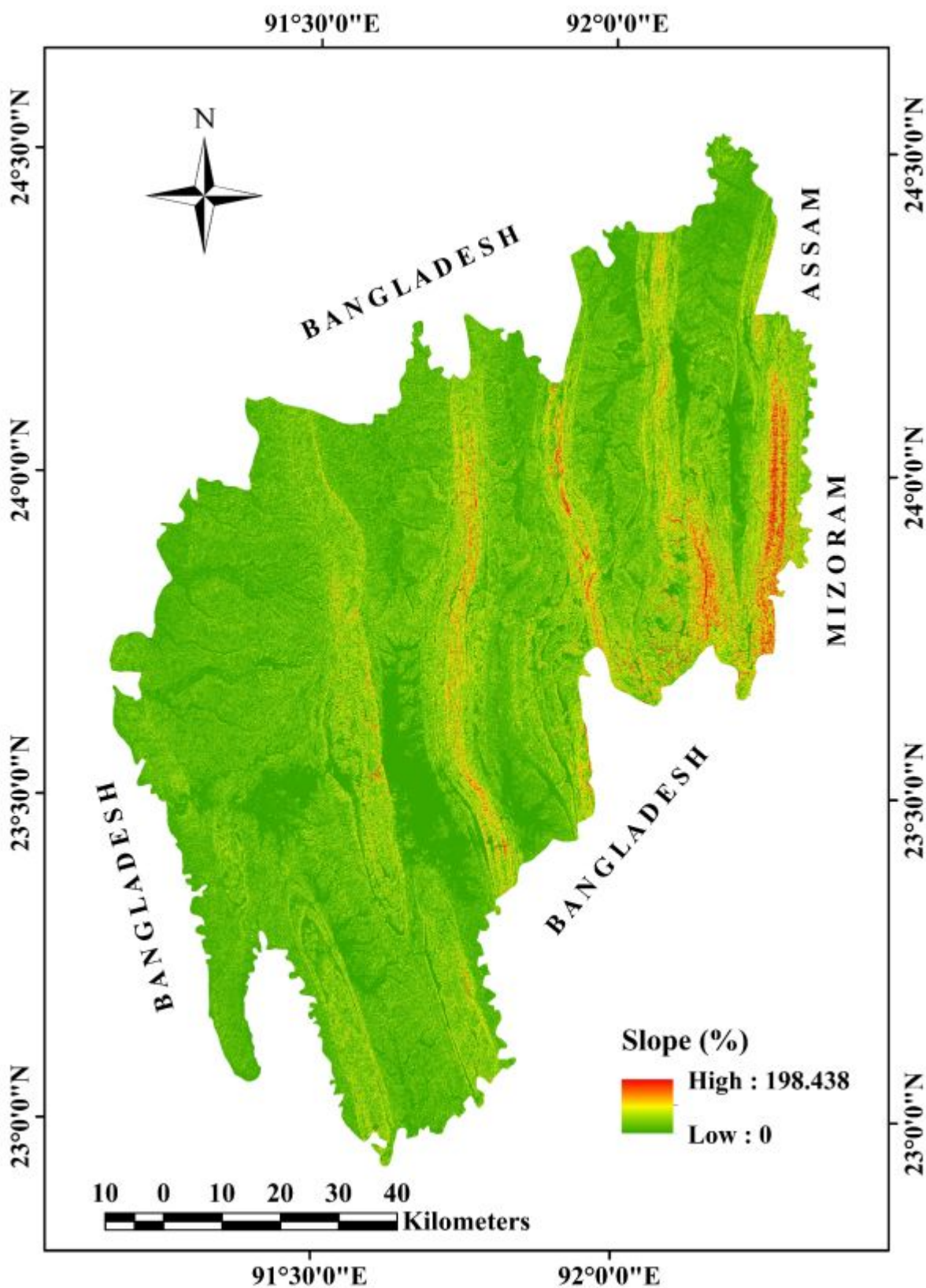


Figure 8. Slope map

created to calculate the scale weight of respective layers depending on the impact of each of the parameters towards groundwater potentiality (Table

2). AHP is a reliable decision-making tool for a variety of situations with different requirements and qualities, and it may also be used to assess the probability of groundwater occurrence (Jharia et al.

