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ORIGINAL ARTICLE

Assessment of groundwater potentiality using geospatial techniques in Purba Bardhaman district, West Bengal

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Abstract
The word water is life, so life on this planet cannot be possible without water. Water is an essential natural resource that is a surface and groundwater device for human society. The purpose of this research is to assess the groundwater potentiality of the Purba Bardhaman district. All data (primary and secondary) are collected from different sources and analyzed in geographic information system (GIS) software to prepare thematic maps. Different geo-environmental factors like as land use and land cover, soil, lithology, rainfall and distance from the river, etc., can impact on groundwater availability directly or indirectly in Purba Bardhaman area. To identify groundwater potential zones, all these factors are composed into GIS software using multi-criteria decision analysis (MCDA) method. The groundwater potential map has been divided into five classes based on their magnitude as very high, high, medium, low and very low groundwater potential zones. It shows that the areas of very low, low, medium, high and very high groundwater potential zones are 21.54%, 35.80%, 26.47%, 10.13%, 6.06%, respectively, of the total area. Finally, validation is carried out using groundwater depth data collected from 44 drilled tube wells which are located in a scattered manner for whole Purba Bardhaman district which indicates a higher similarity with an area under curve value of 86.8%.

Keywords Groundwater · Purba Bardhaman · Multi-criteria decision analysis · GIS

Introduction

Groundwater is a dynamic resource that plays a vital role in nurturing an ecological balance (Das 2017). The largest freshwater resource in the world is groundwater. Today, the maximum rural population and the total urban population depend on groundwater for their basic needs. Proper management strategies cannot be developed in the context of the groundwater decay scenario due to lack of knowledge in this area. Maximum groundwater is needed for agriculture, drinking water and industry. The absence of groundwater is a common phenomenon in India due to the use of groundwater without proper scientific planning (Rodell et al. 2009). The most valuable resource is groundwater which is unevenly distributed. Distribution of groundwater is controlled according to many criteria, i.e., lithology, geological structure, lineaments, soil, slope, drainage density, distance from the river, vegetation cover, surface water scenario, land use and land cover, rainfall, climatic condition and interrelationship between these factors (Sar et al. 2015; Jothibasu and Anbazhagan2016; Dasho et al.2017).

Six main criteria were used to analyze the groundwater potential of Purba Bardhaman, i.e., soil, land use and land cover, lithology, surface water scenario, water distance and rainfall. In this plain region, they are the most effective. Remote sensing (RS) and GIS techniques (Krishnamurthy et al. 1996; Pothiraj and Rajagopalan 2013; Sar et al. 2015; Anbazhagan and Jothibasu 2016; Jothibasu and Anbazhagan 2017; Choudhari et al. 2018; Das and Pal 2019a, b) are very much useful to delineate the groundwater potential zone. Many researchers in India and aboard have been successfully using this technique to identify groundwater potential zone. Thematic layers have been made through Arc GIS software. Recently, the application of multi-criteria decision making (MCDM) technique in GIS framework plays an important

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role in scientific investigation in groundwater resource management (Chen et al. 2011). The other areas where MCMD technique and GIS both play a vital role, are natural hazard (Ozturk and Batuk 2011), agriculture (Cisneros et al. 2011) and forestry (Zeng et al. 2007). Analytic hierarchy process (AHP) by Saaty of MCMD is playing a vital role to solve socioeconomic decision-making problems (Jhariya et al. 2016; Pal et al. 2019; Das and Pal 2020). In the AHP model, priority is given not only to the single element, but also to the cluster of elements that are often needed (Saaty 1999). In this paper, the AHP model was successfully used to assign relative importance to parameters that elucidate potential groundwater areas (Machiwal et al. 2015; Jhariya et al. 2016; Dasho et al. 2017; Das et al. 2017; Chakrabortty et al. 2018; Das et al. 2019). The main aim of this work is to identify the groundwater potential area of Purba Bardhaman district through the application AHP method and GIS technique. This study may be helpful in future planning for sustainable groundwater management which may help the people from water crisis.

Study area

The Purba Bardhaman district consisted of an alluvial plain. The study area is enclosed between 22° 15′ 08″ N to 23° 15′ 17″ N latitudes and 87° 13′ 17 E to 88° 7′ 22″ E longitudes (Fig. 1). In this district, the three major rivers are Ajay, Bhagirathi and Damodar, which are situated on the north, east and south side of the district. The undulating lateritic topography is found in the Ausgram region, which is part of the Paschim Bardhaman district. The study area is part of the tropical region. According to the 2011 census, the total population of the district was 48,35,532. Agriculture with a limited number of agricultural industries is a main occupation in this region. In this analysis, there are 11 community blocks, i.e., Ketugram-I, Ketugram-II, Bhatar, Raina-I, Raina-II, Kalna-II, Mongalkote, Katwa-II, Katwa-I, Memari-II, Monteswar were identified as semi-critical blocks (CGWB 2013) out of 23 community blocks, and there is a long-term trend in water level fluctuations (CGWB 2016). The central part of this study area received sufficient amount of rainfall which is categorized as high for this study region, i.e., above 1400 mm. The maximum part of this study region encompases with the distribution of 1200 to 1400 mm rainfall, whereas rest of the region has received below 1200 mm rainfall per year.

Database and methodology

Various types of data are presented here in the tabulated form which has been used for preparing the groundwater potential zone in Purba Bardhaman district. The analyses have been started after the collection of all the required datasets. Numerous types of data (Table 1) and software like ArcGIS 10.3 and ERDAS IMAGINE 2014 have been used in this work. In this work, six criteria, i.e., lithology, soil texture, rainfall, distance from river, surface water body and land use land cover, have been taken into consideration to prepare groundwater potential zone. All the maps have been transformed into Universal Transverse Mercator (UTM) projection northern zone 45 datum WGS 1984 in ArcGIS software. Four thematic layers such as lithology, rainfall, distance from the river and soil texture have been digitized and rectified from various sources which are already mentioned in Table 1. We used the ERDAS 9.0 software for satellite image processing. The maximum likelihood classification method of supervised classification was applied for land use land cover map using the same Landsat 8 OLI satellite imagery of 2019 and software. The surface water body has been extracted using the normalized difference water index (NDWI) method from the same satellite image in ArcGIS 10.3 software. There are various water extraction methods, and one of them is the NDWI method which is used in this paper. Equation of NDWI is as follows:

$$\mathrm{NDWI} = (\mathrm{Green} - \mathrm{NIR})/(\mathrm{Green} + \mathrm{NIR})$$

After preparation of all thematic layers, the AHP method has been applied. Regarding this, the spatial distributions of all geo-environmental variables are from different data sources. AHP is a semiquantitative approach. In the AHP model, score is representing the importance of every individual factor (Saaty 1977, 2000). The preference values are applied for each factor following the importance scale of AHP for the calculation of relative importance in association with the goal (Saaty 1977; Saaty and Vargas 2001).

