Identification of groundwater recharge potential zones using AHP and Fuzzy Logic: A blockwise study of western Purulia district, India

Sauvik Santra and Sujata Biswas

Abstract Managing groundwater resources, particularly under data-scarce and dry regions, involves a lot of difficulties and problems which have driven the planners to apply remote sensing (RS) and geographic information system (GIS) based procedures. In the present study, groundwater recharge potential zones are delineated by integrating the Analytic Hierarchy Process (AHP), GIS, and RS methods in five blocks of Purulia district, India. At first, the adequate thematic layers of factors impacting the groundwater recharge potential, such as drainage density, geomorphology, soil types, land use, geology, rainfall, slope, and lineament density, are extracted from sources like satellite imagery and collateral data. The AHP method is utilized to estimate the weights of different layers for applying the hierarchical fuzzy logic to identify potential zones for groundwater recharge. It is found that about 186.35 km^2 area has very good groundwater recharge potential (GRP), which is only 12.13% of the total study area. The area with good, average, and low GRP are about 359.08, 455.29, and 415.44 km^2 respectively. Analyzing the blockwise distribution of potential zones, it is found that Baghmundi block having 21.9% and 27.76% of its area under very good and good GRP zones respectively, is most suitable for blockwise implementation of groundwater recharge sites.

Keywords Groundwater · Fuzzy logic · AHP · India

1 Introduction

Water is one of the most vital resources for the existence of life on earth. From ancient times, groundwater is preferred over surface water as it is free from most of the pollutants, and its availability is more homogeneous than surface water. A

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constant increase in demand for water leading to rapid growth in water consumption can be seen in recent years, whereas a relatively massive growth in consumption of groundwater over the surface water can be seen prior to 1990 [1].

This extracted groundwater must be recharged to maintain a steady groundwater level. Due to excessive usage, natural groundwater recharge has become insufficient to replenish the groundwater. As a result, the groundwater table has been depressed all over the world [2] and especially in India [3]. In some areas, it has even gone out of the feasible extraction range. This depression of groundwater level affected surface water, resulting in drying up of many rivers, lakes, and shallow water bodies in the last few decades. This has become an international crisis and an alarming concern for today's environmental scientists and water resources engineers. In India, specifically over the northern India, a steady lowering of the groundwater table is observed in the past few decades [4].

As a remedial step, we may use technology to replenish the depleted water level by using the concept of artificial groundwater recharge. Today many researchers are trying to find a proper place, method, and amount of groundwater recharge to mitigate the crisis. As a handy tool for analyzing the large area, remote sensing (RS) and geographic information system (GIS) are playing an important role in these studies.

Utilization of remote sensing and GIS for the exploration of groundwater and the identification of artificial recharge sites can be found in much earlier studies. Data from Linear Imaging Selfscanning Sensor (LISS-II) onboard Indian Remote Sensing Satellites (IRS-1A, 1B and P2) was combined with the information derived from digital elevation model (DEM) using GIS to find the suitable sites for groundwater recharge over the hard rock terrain in the Sironj area of Vidisha district of Madhya Pradesh, India [5]. A similar technique was used to determine groundwater recharge potential zones in Lebanon, where lineament and drainage density, karstic domains, land cover, and lithologic character were determined using satellite images (Landsat 7 ETM & SPOT) and aerial photographs, further integrating them in GIS [6]. Thematic maps constructed merging LISS-III and panchromatic (PAN) remote sensing data and aquifer parameters from field data were integrated using GIS to create a map of groundwater recharge potential zones over the Jammu district, India [7]. Weighted thematic layers of five contributing factors, lithology, land cover, lineaments, drainage, and slope derived using aerial photographs, geology maps, and a land-use database were combined using GIS to delineate groundwater recharge potential zones in Taiwan [8]. With the development of modern computational techniques and the availability of updated computational resources, a scope was created to refine the results from the approaches mentioned above using soft computing. One of the initial studies using an integrated approach to combine GIS with a decision support system (DSS) for the delineation of groundwater recharge potential sites was carried out by [9] over the Meimeh Basin, Iran.

The next big change took place when GIS was combined with numerical modeling techniques to delineate the groundwater recharge potential zones in the arid region of Maknassy basin, Tunisia [10]. A combination of RS, GIS, and multi-criteria decision-making (MCDM) techniques using normalized weights computed using

Saaty's Analytic Hierarchy Process (AHP) was used to delineate artificial recharge zones as well as to identify favorable artificial recharge sites in the West Medinipur district of West Bengal, India [11]. A study over a sub-watershed of River Kanhan, in Nagpur District, Maharashtra, India, was carried out in GIS using the land use, soil types, topography, and rainfall-runoff model data, where AHP with expert's judgment was used for ranking the sites [12]. The next advancement in the method came when [13] coupled GIS with MCDM using fuzzy rules to yield more precise results in selecting the site for managed aquifer recharge.

Later on, [14] used modern satellite imagery to revise the GIS and AHP coupling techniques. In current years, software to process high-resolution satellite data has been improved drastically. [15] used high-resolution layers to find out groundwater (GW) recharge potential zones using AHP. A combination of state-of-the-art groundwater potential mapping (GPM) tool C5.0 along with random forest (RF), and multivariate adaptive regression splines (MARS) algorithms were used recently for generating GPMs in the eastern part of Mashhad Plain, Iran [16]. Other known machine learning-based methods adopted in recent studies include boosted regression tree (BRT), classification and regression tree (CART), support vector machine (SVM), and genetic algorithm optimized random forest (RFGA) [17, 18]. A sensitivity analysis of the effect of sample size on the accuracy of different individual and hybrid models (i.e., adaptive neuro-fuzzy inference system (ANFIS), ANFIS-imperial competitive algorithm (ANFIS-ICA), alternating decision tree (ADT), and random forest (RF)) was carried out by [19].

Although very effective and accurate machine learning and artificial intelligence-based GIS techniques are adopted in current studies, the accuracy and efficiency of most of the approaches heavily depend on the available data size and accuracy. However, most of the areas of acute groundwater depletion problem in the Indian subcontinent suffer from the scarcity of accurate and updated spatial data of most of the critical parameters. Hence, we wanted to evaluate the applicability of a relatively simple and computationally inexpensive approach to delineate the groundwater potential zones with minimal available data. For the present study, AHP is used as a scientific tool to estimate weightage, coupled with a simple Mamdani-based hierarchical fuzzy controller to delineate groundwater recharge potential zones over a data-scarce area.

Purulia district of West Bengal is one of the most water-scarce areas of India. Although this district receives 1400 mm of average rainfall during the monsoon season, most of the precipitation disappears through Kumari and Kangsabati river systems as runoff. Low retention capacity of the soil and the presence of hard crystalline rocks beneath the ground create constraints to groundwater development in the area. In the present study, an endeavor has been made to delineate groundwater recharge potential zones in some severely water-scarce blocks of Purulia district of West Bengal using GIS and fuzzy logic techniques to overcome the limitations due to unavailability of ground-based observational data.

2 Study Area

The study area mainly follows the river Subarnarekha, a major river on the western part of Purulia district. Subarnarekha flows through two blocks of Purulia district, Jhalda-I and Baghmundi. In the present study, three adjacent blocks, Jhalda-II, Joypur, and Balarampur are also taken, as these blocks also have groundwater scarcity [1]. The areal extent of the study area is 1549.13 km^2 lying between 23º North to 23º36" North in latitude and 85º48'36" East to 86º19'12" East in longitude.