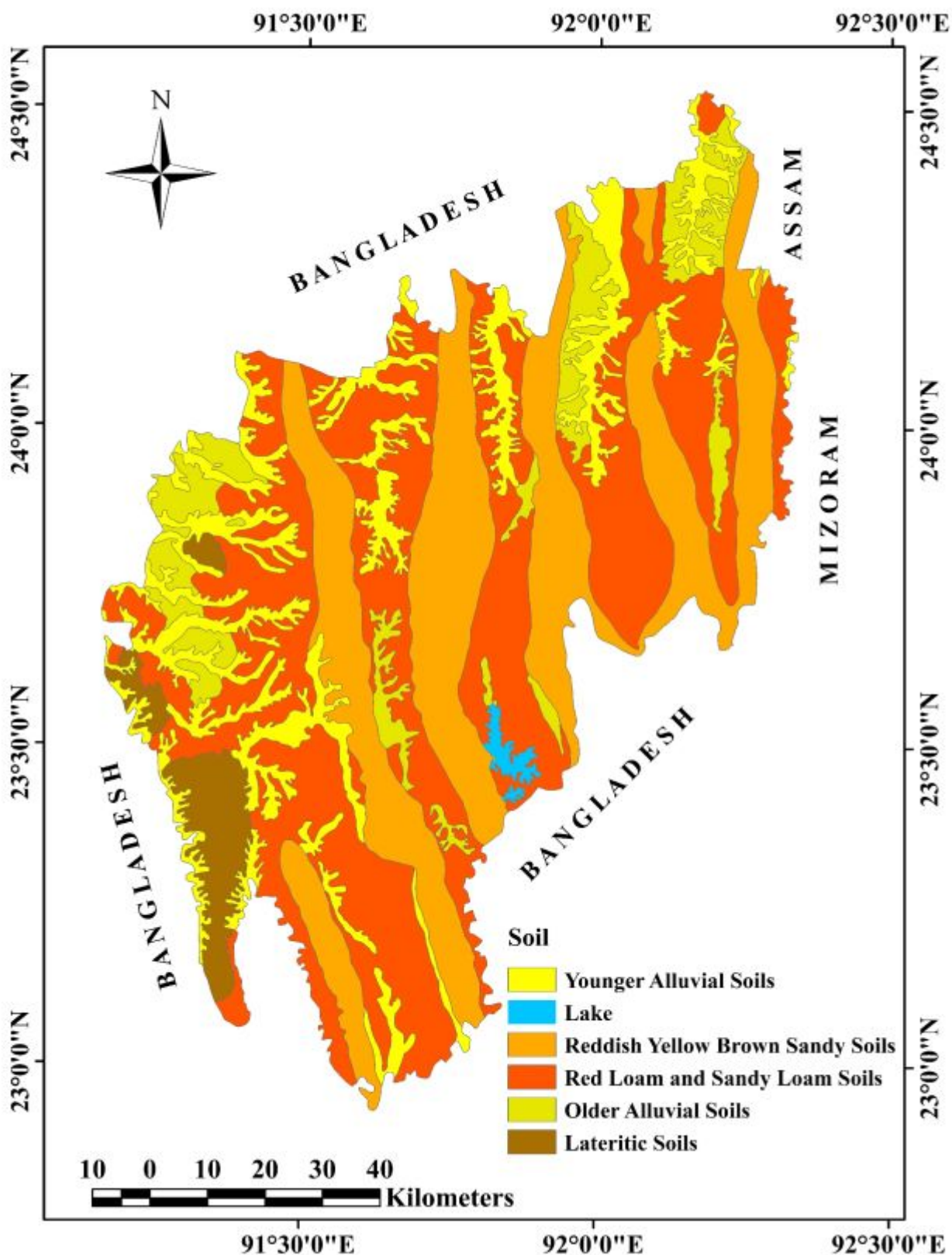


Figure 9. Soil map

2021). The final step in AHP was to test the consistency and judgement of the assigned weights which enable to calculate Consistency Ratio (CR).

Table 3 shows the consistency ratio of individual parameters.