Generation of groundwater potential zone

Variable factor weights (Vi) and individual factor weights (Fi) for each thematic layers have been assigned to delineate groundwater potential zone. The spatial amalgamation of all map layers has been done using the raster calculator tool of ArcGIS 10.3 software version. Finally, a linear sum combination method has been adopted for getting the groundwater potential zone in RS-GIS environment.

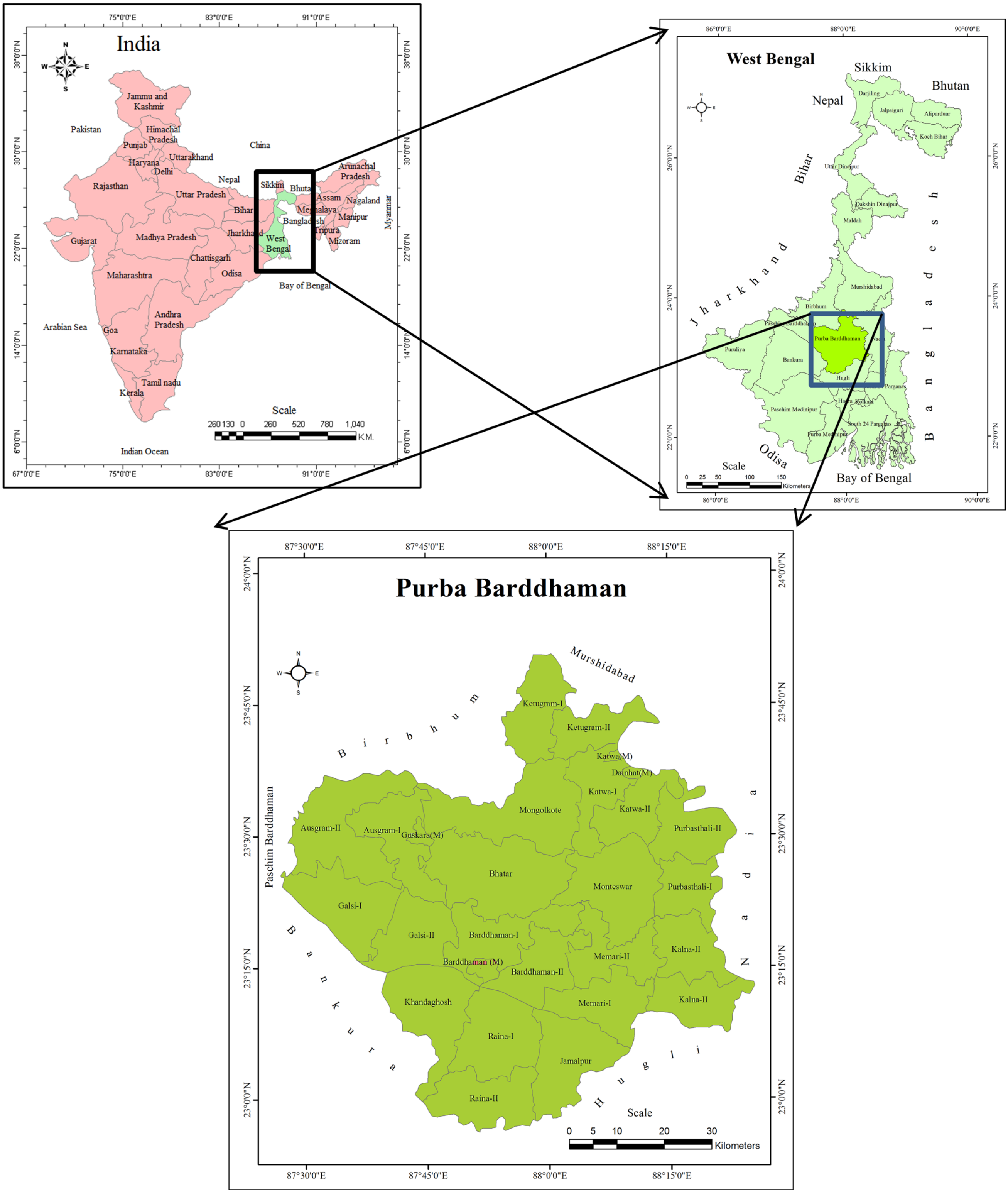

Fig. 1 Location map

Table 1 Sources of data

Attribute	Source
Lithological Unit	Geological Survey of India, Kolkata 2001 (Scale-1:2,50,000)
Soil texture	National Bureau of Soil Survey & Land Use Planning (NBSS&LUP), Kolkata [Soil Survey and Land Use Plan of Bardhaman District, West Bengal]
Rainfall	Central Ground Water Board, Government of India [Scale—1:1,000,000
Land use Land cover, Surface water body	LANDSAT 8, USGS [(Path/Row: 138/44, Acquired date: 2019-01-29, Scene center time: 23:58:53Z) and (Path/Row: 139/44, Acquired date: 2018-12-11, Scene center time: 13:08:32Z)]
Groundwater data	Central Ground Water Board, Government of India
Groundwater depth wells data	India-WRIS webGIS, Water Resources Information System of India (Bardhaman District- 2018)

$$GPZ = [(Liw*Liwi) + (STw*STwi) + (DfRw*DfRwi) + (LULCw*LULCwi) + (SWw*SWwi) + (Rfw*RFwi)]$$

where GPZ = groundwater potential zone, Li = lithology, ST = soil texture, DfR = distance from river, LULC = land use land cover, SW = surface water bodies, Rf = rainfall, the subscripts w and wi refer to the normalized weight of a theme and normalized weight of individual features of a theme, respectively.

