



Assessment of groundwater potential zones using multi-influencing factor (MIF) and GIS: a case study from Birbhum district, West Bengal

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Received: 15 November 2016 / Accepted: 1 May 2017 / Published online: 9 May 2017
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Abstract Remote sensing and GIS play a vital role in exploration and assessment of groundwater and has wide application in detection, monitoring, assessment, conservation and various other fields of groundwater-related studies. In this research work, delineation of groundwater potential zone in Birbhum district has been carried out. Various thematic layers viz. geology, geomorphology, soil type, elevation, lineament and fault density, slope, drainage density, land use/land cover, soil texture, and rainfall are digitized and transformed into raster data in ArcGIS 10.3 environment as input factors. Thereafter, multi-influencing factor (MIF) technique is employed where ranks and weights, assigned to each factor are computed statistically. Finally, groundwater potential zones are classified into four categories namely low, medium, high and very high zone. It is observed that 18.41% (836.86 km^2) and 34.41% (1563.98 km^2) of the study area falls under ‘low’ and ‘medium’ groundwater potential zone, respectively. Approximately 1601.19 km^2 area accounting for 35.23% of the study area falls under ‘high’ category and ‘very high’ groundwater potential zone encompasses an area of 542.98 km^2 accounting for 11.95% of the total study area. Finally, the model generated groundwater potential zones

are validated with reported potential yield data of various wells in the study area. Success and prediction rate curve reveals an accuracy achievement of 83.03 and 78%, respectively. The outcome of the present research work will help the local authorities, researchers, decision makers and planners in formulating better planning and management of groundwater resources in the study area in future perspectives.

Keywords Remote sensing and GIS · Multi-influencing factor (MIF) technique · Groundwater potential zone · Birbhum · West Bengal · India

Introduction

In India demand of groundwater resources continuously increases with the advent of industrialisation and population expansions. Hence, assessment, planning and management of groundwater resource become crucial and essential phenomena. Remote sensing and GIS technique facilitate time and cost effective, rapid assessment of groundwater resource, which otherwise through traditional method becomes very costly, laborious and time consuming work (Moore et al. 1991; Krishnamurthy et al. 2000; Jha et al. 2010; Arkoprovo et al. 2012; Hammouri et al. 2012; Lee et al. 2012a; Davoodi et al. 2015). To delineate groundwater potential lineament and hydrogeomorphology, groundwater level decline and its impacts on regional subsidences and karst hazards, and groundwater vulnerability to pollution are applied by GIS-based approaches by several researchers (Nag 2005; Taheri et al. 2015; Singh et al. 2015; Taheri et al. 2016). In delineation of groundwater potential zone

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various factors such as lineament, faults and hydrogeomorphology (Nag 2005; Senthil-Kumar and Shankar 2014; Singh et al. 2014; Taheri et al. 2015), rainfall, soil, lithology and soil texture (Magesh et al. 2012), slope, elevation (Magesh et al. 2011; Thomas et al. 2012), drainage systems (Rassam et al. 2008; Preeja et al. 2011; Dabral et al. 2013) and groundwater table distribution (Arkoprovo et al. 2012) play a crucial role.

So far, various techniques have been adopted by various researchers such as, frequency ratio (Manap et al. 2014; Razandi et al. 2015), multi-criteria decision evaluation (MCDE) (Murthy and Mamo 2009; Machiwal and Singh 2015; Jothibasu and Anbazhagan 2016), artificial neural network (ANN) (Lee et al. 2012b), random forest model (Naghibi et al. 2016; Zabihi et al. 2016) logistic regression model (Pourtaghi and Pourghasemi 2014) and analytic hierarchy process (AHP) (Adiat et al. 2012). Most of the bivariate and multivariate statistical techniques have their drawbacks in making assumptions prior to investigation and sensitivity towards outlier values (Abrahart et al. 2008; Tehrany et al. 2013; Umar et al. 2014). In this context, multi-influencing factor technique (MIF) is rather a simple, effective and reliable technique for delineating groundwater potential zones (Shaban et al. 2006; Magesh et al. 2012; Selvam et al. 2014).