Groundwater potential zones

Groundwater potential zone map was prepared by

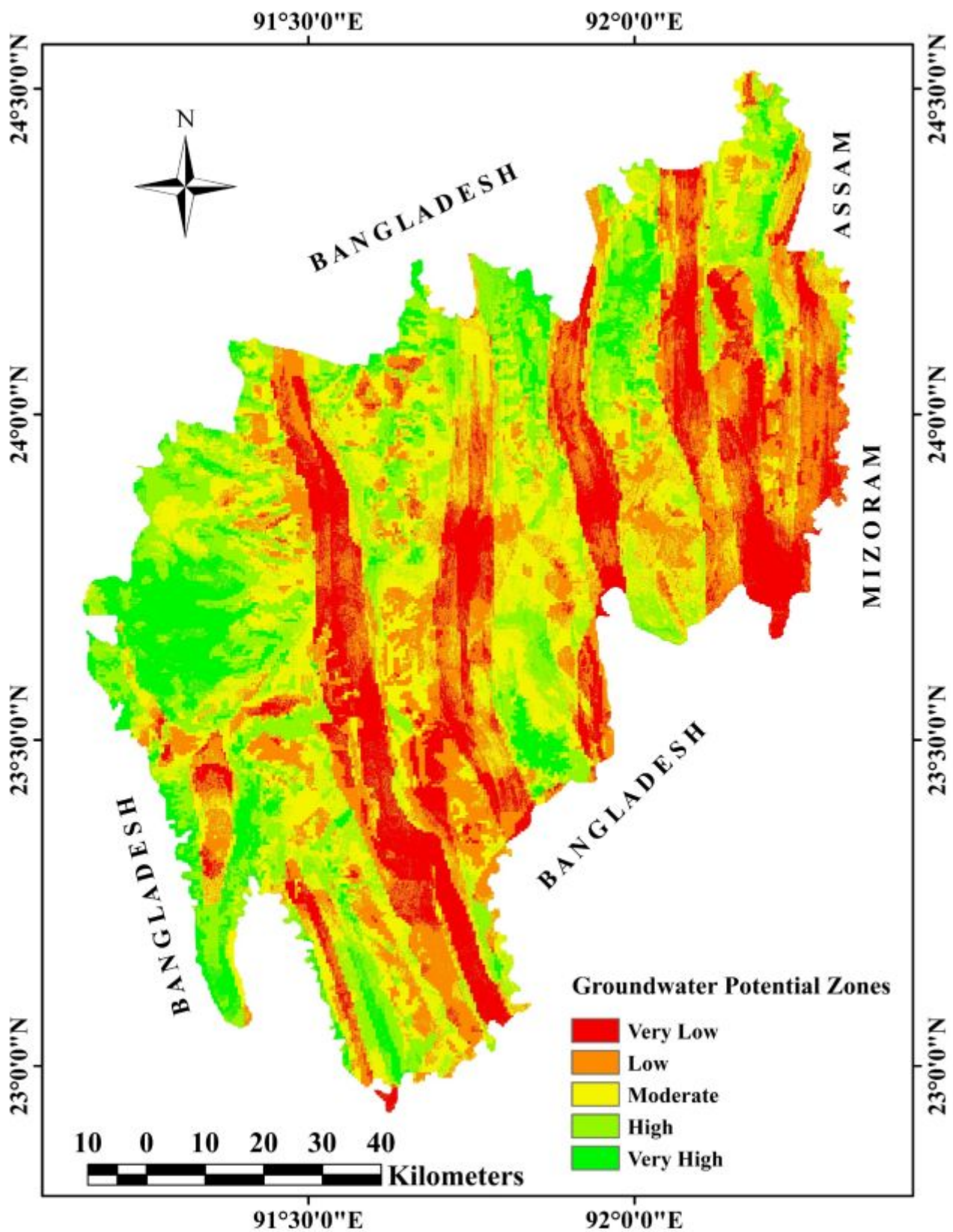


Figure 10. Groundwater potential zonation map

combining the eight thematic maps like geology, hydrogeomorphology, lineament density, rainfall, drainage density, slope, land use land cover and soil using the weighted overlay approach in ArcGIS 10.3

software. Five categories - very low, low, moderate, high, and very high - were used to categorise the groundwater potential zone map. It was clearly evident from the groundwater potential zonation map