Thereafter, the groundwater potential zone map has been validated by the CGWB bore wells data with the help of the interpolation method (Inverse distance weighted (IDW)) in the ArcGIS environment (Fig. 2).

Results and discussion

Lithological unit

Lithology acts as an important role in groundwater potential because the permeability of the rocks directly influences infiltration. The lithological unit determines the movement and prosperity of groundwater (Jhariya et al. 2016). In this study area, four types of lithological unit are found, namely laterite, clay with caliche concretion, clay alternating with silt and sand, sand-silt–clay (Fig. 3). Mainly, 53.36% of the total area in Purba Bardhaman district clay with caliche concretion is higher than another lithological unit. Three units of lithology, i.e., Q1S, Q2K, Q2D, have been made in Pleistocene to Holocene epoch and L units in Cainozoic epoch (Table 2).

Soil texture

The soil potential depends heavily on the soil texture as the soil texture directly affects the infiltration and aquifer conditions. On the basis of porosity and permeability, the infiltration capacity of coarse-grained soil is high compared to fine-grained soil. In this study area, twelve types (Fig. 4) of soil are found which are derived from weathering of laterite soil and transportation of silt soil by the river. Soil types with their percentage of the area are shown in Table 3.

Mainly, three major types of soil in this region are sandy loam, clayey loam and silty loam. Among those types of soil, sandy loamy soil texture is more permeable than others.

Distances from river

A positive relationship has been found with river and groundwater. Rivers have multifarious interaction with groundwater. Subsurface water flow occurs from river to groundwater zone. This is an uninterrupted flow which increases the groundwater zone. When the groundwater enters the river, it is called base flow. We found a reverse relationship with the river and distance from it for the subsurface and surface flow of the river to the groundwater zone. So groundwater recharge decayed with the increase in distance from the river (Fig. 5).

Land use and land cover

Land use and land cover (LULC) is one of the vital factors which directly affect the development of groundwater recharge. Different types of land use act as differently in the runoff, infiltration and groundwater recharge. Generally, forest cover and agricultural land are most suitable for groundwater recharge. On the other hand, the built-up area is not suitable for groundwater recharge. LULC map has been prepared from mosaics of OLI-TRIS Landsat image. In this study area, LULC map has been classified into major five classes, i.e., agricultural land (36.8%), vegetation (19.1%), built-up area (18.97%), fallow or others types of land (17.89%), and water body (7.24) as shown in Fig. 6. Majority of land in this district is under the cover of agriculture and vegetation. Agricultural activities rely on monsoon rainfall, which is why most agricultural land remains vacant during the cold season. The map shows only a few urban settlements and large rural settlements (Fig. 6). In the LULC classification, water bodies, farm property, woodland, other

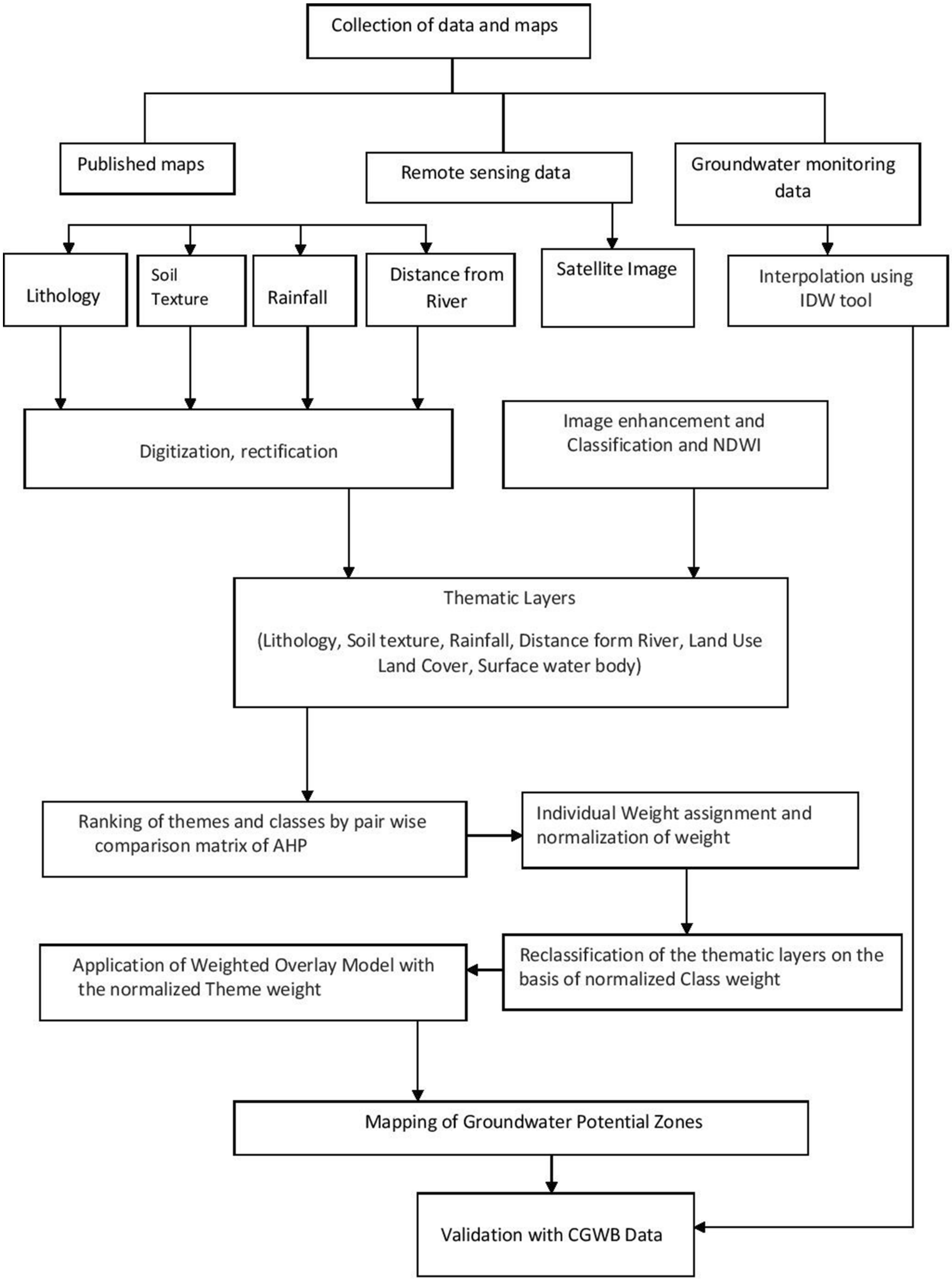

Fig. 2 Flowchart of methodology

property and built-up areas shall be given the highest to the lowest weight as shown in Table 4.