Subarnarekha is known for its flash floods during the monsoon season. But with contrast, it is also the river basin having the lowest groundwater potential with a groundwater potential of 1.82 bcm (lowest among all the rivers of India) [20]. Average rainfall in the area remains minimal throughout the year except during the monsoon period. Residents of the area, therefore, depend mostly on the available groundwater for their daily needs as well as irrigation. As a natural outcome, groundwater is being depleted very fast [21, 22]. In the past few years, irregularity of rainfall joined the fleet, and the area is going through a severe groundwater crisis [23].

3 Methodology

Some physical methods like groundwater depth, bore well data, soil type, slope, local status, availability of land, presence of harmful metals and chemicals nearby, presence of industry, and presence of harmful organic substances are used for selection of appropriate recharge site in localized studies. But to select those recharge sites on a large scale, the analysis may be done using GIS. Among the different aspects of using GIS, the basic difference is in the selection of layer used and method adopted to obtain the final output.

In the present study, soil type, drainage density, lineament density, geology, geomorphology, land-use type, and rainfall data are used as layers, and analytic hierarchical process (AHP) [24] is used to calculate the weight of each of the individual layers as the input of the hierarchical fuzzy logic. Finally, hierarchical fuzzy logic is used through a total of seven steps to finding the output layer.

The district block boundary map of Purulia is collected from [24] at a scale of 1:2,50,000. From this map, an area has been extracted, taking five blocks (Fig. 1).

3.1 Analysis of Digital Elevation Model

3.1.1 Digital Elevation Model

Digital elevation model (DEM) is a 3D representation of a terrain's surface created from terrain elevation data. From satellite data, latitude and longitude of the
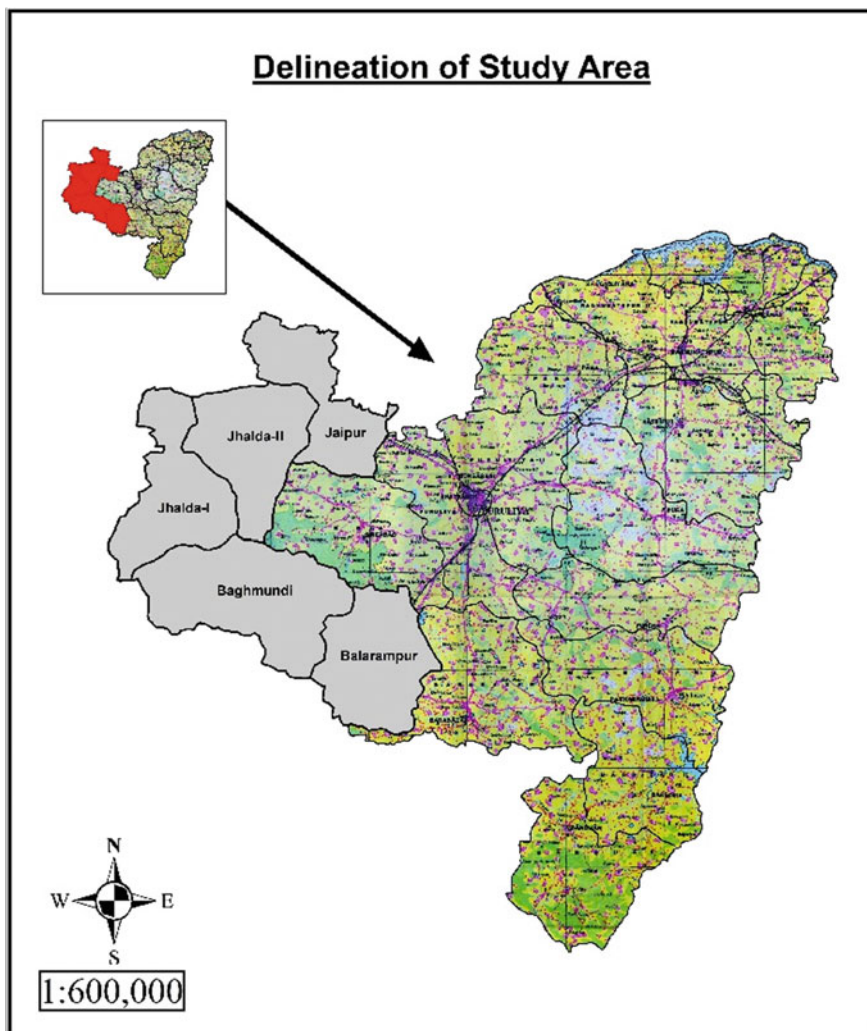
Fig. 1 Selected study area

boundary points are calculated. Using these coordinates, the digital elevation model is downloaded from [25]. This DEM is then geo-corrected and mosaicked together (Fig. 2).

3.1.2   Preparation of Slope Map

The slope is the measure of steepness or the magnitude of inclination of a plane relative to the horizontal plane, typically expressed as a percentage. Slope plays
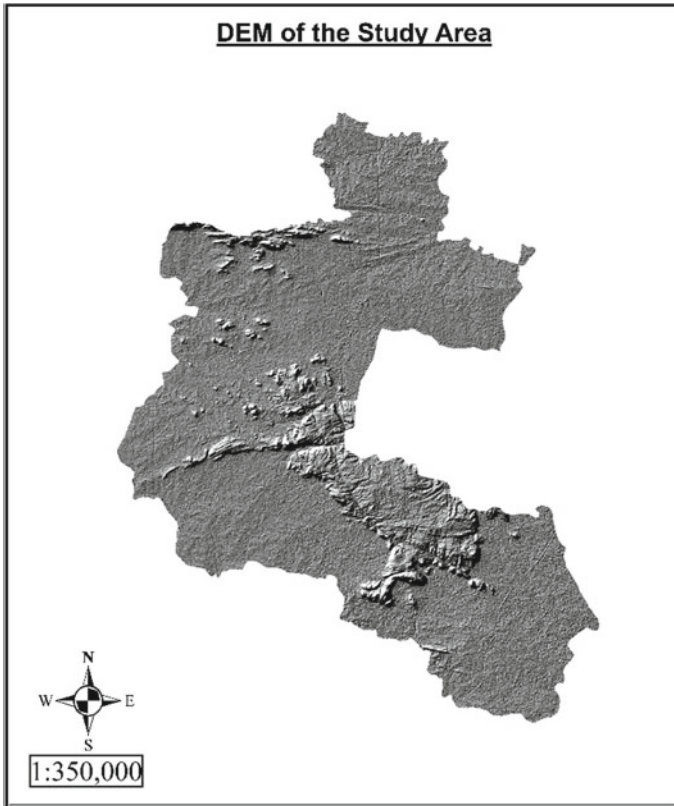
Fig. 2 DEM of the study area

a significant part in governing the hydrological balance of terrain, influencing the orientation and volume of surface runoff and subsurface drainage approaching a site. It also determines the duration and velocity of surface flow, subsurface flow, and amount of infiltration [26]. Steep slope generates more runoff, and less infiltration takes place. However, if the slope is less, more infiltration or recharge will take place, decreasing the runoff amount [27]. DEM is used to generate a slope map to observe the topographic attributes (slope aspects and steepness), which facilitate the evaluation of the variables affecting the presence and flow of groundwater in the area. The slope (Fig. 9), ranging from 0 to 57º, is categorized into five classes.

3.1.3 Preparation of Drainage Map

The drainage map of the study area is derived from DEM using ArcGIS software. This obtained drainage map shows that rivers and channels flow toward east and west from the central axis of the study area. This drainage map is then validated by lying it

over the satellite image of the study area to see if the generated river channels overlap with the actual ones. The process of generating a drainage map starts with the creation of 'Fill'. After the DEM is extracted, it had to be ensured that it had no erroneous depressions. So it is filled using GIS software tools. The depressionless DEM is then used to calculate the probable flow direction in the region. Flow direction is important while working with hydrological modeling, because in order to calculate the drainage network in a watershed, it is essential to determine the direction of flow in each cell of the area. This is done by calculating the relative slope between each cell of the DEM.