Table 1. Assignment of weights of individual parameters and ranking of their features

Thematic parameters	Assigned weight	Feature class/Sub-class	Rank
Hydrogeomorphology	8	Moderately dissected denudational hills	4
		Undulating plains and valley fills	5
		Zone of low lying, highly dissected moderately round crested hills	2
		Moderately dissected residual hills with valleys	3
		Flood plains	5
		Zone of resistant structural hill ranges	1
		Low lying, moderately dissected semi-round crested strike parallel ridges	1
		Lake	5
Geology	8	Bokabil	1
		Tipam group	5
		Dupitilla group	4
		Alluvium	5
		Bhuvan	2
LULC	7	Agricultural land	5
		Barren land	1
		Evergreen forest	3
		Built up	3
		Water bodies	5
		Forest plantation	2
Soil	6	Red loam and sandy loam soils	4
		Younger alluvial soils	5
		Reddish yellow brown sandy soils	3
		Lateritic soils	3
		Older alluvial soils	5
		Water bodies	5
Drainage	7	Very low	5
		Low	4
		Moderate	3
		High	2
		Very High	1
Slope	5	Very gentle	5
		Gentle	4
		Moderate	3
		Steep	2
		Very steep	1
Rainfall	5	Very low	1
		Low	2
		Moderate	3
		High	4
		Very high	5
Lineament	5	Very low	1
		Low	2
		Moderate	3
		High	4
		Very high	5

Table 2. Normalized pair-wise comparison matrix of the eight thematic layers

Parameters	Hydrogeo- morphology	Geology	LULC	Soil	Drainage	Slope	Rainfall	Lineament	Geometric mean	Normalized weight
Hydrogeo-morphology	1									
Geology	1	1	1.143	1.333	1.143	1.6	1.6	1.6	1.302	0.157
LULC	0.875	0.875	1	1.167	1	1.4	1.4	1.4	1.139	0.137
Soil	0.75	0.75	0.857	1	0.857	1.2	1.2	1.2	0.976	0.118
Drainage	0.875	0.875	1	1.167	1	1.4	1.4	1.4	1.139	0.137
Slope	0.625	0.625	0.714	0.833	0.714	1	1	1	0.813	0.098
Rainfall	0.625	0.625	0.714	0.833	0.714	1	1	1	0.813	0.098
Lineament	0.625	0.625	0.714	0.833	0.714	1	1	1	0.813	0.098

Table 3. Consistency ratio

Parameters	Hydrogeo- morphology	Geology	LULC	Soil	Drainage	Slope	Rainfall	Lineament	Weighted sum	λ
Hydrogeo-morphology	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	1.256	8.0
Geology	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	1.256	8.0
LULC	0.137	0.137	0.137	0.137	0.137	0.137	0.137	0.137	1.097	8.0
Soil	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.942	8.0
Drainage	0.137	0.137	0.137	0.137	0.137	0.137	0.137	0.137	1.097	8.0
Slope	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.784	8.0
Rainfall	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.784	8.0
Lineament	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.784	8.0

Table 4. Area (%) under different ground water potential zones

Ground water potential zone	Area (%)
Very low	16.56
Low	25.91
Moderate	27.42
High	21.23
Very high	8.89

that the State has vast potential for groundwater. About 16.56% falls under very low, 25.91% under low, 27.42% under moderate, 21.23% under high and 8.89% under very high groundwater potential. Table 4 shows the percentage of area classified under different potential zones.

The prevalence of dug wells, shallow tube wells and hand pumps mostly in the flood plains and synclinal valleys indicate the occurrence of moderate and high to very high groundwater potential in these areas. On the other hand, deep tube wells were mostly located in the anticlinal hills where the potential of groundwater was found to be very low to low.

The groundwater potential map of the State shows that the flood plains and intermontane synclinal troughs exhibit huge prospect for groundwater due to flat topography which induce higher rate of infiltration as compared to the hilly parts of the State (Fig. 10). The areas which show moderate potential for groundwater may be recharged artificially or naturally. Very low potential for groundwater was observed in the anticlinal hill ranges. This may be due to increased surface runoff which further prevents infiltration of water into subsurface owing to its steep and undulating slope. It can also be seen that in extreme north of the State, the potential for groundwater decreases which may be attributed to the physical structure of the state.