Surface water body

There is a complex interconnection between surface water and groundwater. Exchange of surface water and subsurface

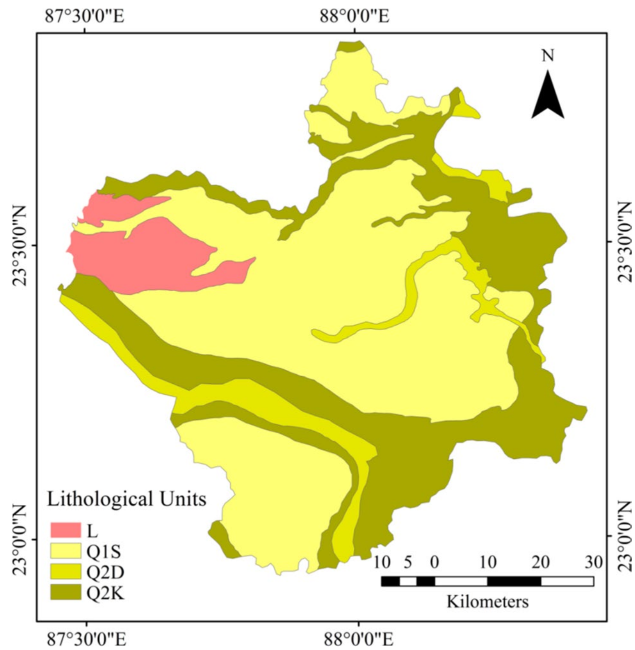

Fig. 3 Lithological map

water is a part of the hydrosphere within the land. This interaction is one of the processes of the natural hydrologic cycle. The interaction between surface water and groundwater is determined by a complex combination of geological, hydrological, geomorphological, climates and landscape factor. Surface water means water reservoirs of this earth such as lakes, swamps, ponds, wetlands, stream, etc. If the permeable rock is present below the surface water penetration stage, it plays a vital role in the recharge of groundwater. The surface water thematic map of the Landsat OLI-TRIS image using the NDWI method has been prepared in this study area as shown in Fig. 7.

Rainfall

Rainfall plays a major role in the management of subsurface and surface water sources. Several studies have been carried out using a particular method to calculate the value of rainfall in groundwater variability. The amount of rainfall in this study region is not that high. The precipitation map is divided into three parts shown in Fig. 8.

Groundwater potential zone

Determination of weighting

At first, on the basis of six major criteria, pair-wise matrix has been done with the help of the AHP method to recognize the priority and rank of the themes. Here, pair-wise matrix $m \times m$ is a real matrix, and m represents the number of criteria which is considered for evaluation. In this matrix, 1–9 scale has been used. Every criterion is given preference according to Table 4. The comparison matrix of the criterion can be set by this equation, i.e., $a_{jk} * a_{kj} = 1$. The consistency ratio is calculated on the basis of the equation

$$\mathrm{CR} = \mathrm{C}I/\mathrm{RI}$$

where CI = consistency index and RI is the random index. Addition or elimination of a feature in the study depends upon the value of consistency ratio. The value of CR should always keep lower than or equal to 0.1 (Saaty 1990). CI

Table 2 Details of the lithological unit in geological framework

Lithological unit	Geological formation	Age		Nature and Characteristics	Area in %
		Period	Epoch		
L	Laterite	Q	Cainozoic	Hard crust	6.68
Q1S	Sijua formation	U A	Upper Pleistocene to Middle Holocene	Soft, unconsolidated sediments (oxidized)	53.36
Q2K	Panskura formation	T E R	Middle to Upper Holocene	Soft, unconsolidated sediments (oxidized)	31.72
Q2D	Diara formation	N A R Y	Upper Holocene to Recent	Soft, unconsolidated sediments (unoxidized)	8.24