In Birbhum district, four blocks namely Murarai II, Nalhati II, Rampurhat II and Nanoor have been categorized as semi-critical, based on the long-term trend of water table fluctuations in pre and post monsoon and stages of groundwater development (CGWB 2009). The district receives its major share of rainfall during monsoon season while remains comparatively dry during rest of the year. Overall, this district experiences a high fluctuation in water table level and the temperature shoots well above 45 °C in the summer season. Farmers suffer from acute shortage of irrigation water (Nag and Ray 2015) as most of the surface streams dry up seasonally and compel to depend on groundwater resources to a great extent. Over-exploitation of groundwater has also led to fluoride contamination in both water table aquifer and confined aquifer of groundwater in some parts of the Birbhum district (PHED report 2007; Mondal et al. 2014; Thapa et al. 2016). In this context, demarcating groundwater potential zone is essential to locate high groundwater potential areas for future consumptive use. The present study aims to elucidate the groundwater potential zone within Birbhum district with the help of remote sensing, and MIF techniques. The results of the present study can serve as first-hand information to planners, policy makers and local authorities for future planning projects to ensure sustainable utilization of groundwater resources.

Study area

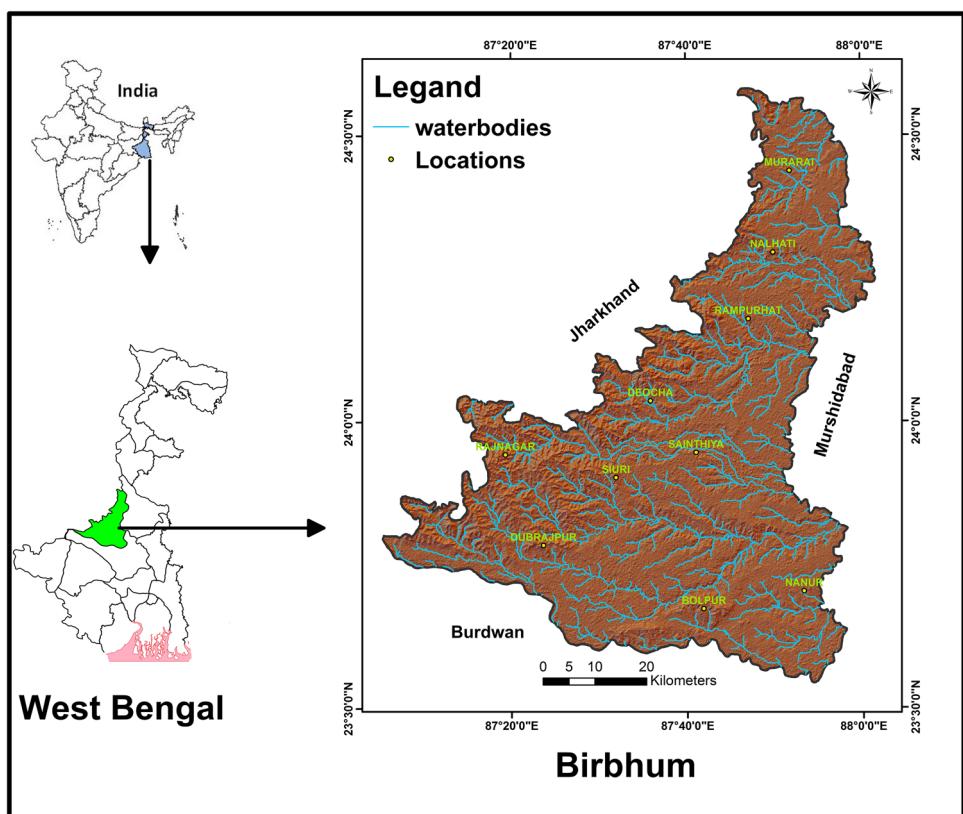
Birbhum, also known as the ‘Land of Red Soil’, is well known for its culture values. The district with its shape similar to isosceles triangles encompasses an area of 4545 km² lying within 23°32'30" and 24°35'0" North latitude and 88°1'40" and 87°5'25" East longitude (Fig. 1). The base of this triangle is marked by river Ajoy separating the boundary of Birbhum with Burdwan district. On the west and north, the district is bounded by the Jharkhand state of India and shares its eastern boundary with districts of Murshidabad and Burdwan of West Bengal. Birbhum district falls under Lower Gangetic plain region as per agro-climatic classification with the majority of soil being red laterite with low alluvium and/or clay content.