The cells with the greatest accumulated flow have been chosen and then converted into a flow accumulation grid, based on the flow direction (Fig. 3). The drainage
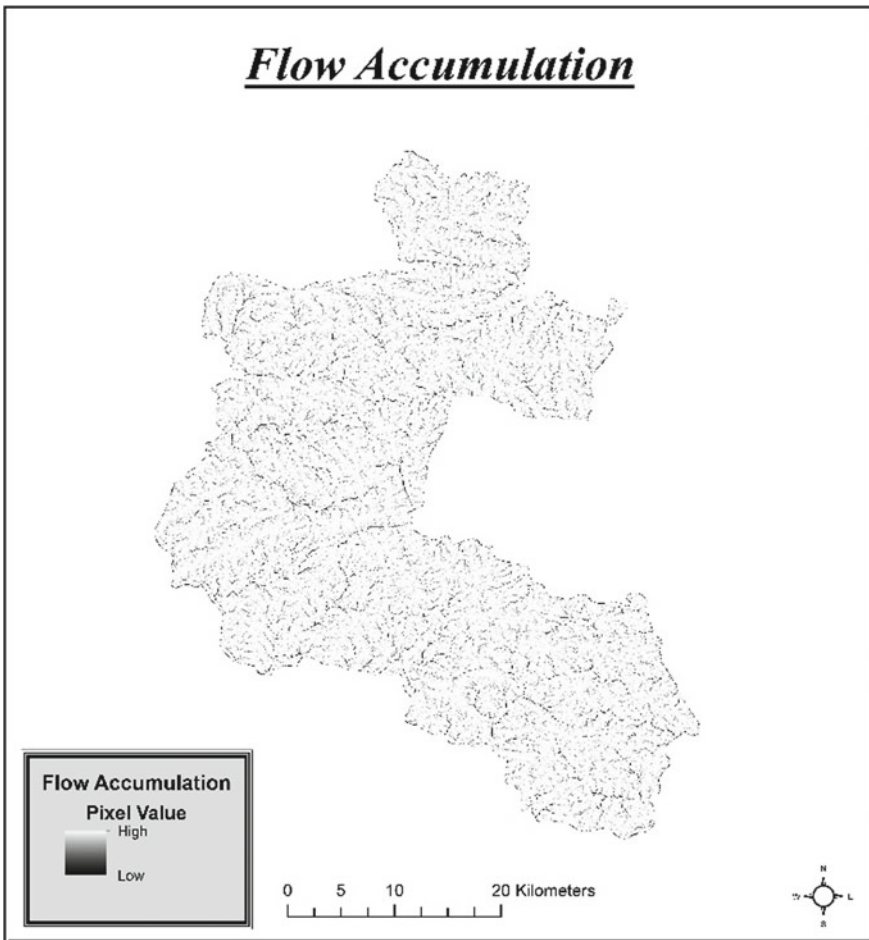

Fig. 3 Flow accumulation map of the area

network in the area is derived from the flow accumulation layer. This method for the creation of a drainage map from flow accumulation works on the probabilistic approach and gives value for each possible flow line. These flow lines are used to delineate possible streamlines. These generated rivers are then validated using the satellite datasets [28]. After the validation, the GIS-based approach is used to classify the rivers into ascending orders (Fig. 4, as rivers having higher-order have a higher contribution in drainage through that area leading to a high rate of infiltration. Universal Transverse Mercator Coordinate system (WGS 1984 UTM Zone 45N) is used to vectorize the flow features in order to quantify the streamflow feature according to respective lengths.
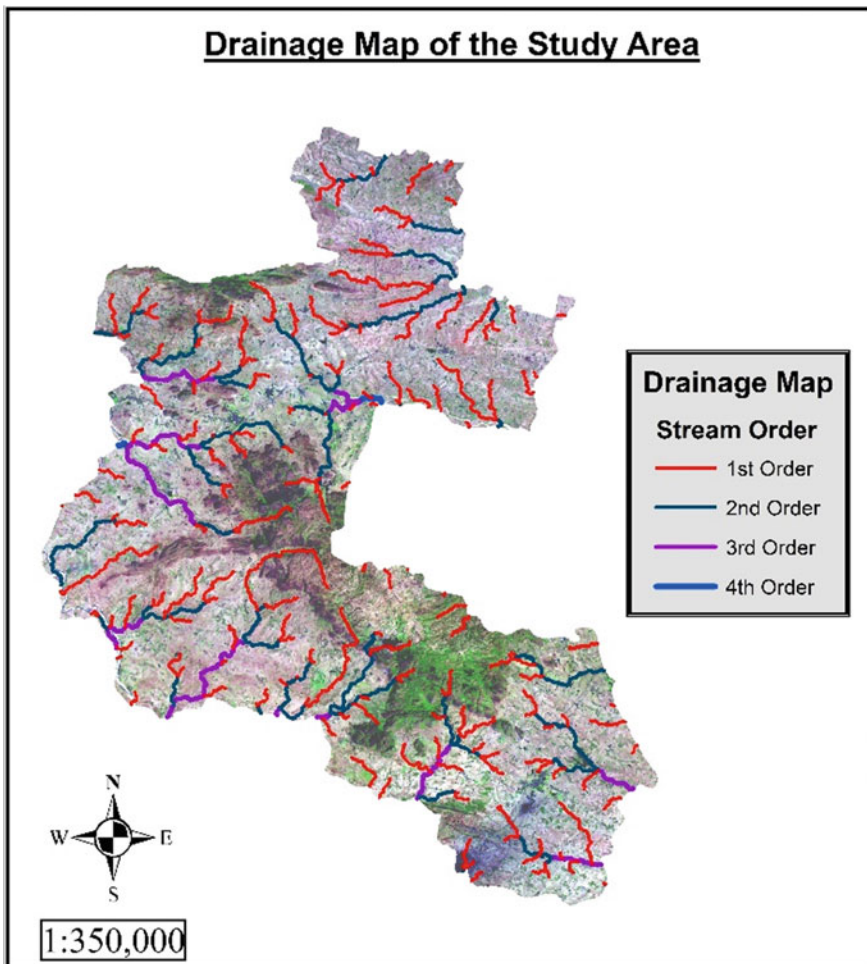

Fig. 4 Drainage map of the area

3.1.4 Preparation of Drainage Density Map

Drainage density is the length of all the streams per unit area of a drainage basin. D_d = L/A, where D_d = drainage density of the area, L = total length of the drainage channel in the study area (m), and A = areal extent of the study area (m^2). It reflects how properly or how poorly a watershed is drained by stream channels. The impact of drainage density on infiltration can be considered from two different aspects. If the river is of a lower order, it contributes mainly to drainage, leading to a lower rate of infiltration. On the other hand, for higher-order rivers, more infiltration takes place due to less slope of the terrain and more availability of water. Drainage density for the area is calculated using GIS (Fig. 10).

3.1.5 Preparation of Lineament Density Map

In the rocky areas, the occurrence and movement of groundwater depend mainly on the permeability resulting from the lineament of the area due to faulting, fracturing, etc. Lineament is an essential parameter in calculating the groundwater recharge potential as it indirectly gives knowledge about the storage and movement of groundwater. Straight stream valleys and aligned segments of a valley are typical geomorphological expressions of lineaments. In this study, after stream ordering, a surface lineament map is prepared from the drainage map. The drainage lines having stream order one, which is parallel to each other, are delineated as features of lineament.