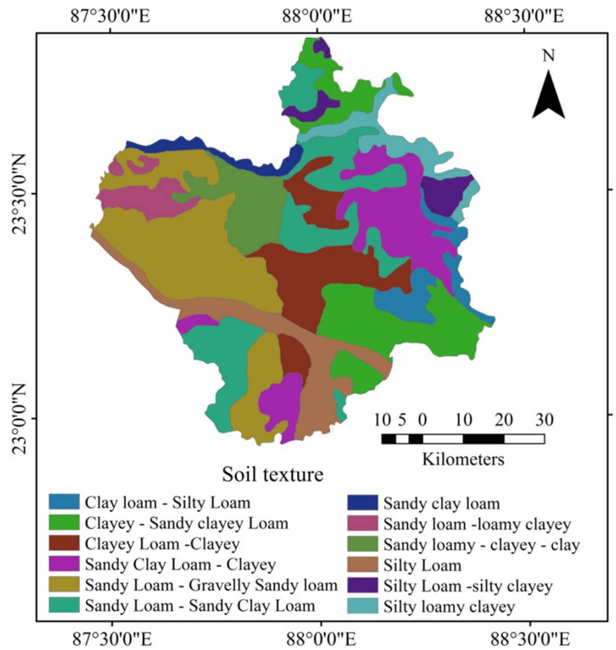

Fig. 4 Soil texture map

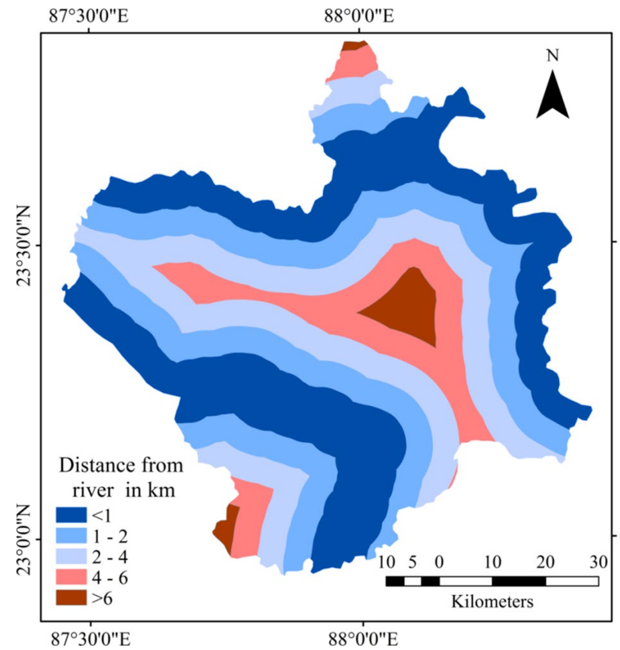

Fig. 5 Buffer zone from River

Table 3 Details of soil texture with the percentage of area

Serial no.	Soil texture	Description	Area in %
1	S1	Sandy loam—gravelly sandy loam	20.35
2	S2	Sandy loam—loamy clayey	3.17
3	S3	Sandy loam—sandy clay loam	13.86
4	S4	Sandy clay loam—clayey	10.83
5	S5	Clayey loam—clayey	10.79
6	S6	Sandy loamy—clayey—clay Loam	5.72
7	S7	Clay loam—silty loam	5.61
8	S8	Clayey—sandy clayey loam	13.01
9	S9	Silty loam—silty clayey	2.6
10	S10	Silty loamy clayey	4.12
11	S11	Silty loam	7.96
12	S12	Sandy clay loam	1.98

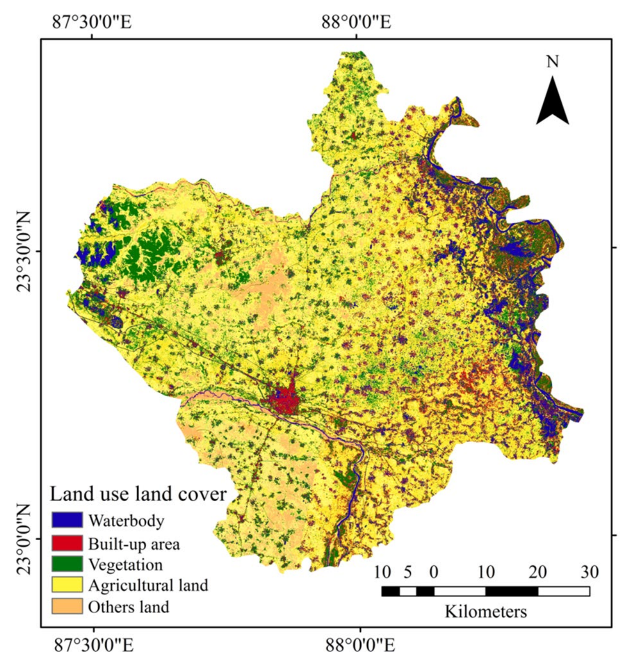

Fig. 6 Land use land cover map

Table 4 Pair-wise comparison matrix for AHP and priority and rank of themes

Serial no.	Category	AHP weightage values						Priority (%)	Rank	AHP Weight
		1	2	3	4	5	6			
1	Lithological unit	1	1.00	2.00	2.00	3.00	4.00	27.1	1	0.271
2	Soil texture	1.00	1	2.00	2.00	3.00	3.00	26.2	2	0.262
3	Distance from river	0.50	0.50	1	2.00	3.00	3.00	18.8	3	0.188
4	Land use land cover	0.50	0.50	0.50	1	2.00	3.00	13.7	4	0.137
5	Surface water body	0.33	0.33	0.33	0.50	1	2.00	8.3	5	0.083
6	Rainfall	0.25	0.33	0.33	0.33	0.50	1	5.9	6	0.059
CR = 2.3%										