Geological and hydrogeological framework

Chottanagpur Gneissic Complex marks the metamorphic basement rocks which comprise of pink granite, granite gneiss and epidote granite with veins of quartz and pegmatite (Mukherjee et al. 1969; Sen et al. 1987; Sen and Vijaya 2005; Mondal et al. 2014) and are exposed in the south-west and north-west part of the district. With moderate dip towards the northeast, foliation is generally trending in NW–SE directions. Early Cretaceous Rajmahal Trap Formation consisting of gray, hard and compact basalt with a network of siliceous veins and zeolites are exposed in the northern part. Tertiary deposits consisting of claystone with silty and sandy layers with variegated colors are exposed in patches in eastern and south-eastern part of the district. Along the stream course, a recent Quaternary deposit consisting mostly of clayey soil/alluvium of yellowish gray to khaki gray color with iron nodules along with sandy sludge of medium to coarse grain size with pebbles and boulders bed at the base are observed (Sen and Vijaya 2005; Mondal et al. 2014).

In Birbhum district, groundwater occurs in both confined and water-table conditions with resultant flow direction from west to east. Groundwater under water table condition occurs in both alluvium and hard rock terrains whereas a confined condition occurs under the deep alluvium aquifer where the confined aquifer's piezometric head vary 3–4 m bgl (meter below ground level) on an average (Mondal et al. 2014). The deeper tube well in the east generally has higher yield in comparison to the western zones with shallower tube wells (Mondal et al. 2014). Recent alluviums of quaternary age group bearing porous formations are fairly thick and are spreading over an area of 210 km² (4.5%) of the total area in the southern and south-eastern part have very large yield prospects of about 200 m³/h. Older alluvium and older alluvium with

Fig. 1 Location map of the study area



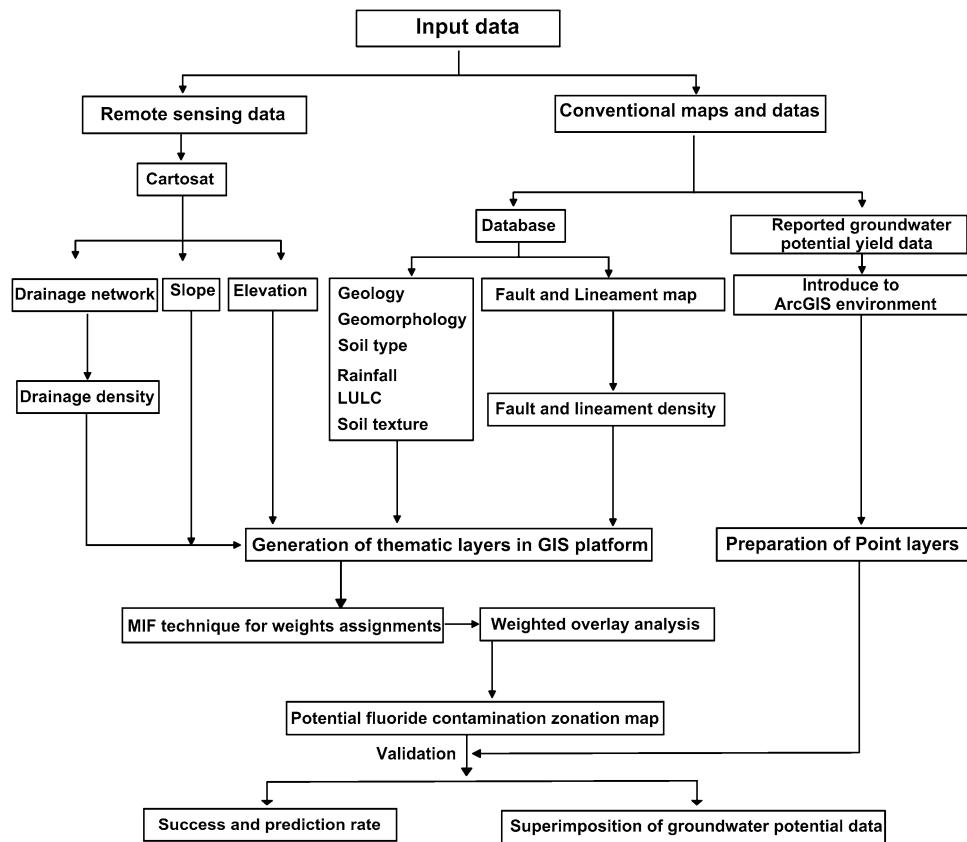
laterites, etc. belonging to upper tertiary to lower quaternary age group accounts for approximately 48 and 29% of the study area, respectively. Older alluviums are associated with moderate yield prospects of about 70–180 m³/h where very limited yield prospects of below 50 m³/h are observed in older alluvium with laterites, etc. types of aquifers. Basalt with Intertrapean Clay of Mesozoic–Palaeozoic age occurs at the western end and Gneiss and associated rocks of Archean age have very restricted groundwater yield of below 10 m³/day as groundwater are restricted to weathered residuum only along with fracture zones having secondary porosity.