CONCLUSION

The present study suggests that GIS approaches when integrated with AHP technique are useful tools in assessing groundwater potential zones necessary for protection and preservation in the long run. This study has provided preliminary knowledge on the development of groundwater prospects in Tripura. In the present research, studies done using GIS and

AHP techniques reveal high potential for groundwater in the synclinal troughs and flood plains. AHP and GIS study deduce that majority of the study area falls within medium probable zone of groundwater, with roughly 27.42% located in the upstream areas. These areas may be prioritized for artificial recharge through construction of check dams, trenches etc. to reduce the surface runoff. About 16.56% of the area is covered by a very low groundwater potential zone which is largely found in anticlinal hill ranges. The findings of the study can help decision-makers establish strategies to ensure that this resource is used efficiently and sustainably in the long run.

ACKNOWLEDGEMENTS

The authors would like to thank the Govt. departments of Tripura like Soil and land use planning, Agriculture and Farmers Welfare for providing the soil and rainfall data. The authors acknowledge the help received from Geological Survey of India's Tripura-Mizoram Division in Agartala for providing the geological map. The authors also would like thank other Govt. agencies like NRSC Bhuvan website, Govt. of India to access the land use land cover map, Central Groundwater Board for providing hydrogeomorphology map and United States Geological Survey for providing the open-source data (Shuttle Radar Topographic Mission (SRTM) digital elevation model.

Authors' contribution: Both the authors contributed equally.

Conflict of interest: The authors declare no conflict of interest.

REFERENCES

- Ahirwar, S., Malik, M.S., Ahirwar, R. and Shukla, J.P. 2020. Application of remote sensing and GIS for groundwater recharge potential zone mapping in Upper Betwa Watershed. *Journal of the Geological Society of India*, 95(3), 308-314.
- Ali, H.Y., Pricu, C.P. and Prasad, N.B.N. 2015. Delineation of groundwater potential zones in deep midland aquifers along Bharathaphuza river basin, Kerala using geophysical methods. *Aquatic Procedia*, 4, 1039-1046.
- Allafta, H., Opp, C. and Patra, S. 2021. Identification of