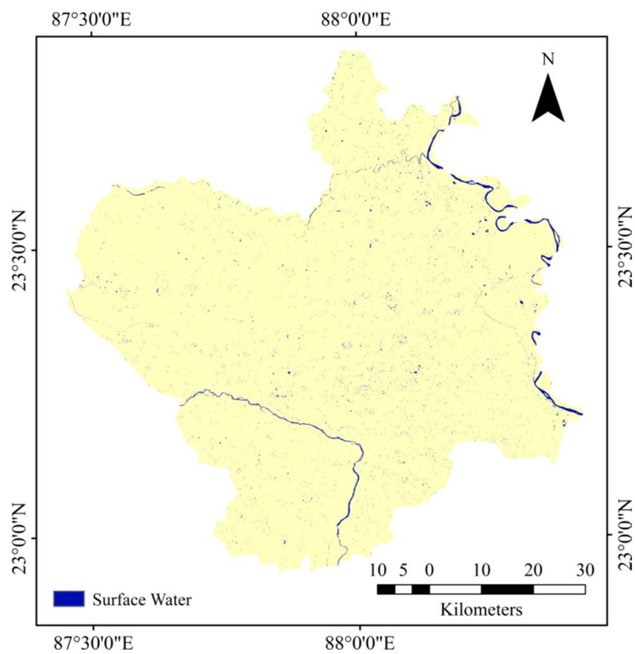

Fig. 7 Surface water map

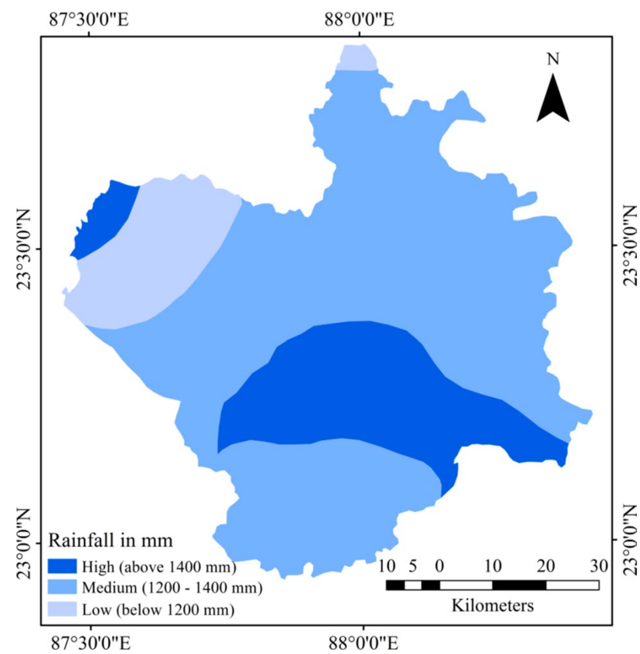

Fig. 8 Rainfall distribution map

reflects the consistency of one's judgment. CI can be calculated by the following equation

$$CI = \lambda \max - n/n$$

where n = order of the matrix, λmax is the largest eigenvalue. CR of each and every individual feature is observed for the inclusion or exclusion in the study.

Calculated priority, rank and AHP weight of individual are presented in Table 4 with the help of above-mentioned procedure and consistency ratio is 2.3% which is below 10% and accepted according to Saaty (1994). The weightage of each class of every parameter has been calculated and presented in Table 5.

The groundwater potential zone map is classified in five distinct zones representing very low potential, low potential, medium potential, high potential and very high potential which consist of area of 21.54%, 35.8%, 26.47%, 10.13% and 6.06% of total area. In this district, very high potential and high potential zone areas are found in the side of river Damodar, Ganga and Ajay and dense vegetation areas of the west part of this district, shown in Fig. 9.

Validation

The groundwater potential zone area was verified with the help of 12 dug well station and 32 tube well data of 44 stations that were collected from CGWB-2018. These 44 stations are distributed throughout the district shown in Fig. 10. Details of tube well location and actual yield are shown in Table 6.

Table 5 Weightage of different parameters for groundwater potential zones mapping

Factor	Sub-class	AHP weightage values												AHP weight
		1	2	3	4	5	6	7	8	9	10	11	12	
Lithological unit	Q1S	1	2.00	3.00	5.00									0.483
	Q2D	0.50	1	2.00	3.00									0.272
	Q2K	0.33	0.50	1	2.00									0.157
	L	0.20	0.33	0.50	1									0.088
CR = 0.005														
Soil texture	S1	1	3.00	3.00	3.00	3.00	3.00	4.00	4.00	4.00	5.00	5.00	5.00	0.229
	S2	0.33	1	1.00	1.00	1.00	1.00	3.00	3.00	3.00	4.00	4.00	4.00	0.011
	S3	0.33	1.00	1	1.00	1.00	1.00	3.00	3.00	3.00	4.00	4.00	4.00	0.011
	S4	0.33	1.00	1.00	1	1.00	1.00	3.00	3.00	3.00	4.00	4.00	4.00	0.011
	S5	0.33	1.00	1.00	1.00	1	1.00	3.00	3.00	3.00	4.00	4.00	4.00	0.011
	S6	0.33	1.00	1.00	1.00	1.00	1	3.00	3.00	3.00	4.00	4.00	4.00	0.011
	S7	0.25	0.33	0.33	0.33	0.33	0.33	1	1.00	1.00	3.00	3.00	3.00	0.049
	S8	0.25	0.33	0.33	0.33	0.33	0.33	1.00	1	1.00	3.00	3.00	3.00	0.049
	S9	0.25	0.33	0.33	0.33	0.33	0.33	1.00	1.00	1	3.00	3.00	3.00	0.049
	S10	0.20	0.25	0.25	0.25	0.25	0.25	0.33	0.33	0.33	1	1.00	1.00	0.025
	S11	0.20	0.25	0.25	0.25	0.25	0.25	0.33	0.33	0.33	1.00	1	1.00	0.025
	S12	0.20	0.25	0.25	0.25	0.25	0.25	0.33	0.33	0.33	1.00	1.00	1	0.025
CR = 0.024														
Distance from river (in km)	< 1	1	2.00	3.00	4.00	5.00								0.419
	1–2	0.50	1	2.00	3.00	4.00								0.263
	2–4	0.33	0.50	1	2.00	3.00								0.160
	4–6	0.25	0.33	0.50	1	2.00								0.097
	> 6	0.20	0.25	0.33	0.50	1								0.062
CR = 0.015														
Land use land cover	Water	1	2.00	3.00	4.00	5.00								0.419
	Agricultural land	0.50	1	2.00	3.00	4.00								0.263
	Vegetation	0.33	0.50	1	2.00	3.00								0.160
	Others land	0.25	0.33	0.50	1	2.00								0.097
	Built up area	0.20	0.25	0.33	0.50	1								0.062
CR = 0.015														
Surface water body	Water body	1	5.00											0.833
	Others	0.20	1											0.167
CR = 0.0														
Rainfall	High	1	2.00	3.00										0.540
	Medium	0.50	1	2.00										0.297
	Low	0.33	0.50	1										0.163
CR = 0.01														

Table 6 expresses similarity between actual class and expected class. A remark of agreement and disagreement is also prepared in Table 6. In this study area, the total number of tube well and dug well is 44. The number of tube well and dug well under the agreement of coherence between actual and predicted yield range is 39, and the number of tube well and dug well under disagreement of coherence between actual and predicted yield range is 5.