In the present study area, the lineament density ranges from 0 to 3 m/m^2. Particularly in the north, south, and southwest parts of the study area, the density range from 0.5 to 2.5 m/m^2, and these sites are considered as potential zones for groundwater recharge as these sites are most suitable for infiltration of surface water into the ground. Those areas, which have a lineament density of less than 0.5 m/m^2, are not suitable for groundwater recharge (Fig. 11).

3.2 Mapping with Remote Sensing and GIS Techniques

IRS-P6 LISS-III satellite image of Purulia district (dated March 8, 2011) is collected (Fig. 5). Satellite images can be used to verify several artificially generated data. It can also be used as an input to generate some further map layers.

3.2.1 Preparation of Land-Use Map

The extracted satellite image is classified according to land use. For this, we followed a supervised classification technique. In supervised classification, some training polygons are created to train computer about the type of land cover. The maximum likelihood supervised classification technique is then applied using ArcGIS to get an
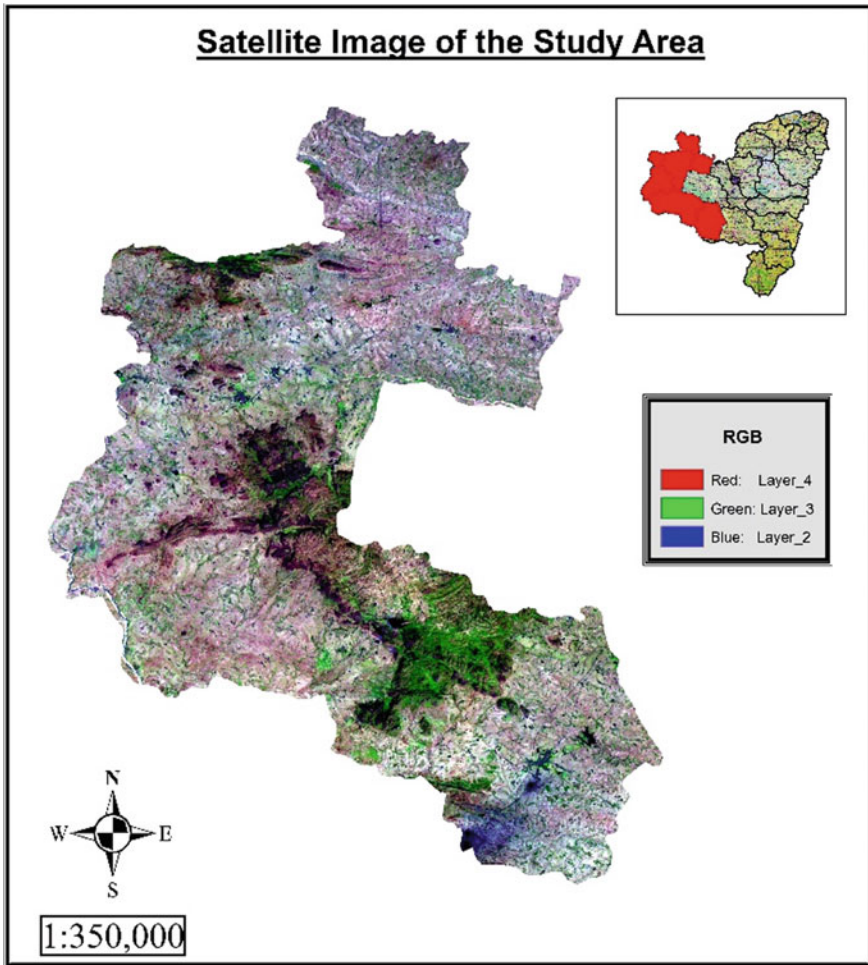
Fig. 5 Satellite image of the area

output image that is classified into four sets of land-use types (Fig. 12; Table 1), 1. dense forest, 2. agricultural land, 3. water bodies, and 4. bare land.

Table 1 Land-use type

Land-use type	Dense forest	Agricultural land	Water body	Bare land
Area (km^2)	472.5	545.17	3.33	521.33

3.2.2 Preparation of Soil Map

Soil plays an important role in the infiltration rate of an area. This again directly affects groundwater recharge potential of that area. Different soils have different infiltration rates. So, it is important to prepare a soil map of the study area, which has been derived from the National Bureau of Soil Survey and Land Use Planning (ICAR) at a scale of 1:500,000. There are five types of soil (Fig. 6) present in the area,
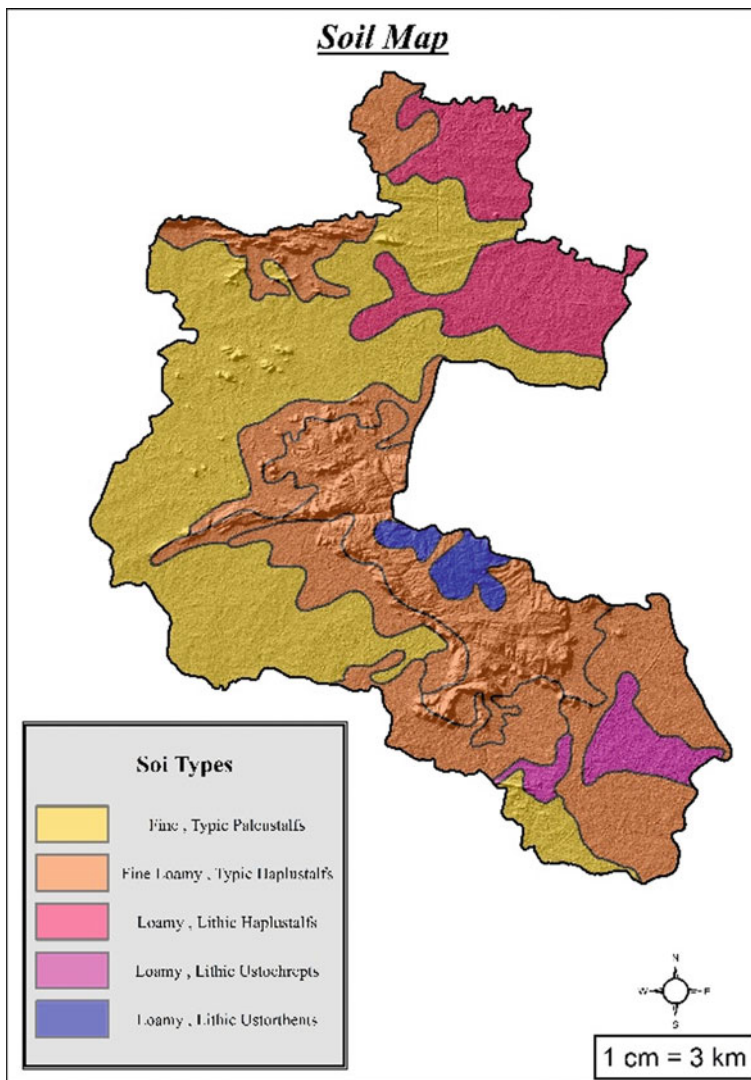

Fig. 6 Soil map of the area

Table 2 Soil types of the area

Type of soil	Soil code as per ICAR	Area covered (km^2)
Ustochrepts (Loamy)	W093, W095	64.02
Haplustalfs (Loamy)	W096	191.15
Haplustalfs (Fine Loamy)	W091, W094, W102	657.71
Paleustalfs (Fine)	W104	602.54
Ustorthents (Loamy)	W092	32.74

i.e., Paleustalfs (Fine), Haplustalfs (Fine Loamy), Haplustalfs (Loamy), Ustochrepts (Loamy), and Ustorthents (Loamy) (Table 2).