- groundwater potential zones using remote sensing and GIS techniques: A case study of the Shatt Al-Arab basin. *Remote Sensing*, 13(1), 1-28.
- Anbazhagan, S., Ramasamy, S.M. and Gupta, S.D. 2005. Remote sensing and GIS for artificial recharge study, runoff estimation and planning in Ayyar basin, Tamil Nadu, India. *Environmental Geology*, 48(2), 158-170.
- Andualem, T.G. and Demeke, G.G. 2019. Groundwater potential assessment using GIS and remote sensing: A case study of Guna Tana landscape, Upper Blue Nile Basin, Ethiopia. *Journal of Hydrology: Regional Studies*, 24, 1-13.
- Ardakani, A.H.H. and Ekhtesasi, M.R. 2016. Groundwater potentiality through Analytical Hierarchy Process (AHP) using remote sensing and Geographical Information System. *Journal of Geope*, 6(1), 75-88.
- Arulbalaji, P., Padmalal, D. and Sreelash, K. 2019. GIS and AHP techniques based delineation of groundwater potential zones: A case study from Southern Western Ghats, India. *Scientific Reports*, 9(1), 1-17.
- Aryanto, D.E. and Hardiman, G. 2018. Assessment of groundwater recharge potential zone using GIS approach in Purworejo regency, Central Java Province, Indonesia. *E3S Web of Conferences*, 3(2), 1-8.
- Chenini, I., Mammou, A.B. and May, M.E. 2010. Groundwater recharge zone mapping using GIS-based multi-criteria analysis: A case study in central Tunisia (Maknassy Basin). *Water Resource Management*, 24(5), 921-939.
- Etikala, B., Golla, V., Li, P. and Renati, S.R. 2019. Deciphering groundwater potential zones using MIF technique and GIS: A study from Tirupati area, Chittoor District, Andhra Pradesh India. *Hydroresearch*, 1, 1-7.
- Ghasemzadeh, R., Hellweger, F., Butscher, C., Padilla, I., Vesper, D., Field, M. and Alshawabkeh, A. 2012. Review: Groundwater flow and transport modeling of karst aquifers, with particular reference to the North Coast Limestone aquifer system of Puerto Rico. *Hydrogeology Journal*, 20(8), 1441-1461.
- Golla, V., Etikala, B., Veeranjanyulu, A., Subbarao, M., Surekha, A. and Narasimhlu, K. 2018. Data sets on delineation of groundwater potential zones identified by geospatial tool in Gudur area, Nellore district, Andhra Pradesh, India. *Data in brief*, 20, 1984-199.
- Gupta, M. and Srivastava, P.K. 2010. Integrating GIS and remote sensing for identification of groundwater potential zones in the hilly terrain of Pavagarh, Gujarat, India. *Water International*, 35(2), 233-245.
- Jaiswal, R.K., Mukherjee, S., Krishnamurthy, J. and Saxena, R. 2003. Role of remote sensing and GIS techniques for generation of groundwater prospect zones towards rural development: an approach. *International Journal of Remote Sensing*, 24(5), 993-1008.
- Jha, M.K., Chowdary, V.M. and Chowdhury, A. 2010. Groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques. *Hydrogeology Journal*, 18(7), 1713-1728.
- Jharia, D.C., Khan, R., Mondal, K.C., Kumar, T., Indulekha, K. and Singh, V.K. 2021. Assessment of groundwater potential zone using GIS-based multi-influencing factor (MIF), multi-criteria decision analysis (MCDA) and electrical resistivity survey techniques in Raipur city, Chhattisgarh, India. *Aqua-Water Infrastructure, Ecosystems and Society*, 70(3), 375-400.
- Kaliraj, S., Chandrasekar, N. and Magesh, N.S. 2014. Identification of potential groundwater recharge zones in Vaigai upper basin, Tamil Nadu, using GIS-based analytical hierarchical process (AHP) technique. *Arabian Journal of Geosciences*, 7(4), 1385-1401.
- Kebede, S. 2013. *Groundwater in Ethiopia: Features, Numbers and Opportunities*. Springer Berlin, Heidelberg. 283 pages.
- Krishnamurthy, J., Mani, A., Jayaraman, V. and Manivel, M. 2000. Groundwater resources development in hard rock terrain-an approach using remote sensing and GIS techniques. *International Journal of Applied Earth Observation and Geoinformation*, 2(3-4), 204-215.
- Lillesand, T., Kiefer, R.W. and Chipman, J. 2015. *Remote Sensing and Image Interpretation*. Seventh edition. Wiley, New York. 736 pages.
- Magesh, N.S., Chandrasekar, N. and Soundranayagam, J.P. 2012. Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. *Geoscience Frontiers*, 3(2), 189-196.
- Rahmati, O., Samani, A.N., Mahdavi, M., Pourghasemi, H.R. and Zeinivand, H. 2015. Groundwater potential mapping at Kurdistan region of Iran using analytic Hierarchy Process and GIS. *Arabian Journal of Geosciences*, 8(9), 7059-7071.
- Saaty, T.L. 1980. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. McGraw-Hill International Book Company. New York. 287 pages.
- Sharaf, A.K. and Choudhury, P.R. 1998. Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. *International Journal of Remote Sensing*, 19(10), 1825-1841.
- Sharma, M.P. and Kujur, A. 2012. Application of remote sensing and GIS for groundwater recharge zone in and around Gola Block, Ramgarh district, Jharkhand, India. *International Journal of Scientific and Research Publications*, 2(2), 1-6.
- Thapa, R., Gupta, S., Guin, S. and Kaur, H. 2017. Assessment of groundwater potential zones using Multi-influencing Factors (MIF) and GIS: A case study from Birbhum district, West Bengal. *Applied Water Science*, 7, 4117-4131.
- Yeh, H., Cheng, Y., Lin, H. and Lee, C. 2016. Mapping groundwater recharge potential zone using a GIS approach in Hualian River, Taiwan. *Sustainable Environment Research*, 26(1), 3343.

Received: 23rd June 2023

Accepted: 7th August 2023