The equation of accuracy prediction

$$\begin{aligned} &= \text{No. of tube well and dug well under the agreement of coherence} \\ &\quad / \text{Total number of tube well and dug well surveyed} \times 100 \\ &= 39 / 44 \times 100 \\ &= 88.64\% \end{aligned}$$

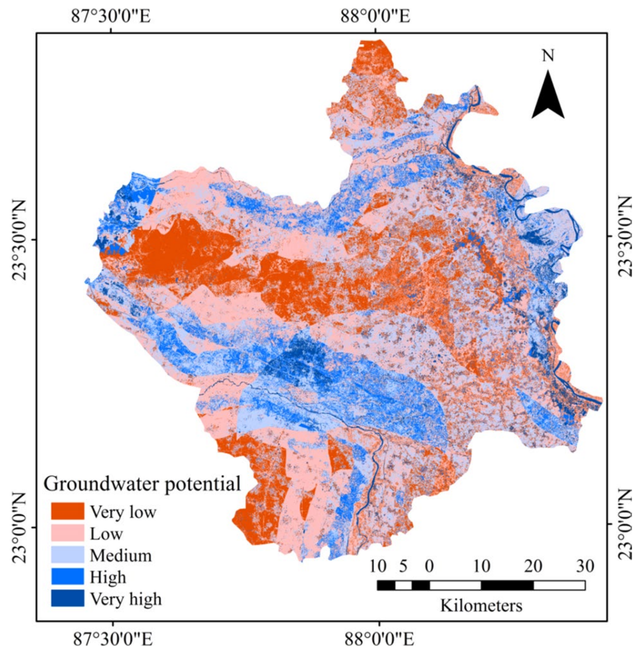

Fig. 9 Groundwater potential zone map

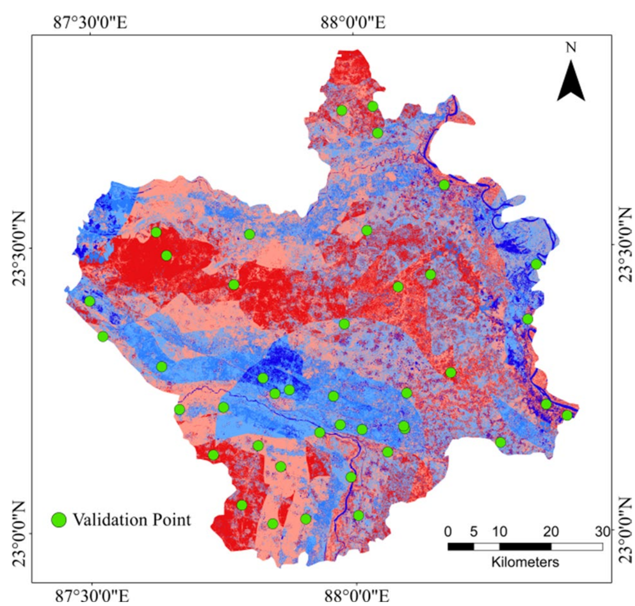

Fig. 10 Groundwater validation point

The prediction accuracy value of 88.64 reflects the fact that the AHP model and GIS techniques used in this work are significantly robust and accurate. For validation of this work, groundwater depth zone map (Fig. 11) prepared using the IDW method in ArcGIS is applied and it is compared with the potential zone map (Fig. 10). In order to demonstrate the accuracy, the receiver operating characteristic (ROC) curve was used in this analysis, which compares the tube well data with the groundwater potential area. The ROC curve represents (Fig. 12) that the area under curve (AUC) is 0.868 which means 86.8%. So this ROC result also accepts the AHP model in this work.

Conclusion

Groundwater is the world's greatest resource. Groundwater contamination is a big problem for our future climate. To this end, the purpose of this paper is to explore potential groundwater zones using AHP and GIS techniques in the Purba Bardhaman district. In this analysis, six main parameters were taken into account to determine the potential groundwater zone. Low and very low potential zones account for 57.34% of the total area, although the Purba Bardhaman district is a deltaic region. The rest of 43.38% area was covered with medium to very high groundwater potentiality zones. It is obvious that the porous lithological setting, permeable soil texture, location of surface water bodied coupled with rainfall distribution and vegetative cover result in the formation of a high potential area. The central part of the district is mainly characterized by a low and very low field. These areas have low strength, irrespective of the distance from the sea. This work is much more important in the age of drinking water crisis, as this final map would have been useful in the planning and management of water resources. This work has been validated with the results of the 44 tube well station. The empirical study IDW method is used to test and show the precision of the receiver operating characteristic (ROC) curve. The method used is reliable and can be used successfully elsewhere with the required modifications. This study would enable the decision-makers concerned to establish an appropriate study policy.