3.2.3 Preparation of Geology Map

Geology of an area plays a vital role in this study. Several rock formations give an idea about the groundwater depth and subsurface flow characteristics. The map has been prepared from the Geological Survey of India at a scale of 1:250,000. After extracting the study area from the map, a vector layer is created over it to get the characteristics and area of each geology type (Fig. 7).

3.2.4 Preparation of Geomorphology Map

Geomorphology tells us about the creation and transformation of topographic and bathymetric features created by physical, chemical, or biological processes operating at or near the earth's surface. Geomorphology map is obtained from the Geological Survey of India at a scale of 1:1,000,000, which is then georeferenced, and the study area is extracted. After vectorization, the final geomorphology thematic layer map is prepared (Fig. 8).

3.2.5 Rainfall Distribution Map

Rainfall is the main contributor for artificial recharge. Areas with more rainfall are naturally more suitable for artificial recharge sites. Rainfall data for the area is downloaded from ECMWF [29]. This is utilized to develop the rainfall distribution map using the Inverse Distance Weighted (IDW) interpolation technique in the ArcGIS spatial analyst tool.

Inverse distance weighted (IDW) interpolation is a technique based on the assumption that objects closer to each other are more identical than those which are more separated. The measured values around the prediction location have a more significant impact on the forecasted value than those farther away. It gives higher importance to points closest to the forecast location, and the weights decrease as a function
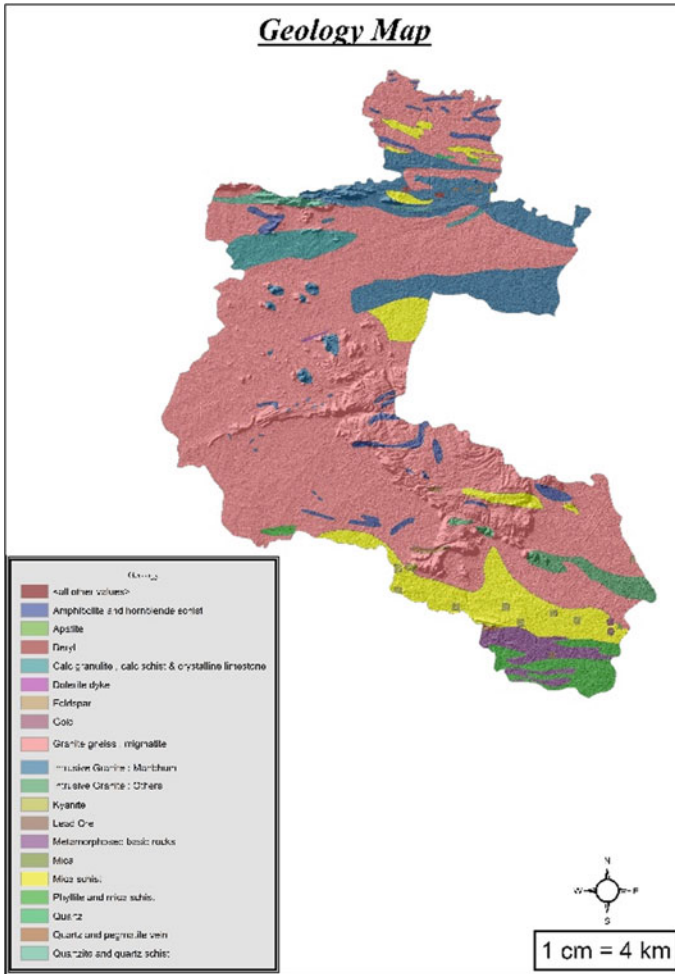
Fig. 7 Geology map of the area

of distance. Result of the IDW analysis of rainfall distribution is further used as a thematic layer in the calculation (Fig. 13).

3.3 Hierarchical Fuzzy Logic

Fuzzy logic is a tool to deal with uncertainty where normal probability theory fails to work due to large computational expensiveness. Fuzzy logic takes into account all the possible combinations of inputs and possible outcomes for each case. It then considers the possible fuzziness of the output and gives a more humanlike response
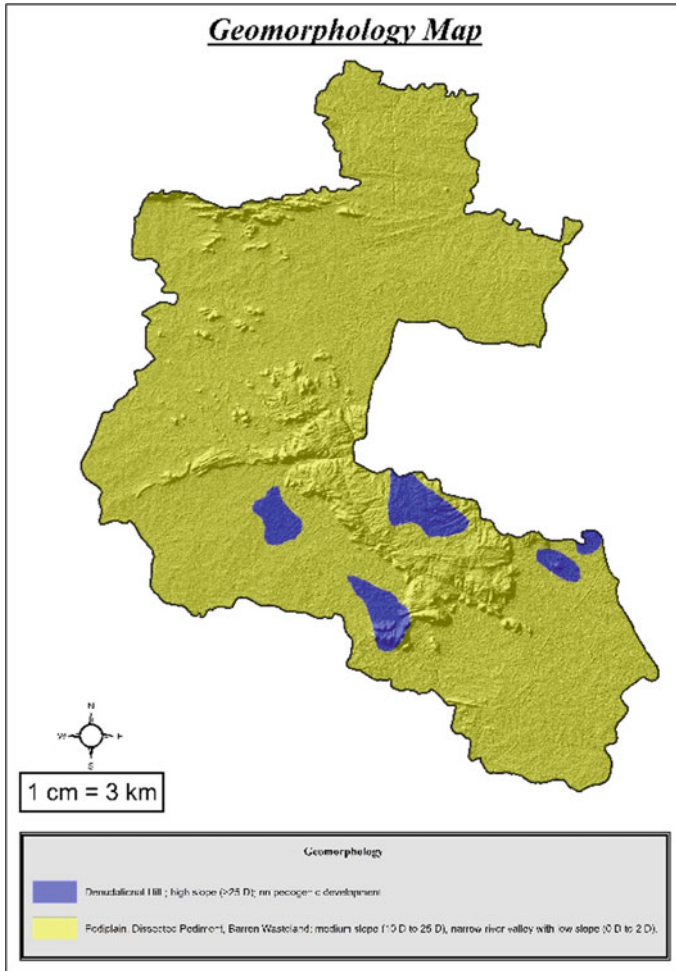
Fig. 8 Geomorphology map of the area

toward the problem. The main problem with the fuzzy sets is the number of rules (predefined relations between input set and output) increase exponentially with the number of inputs used. To overcome this shortcoming, hierarchical fuzzy logic (HFL) is introduced where inputs are sorted according to relative importance, and then fuzzy logic-based calculations are carried out stepwise. Here, we have used the same approach, and to find the initial relative weights among the parameters, AHP is used.

3.3.1   Analytic Hierarchy Process (AHP)

AHP is a mathematical, matrix-based technique, widely used as a decision-making tool in various complex methods. It helps to capture both subjective and objective aspects of a decision. Hierarchical structures have been used here to represent a complex problem and develop local priorities for alternatives based on the judgment of the user, and then synthesizes the results for the calculation of global priorities [24].

AHP, as a weight estimating technique, enables decision-makers to derive weights rather than assign them arbitrarily. AHP maintains complexity and suitable judgment while allowing both objective and subjective considerations to be incorporated in the decision-making process [30].

 (i.)   The dominant objective is specified first as a goal
(ii.)   The goal is then broken down step by step into more specific objectives that can further be broken down into subobjectives:
(iii.)   The attributes lie at the tip of the hierarchy.

3.3.2   Applying AHP in Present Study

In the present study, AHP proposed by [24] is applied to determine the weights. The AHP method used here has four steps of calculations.