Table 6 Detail account of the validation points

Serial no.	Block name	Latitude	Longitude	Site name	Site type	Well code	Actual class	Estimated class	Similarity between actual class and expected class
1	Ausgram-i	23.52722	87.6238889	Bannabagram-1	Tube Well	W10222	High	Low	No
2	Bardhaman	23.24361	87.8475	Amra	Dug Well	W20989	Very high	Very high	Yes
3	Bardhaman	23.25	87.875	Bardhaman	Dug Well	W10230	Very high	Very high	Yes
4	Bardhaman	23.23833	87.9583333	Raipur2	Dug Well	W28308	Very high	Very high	Yes
5	Bardhaman	23.27083	87.825	Jhinguti	Tube Well	W10231	Medium	Medium	Yes
6	Bhatar	23.36472	87.9797222	Kubajpur	Dug Well	W28409	Very low	Very low	Yes
7	Bhatar	23.43472	87.7708333	Orgram	Dug Well	W10235	Very low	Very low	Yes
8	Bhatar	23.43472	87.7708333	Orgram Pz-2	Tube Well	W28470	Very low	Very low	Yes
9	Galsi-i	23.345	87.5222222	Kasba	Tube Well	W10250	Very high	High	No
10	Galsi-i	23.40694	87.4972222	Bud Bud Pz-1	Tube Well	W10247	Very high	Very high	Yes
11	Galsi-i	23.48639	87.6433333	Chak-Radhamohanpur	Dug Well	W28503	Very high	Low	No
12	Galsi-ii	23.29167	87.6333333	Galsi	Tube Well	W10253	High	High	Yes
13	Jamalpur	23.14	88.0602778	Ajhapur1	Dug Well	W28212	Very high	Very high	Yes
14	Jamalpur	23.02917	88.0041667	Chakdigi	Tube Well	W10261	High	High	Yes
15	Jamalpur	23.09639	87.9905556	Berugram (Moralpara)	Dug Well	W28185	Very high	Very high	Yes
16	Kalna-i	23.27833	88.1808333	Madhyamgram Pz	Tube Well	W10270	Medium	Medium	Yes
17	Kalna-ii	23.15528	88.2738889	Bara Dhamas	Tube Well	W10272	Low	Medium	No
18	Kalna-ii	23.22139	88.3608333	Kalna	Tube Well	W10274	High	High	Yes
19	Kalna-ii	23.20167	88.4002778	Bandebaz	Dug Well	W28278	Very high	Very high	Yes
20	Kalna-ii	23.15528	88.2738889	Bara Dhamas	Tube Well	W10272	Low	Low	Yes
21	Katwa-i	23.60694	88.1711111	Dainhat2	Dug Well	W28570	Very high	Very high	Yes
22	Ketugram-i	23.73889	87.9777778	Ramjibanpur	Tube Well	W11151	Low	Low	Yes
23	Ketugram-i	23.74556	88.0366667	Hat Murgram	Tube Well	W10288	Low	Low	Yes
24	Ketugram-ii	23.69889	88.0455556	Ketugram1	Tube Well	W28631	Low	Low	Yes
25	Kandaghosh	23.22	87.75	Khejurhati1	Dug Well	W28299	High	High	Yes
26	Kandaghosh	23.13667	87.7302778	Bowaichandi	Tube Well	W28210	Medium	Medium	Yes
27	Kandaghosh	23.21667	87.6666667	Metedanga-2	Tube Well	W10278	High	High	Yes
28	Memari-i	23.18833	87.9708333	Barsul Pz	Tube Well	W10306	Very high	Very high	Yes
29	Memari-i	23.18083	88.0927778	Memari1	Bore Well	W28255	Very high	Very high	yes
30	Memari-i	23.17972	88.0119444	Pallaroad Pz	Tube Well	W28252	High	High	Yes
31	Memari-i	23.18528	88.0908333	Dakshin Radhakantapur	Dug Well	W28259	High	Very high	No
32	Memari-ii	23.24306	88.0969444	Paharhati	Tube Well	W10312	Low	Low	Yes
33	Mangalkot	23.52833	88.0238889	Koichor	Tube Well	W10298	Very low	Very low	Yes
34	Mangalkot	23.52278	87.8011111	Charnak Pz	Tube Well	W10297	Low	Low	Yes
35	Manteswar	23.42917	88.0822222	Maldanga	Tube Well	W28468	Very low	Very low	Yes
36	Manteswar	23.45028	88.1438889	Denur	Bore Well	W28480	Very low	Very low	Yes
37	Purbasthali-i	23.37083	88.3275	Samuagrah	Tube Well	W28413	High	High	Yes
38	Purbasthali-ii	23.46667	88.3444444	Chupi	Tube Well	W28490	High	High	Yes
39	Rayna-i	23.11556	87.8577778	Rayna Pz	Tube Well	W28199	Low	Low	Yes
40	Rayna-i	23.1525	87.8152778	Sagrai Pz (swid)	Tube Well	W28219	low	low	yes
41	Rayna-i	23.175	87.9319444	Haripur3	Tube Well	W28249	High	High	Yes
42	Rayna–ii	23.01556	87.8419444	Kaity	Tube Well	W10325	Medium	Medium	Yes
43	Rayna–ii	23.02361	87.9044444	Barpur (pashanda)	Tube Well	W28134	High	High	Yes
44	Rayna–ii	23.04861	87.7838889	Dommara Pz	Tube Well	W10324	Medium	Very low	No

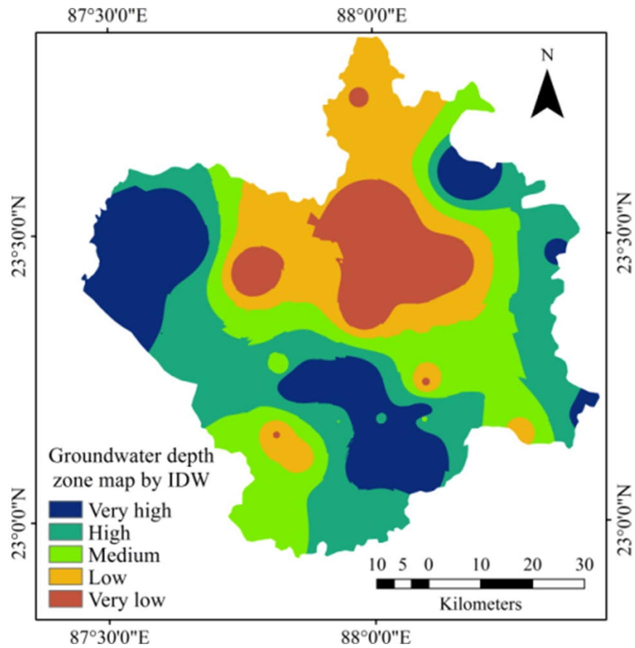

Fig. 11 Ground water depth zone

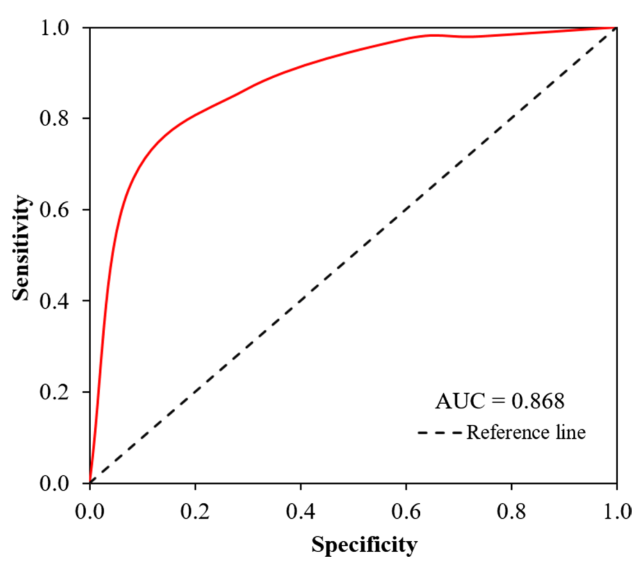

Fig. 12 Receiver operating characteristic (ROC) curve

Compliance with ethical standards

Conflict of interest There is no conflict of interest among the authors.

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