- Creating pairwise comparison matrix;
- Finding highest eigenvalue and then right eigenvector for each criterion;
- Normalizing right eigenvector to delineate weight for individual layers;
- Checking for consistency.

3.3.3   Deriving Pairwise Comparison Matrix

The AHP pairwise matrix is developed by putting relevant importance value for each criterion involved in the present study. The relative importance values are defined with the Saaty's 1 to 9 scale, where a score of 1 denotes equal weight between the two cases, and a score of 9 means the absolute importance of one case compared to the other one [24]. An unbiased opinion is taken from each of the individuals of a three-member expert panel. The average of three individual datasets is then used as the base pairwise comparison matrix. Table 3 represents the pairwise comparison matrix obtained based on average expert opinion using Saaty's nine-point importance scale used to calculate relative weights for the thematic layers.

Table 3 Pairwise comparison matrix

	Drainage density	Geomorphology	Soil	Land use	Geology	Rainfall	Slope	Lineament density
Drainage density	1	¼	3	6	1/2	4	5	2
Geomorphology	4	1	6	9	3	7	8	5
Soil	1/3	1/6	1	4	1/4	2	3	½
Land use	1/6	1/9	1/4	1	1/7	1/3	½	1/5
Geology	2	1/3	4	7	1	5	6	3
Rainfall	¼	1/7	1/2	3	1/5	1	2	1/3
Slope	1/5	1/8	1/3	2	1/6	1/2	1	¼
Lineament density	½	1/5	2	5	1/3	3	4	1

Table 4 Right eigenvectors of the thematic layer parameters

	Eigenvector	Normalized weight
Drainage density	−0.299	0.144
Geomorphology	−0.804	0.3867
Soil	−0.137	0.0658
Land use	−0.046	0.0221
Geology	−0.434	0.2087
Rainfall	−0.092	0.0442
Slope	−0.064	0.0309
Lineament density	−0.203	0.0976
Sum	**−2.08**	**1**

3.3.4 Evaluation of Eigenvalue Analysis

AHP captures the idea of uncertainty in judgments through the principal eigenvalue and the consistency index [31]. In the present study, maximum eigenvalue and corresponding right eigenvector are calculated for the pairwise comparison matrix shown above; the maximum eigenvalue is 8.3458721. The resultant right eigenvector is shown in Table 4.

3.3.5 Normalizing Right Eigenvector to delineate weight for individual layers

In the final step of AHP analysis, the normalized weights are computed from the corresponding eigenvector values using the formula as mentioned below.

$$Normalized\ Weight = \frac{Eigenvector\ value\ of\ a\ feature\ class}{Sum\ of\ all\ the\ Eigenvectors}$$

These normalized weights are then used for sorting the inputs for calculations using HFL.

3.3.6 Checking for Consistency

Saaty's eigenvector method is used to find out the consistency ratio (CR) for errors in the judgment of parameter weights. CR is calculated using the formula:

$$C.R. = \frac{C.I.}{R.I.} \tag{1}$$

where CI represents for consistency index, derived using the formula.

$$C.I. = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

and RI stands for ratio index, the value of which is specified by Saaty (Table 5), where n is the number of parameters, hence 8.

If the value of CR is less than 0.1, then it is accepted, whereas for CR values greater than 0.1, reconsideration of judgments is required. In our case, the CR value is 0.035, which is well below the permissible limit.

Table 5 Saaty's ratio index for different number of parameters (n)

n	R.I.
1	0
2	0
3	0.58
4	0.89
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Table 6 Design of hierarchical fuzzy logic controller

Stage	INPUT 1	INPUT 2
Stage 1	Geomorphology	Geology
Stage 2	Output of Stage 1	Drainage density
Stage 3	Output of Stage 2	Lineament density
Stage 4	Output of Stage 3	Soil
Stage 5	Output of Stage 4	Rainfall
Stage 6	Output of Stage 5	Slope
Stage 7	Output of Stage 6	Land use

3.3.7   Applying Hierarchical Fuzzy Logic

After the satisfactory estimation of the final weighted sequence for the input parameters through the application of AHP, calculation through HFL is implemented. As discussed earlier, to reduce the computational load, the total fuzzy logic controllers are divided into a total of seven stages to form an HFL, namely stage 1 through stage 7.

Gaussian distribution is applied to each of the stages, and two stages are fuzzified using the Mamdani approach at each level. The distribution of levels is presented in Table 6. Each of the feature maps is classified in a total of five levels of groundwater potential, namely very poor, poor, average, high, and very high. Final values are calculated by defuzzification of the fuzzy membership values from the output of stage 7 using the small of maximum (SOM) method of defuzzification. Defuzzified fuzzy membership values (FMV) corresponding to the suitability of groundwater recharge range from 0 to 1 ('0' being the least suitable and '1' being the most suitable). The study area is categorized into five groundwater recharge potential zones, namely very poor ($0 \leq FMV \leq 0.125$), poor ($0.125 < FMV \leq 0.375$), moderate ($0.375 < FMV \leq 0.625$), good ($0.625 < FMV \leq 0.875$), and very good ($0.875 < FMV \leq 1$).

4   Results and Discussions

The spatial distribution map of slope, drainage density, and lineament density using the digital elevation model is presented in Figs. 9, 10, and 11, respectively. The spatial distribution map of land-use types estimated through the application of remote sensing using a high-resolution satellite image of the study area is presented in Fig. 12. The spatial map of IDW analysis of rainfall distribution is shown in Fig. 13. The final output from the fuzzy AHP analysis is plotted in GIS to obtain the spatial map showing different types of potential zones (Fig. 14).

From the output map (Fig. 14), it is observed that most of the high groundwater recharge potential zones lie in the northeast and central part of the study area. In Table 7 below, the area under each potential zone is shown, and the blockwise distribution
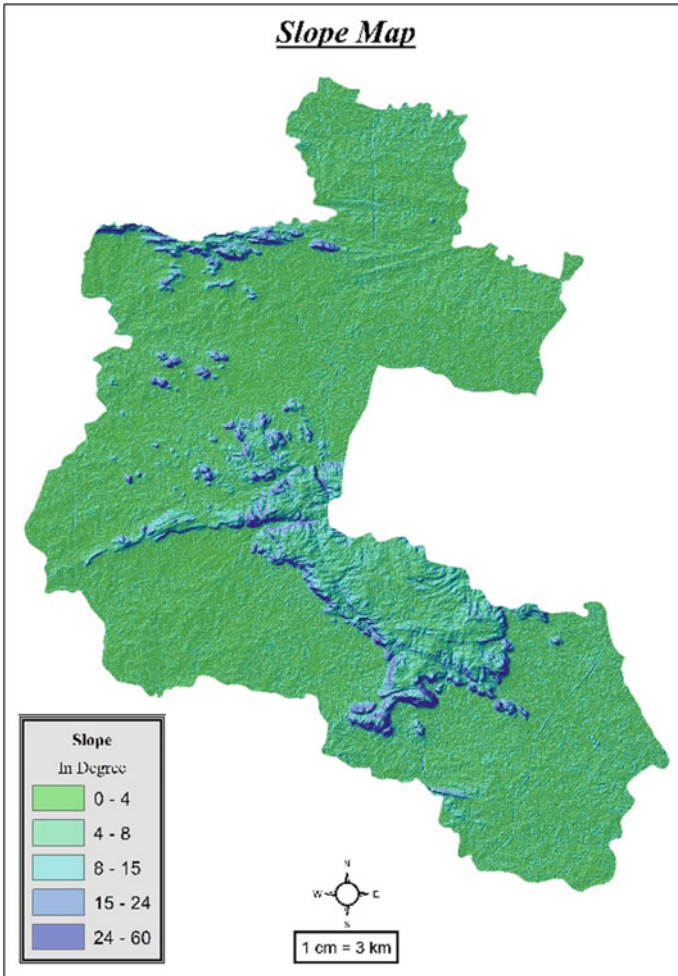
Fig. 9 Slope map of the area

of area is shown in Table 8. The table highlights that the recharge potential zones are spread among all the blocks, though Baghmundi block has the best potential for groundwater recharge having 21.9% and 27.76% of its area under very good and good recharge potential zone, respectively.

In this study, a fuzzy-based method that maintains the relativistic influence of various thematic layers and their corresponding classes affecting groundwater has been adopted to predict groundwater recharge potential zones of the area. Five blocks of Purulia district of West Bengal are chosen as the study area and eight thematic layers, viz. geomorphology, land use, density of drainage network, soil types, geology, rainfall, slope, and lineament density, have been incorporated for estimating groundwater recharge potential zones. Results indicate that 12.13% of
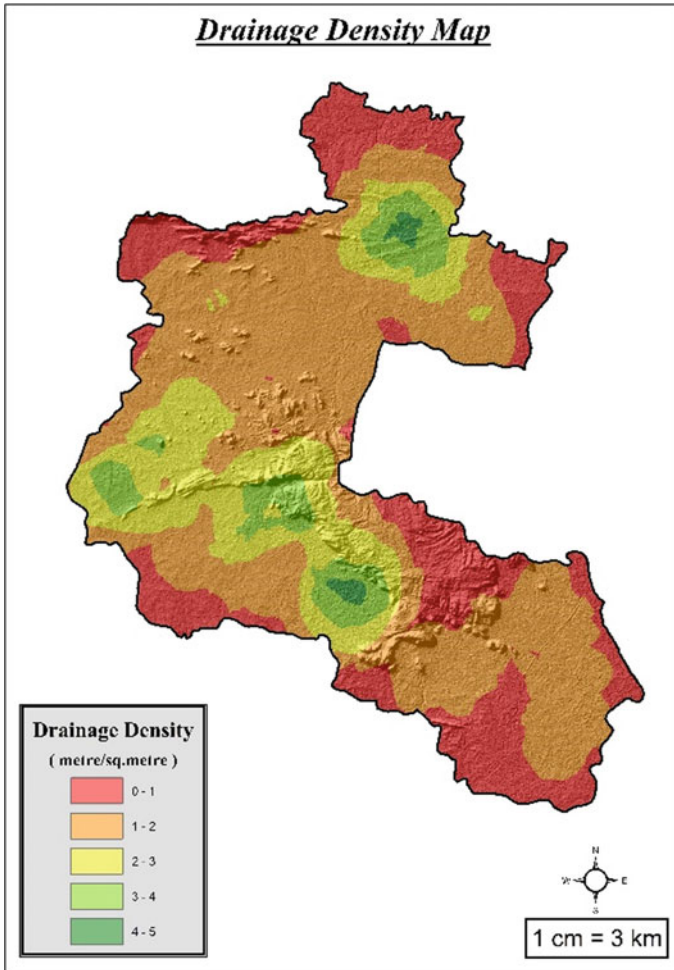
Fig. 10 Drainage density map of the area

the area has very good groundwater recharge potential, and 29.37% of the area is designated as having good groundwater recharge potential, with over 29.64% being moderate and 27.04% area has poor groundwater recharge potential. 7.82% of the area has very poor groundwater recharge potential.

From blockwise statistics, it is seen that Baghmundi block has the highest percentage of area suitable for groundwater recharge. This block has 21.9% of its area, having very good and 27.76% of its area having good groundwater recharge potential. It can be seen that areas with dense forest, higher lineament density, and soil type having a high infiltration rate have been detected to be having very good recharge potential.
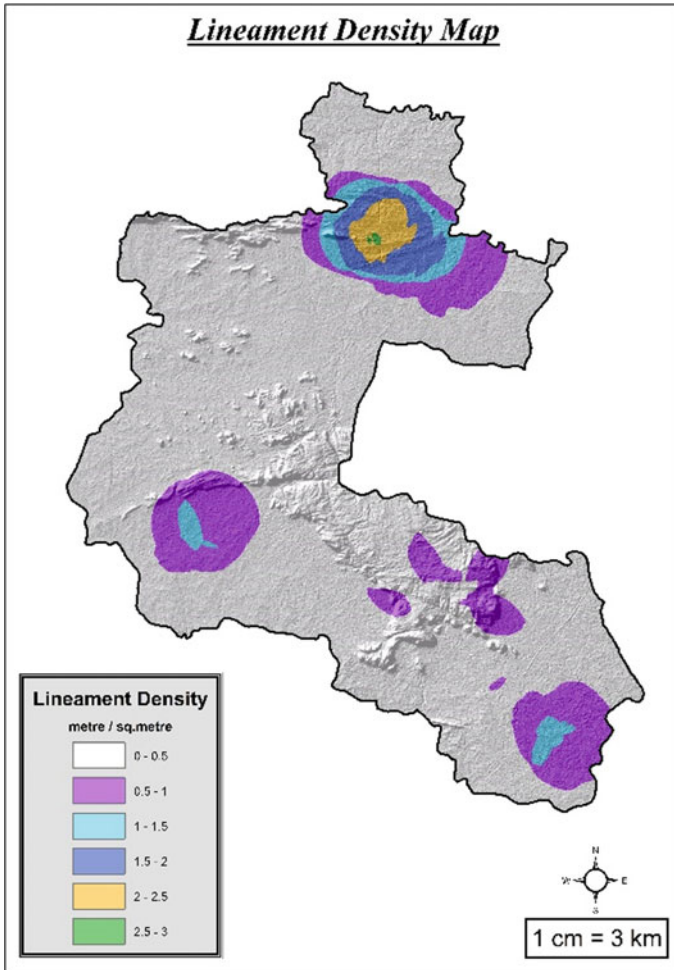
Fig. 11 Lineament density map of the area

The area under study is one of the areas to have the minimal presence of ground-based data, thus inhibiting any past study over the region. Although this study exhibits the efficacy of a coupled yet simple numerical approach to delineate groundwater potential zones, the availability of more observational data over the region is expected to aid the approach in both the accuracy and viability aspect.
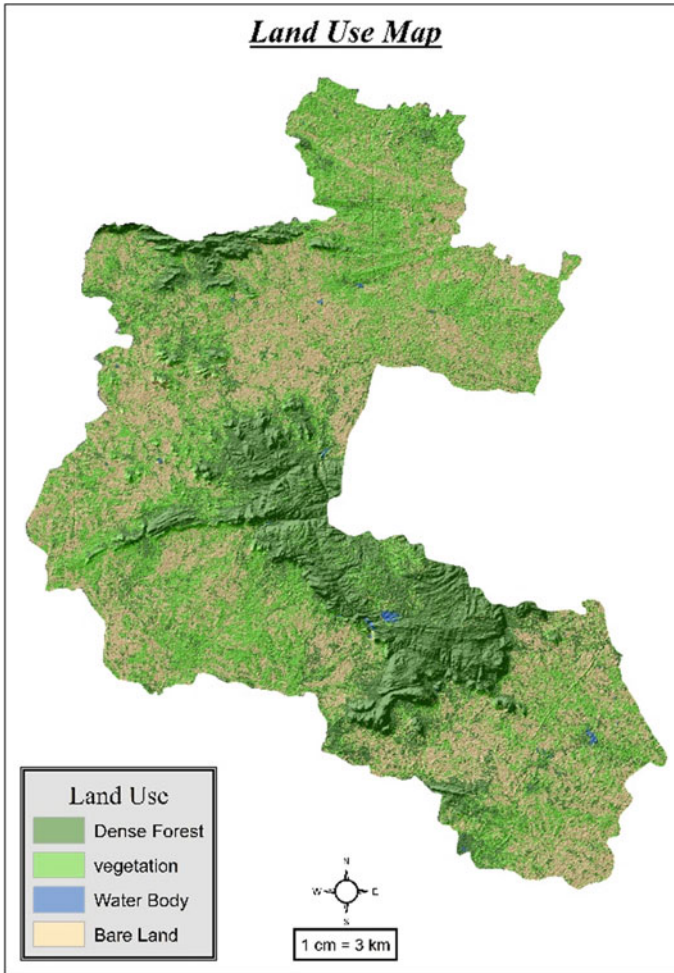
Fig. 12 Land-use types over the area

5 Conclusion

The present research has shown the abilities of AHP with geoinformatics coupled with fuzzy logic techniques for the identification of groundwater recharge potential zones, specifically over a data-scarce region. Based on the results of this research, it can be concluded that the applied methodology is a valuable framework for the prompt evaluation of groundwater recharge potential and can be suggested to be implemented in other areas, especially in areas having insufficient ground data. Therefore, the outcome of this study can also be utilized for developing irrigation facilities in the future, which in turn will accelerate the crop production. The study
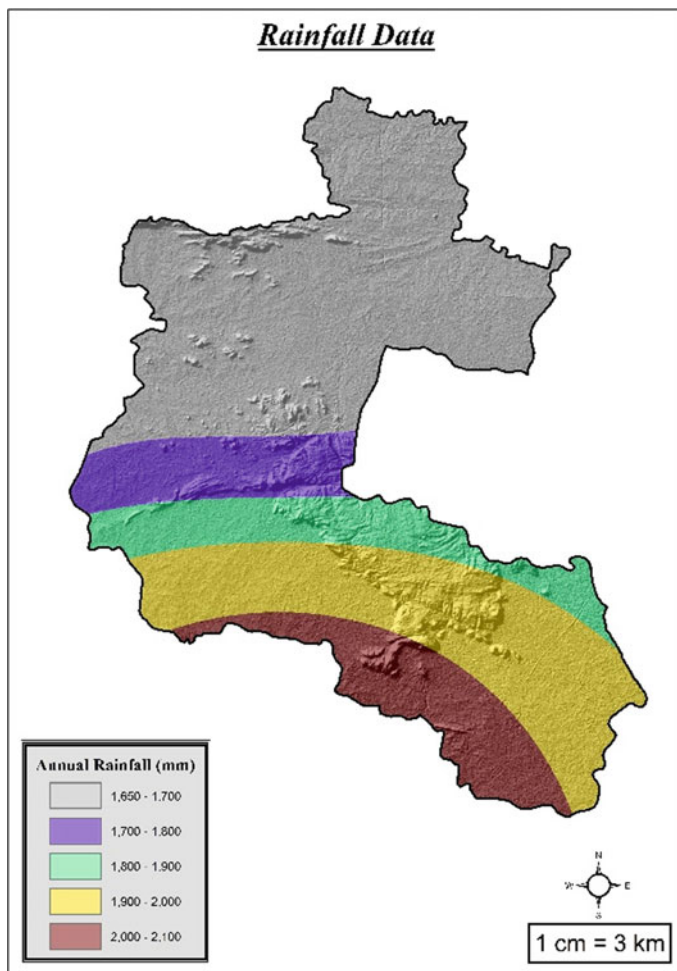
Fig. 13 Rainfall distribution map of the area

will be helpful for adopting suitable sites for water harvesting structures. Thus, the study is expected to lead to a good path for future planning of water resources in the blocks of the Purulia district.
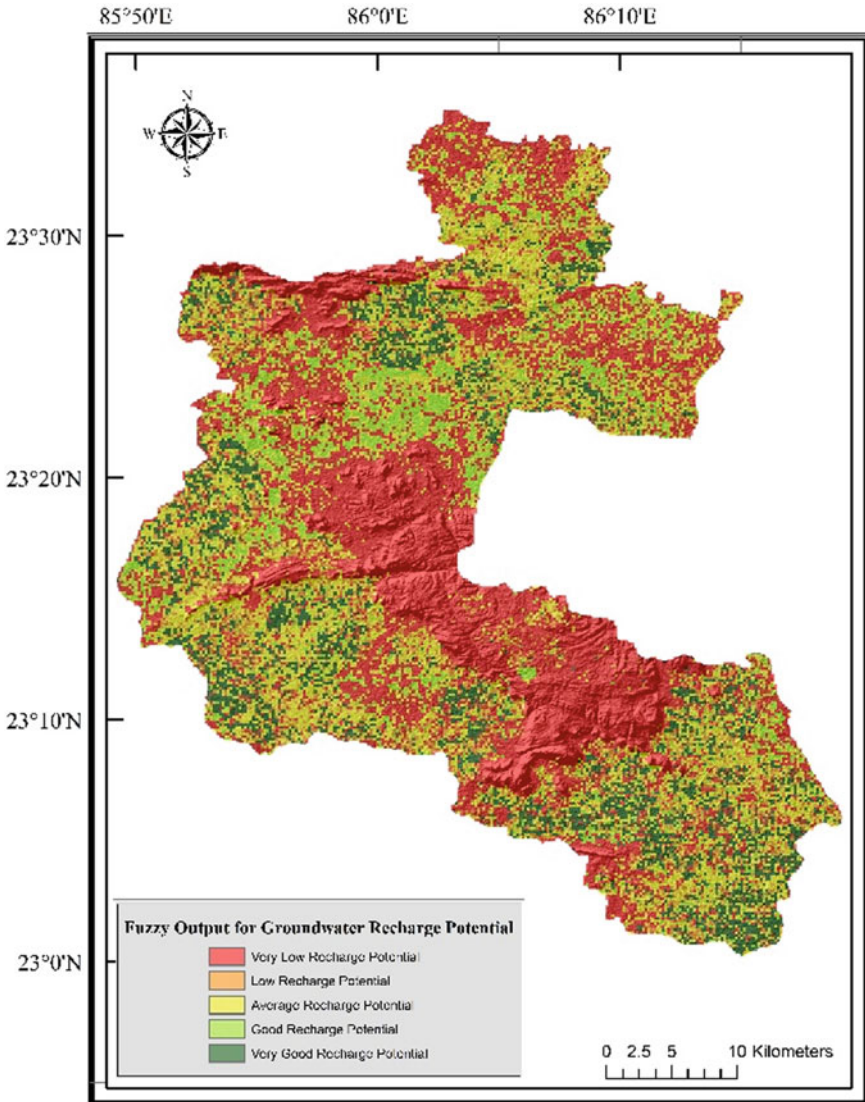
Fig. 14 Final fuzzy output for the area

Table 7 Percentage and area under each potential zone

Potential zones	Area (km^2)	Percentage of area
Very low	120.08	7.82 %
Low	415.44	27.04 %
Average	455.29	29.64 %
High	359.08	23.37 %
Very high	186.35	12.13 %
Total area = 1536.24 km^2		

Table 8 Blockwise area statistics

	Balarampur (%)	Baghmundi (%)	Jhalda-I (%)	Jhalda-II (%)	Jaipur (%)
Very low	8.22	6.04	6.32	6.11	14.08
Low	27.51	18.43	25.64	34.05	34.96
Average	37.82	25.87	34.32	32.81	16.71
High	24.58	27.76	29.09	13.63	18.93
Very high	1.87	21.9	4.63	13.40	15.32

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