Rainfall is the principle source of recharge, supplemented by influent seepage from the irrigation canal network. Well hydrographs show that recharge from rainfall occur very fast and keep pace with the increasing or decreasing rainfall in this area. Fluctuation of water table is generally constant in the eastern region in comparison to the western region. The tube wells in the east (100 m deep on an average) are deeper in comparison to the western part of the district (Mondal et al. 2014). Several blocks in Birbhum district are affected with fluoride occurrence in groundwater (PHED 2007; Mondal et al. 2014; Thapa et al. 2016).

Methodology

The methodology adopted for the present study is shown in Fig. 2. The base map of Birbhum district was prepared based on Survey of India toposheet (1:50,000 scale). Various thematic layers viz. geology, geomorphology, lineament and fault density, drainage density, rainfall, soil type, slope, elevation, land use/land cover, and soil texture were used to carry out the study. The geology and geomorphology map were digitized from district resource map series of Geological Survey of India (GSI). Soil type, land use land cover, rainfall were georeferenced and digitized from district planning map series of NATMO, 2004. The soil texture map was collected from official Birbhum portal (<http://birbhum.gov.in>). Lineament and fault density map were generated from Bhuvan thematic map portal and BMPTC Atlas. Cartosat-1 (CartoDEM, spatial resolution 2.5 m) has been used to derive drainage density, elevation and slope map of the study area. Slope map of the Birbhum district was generated using ‘raster surface’ function of 3D analyst tool and the drainage density was generated with the help of ‘line density’ under spatial analyst tool in ArcGIS 10.3 software.

Fig. 2 Flowchart of methodology followed for delineating the groundwater potential zone in Birbhum District, West Bengal, India



Assigning of weights and ranks

The weights of each factor were computed statistically using multi-influencing factor (MIF) technique followed by heuristic approaches/knowledge driven method for assigning ranks to each sub-classes of factor maps. The interrelationship among factors classes (Fig. 3) and assigning of ranks to factor's sub-classes was established based on author's expertise as well as literature review (Kaliraj et al. 2014; Senthil-Kumar and Shankar 2014; Dinesan et al. 2015; Razandi et al. 2015; Taheri et al. 2015; Taheri et al. 2016; Jothibasu and Anbazhagan 2016; Senanayake et al. 2016; Thapa et al. 2016; Zabihi et al. 2016). Factors having major influence were marked as major effect and were assigned a weight of 1.0 whereas, minor influence were marked as a minor effect with a weight of 0.5 as shown in Table 1 (Magesh et al. 2012). Table 2 represents relative rates of each factor calculated by the cumulative sum of both major and minor effect followed by proposed score calculation of each influencing factor using the formula as follows:

$$\text{Proposed Score} = \left[\frac{(X + Y)}{\sum(X + Y)} \right] \times 100,$$

where X represents the major effect of factors and Y represents the minor effect of factors.

Weighted overlay method

After assigning weights and ranks to factors and their subclasses, all the inputs were integrated through weighted overlay method using the Eq. (1):

$$\begin{aligned} \text{GWPZ} = & \sum_i^n G_x G_y + GM_x GM_y + S_x S_y + LULC_x LULC_y + DD_x DD_y \\ & + SI_x SI_y + E_x E_y + R_x R_y + FL_x FL_y + ST_x ST_y, \end{aligned} \quad (1)$$

where GWPZ represents the groundwater potential zonation, ' x ' and ' y ' represents factor maps and factor subclass, respectively, G represents geology, GM represents geomorphology, S is soil, $LULC$ is land use land cover, DD is drainage density, SI is slope, E is elevation, R is Rainfall, FL is fault and lineament density and ST is the soil texture.

Results and discussion

Input parameters for MIF

Geology

Geology plays a vital role in determining the groundwater potential of an area. The porosity of rocks, alluvium/

Fig. 3 Interrelationship between the multi-influencing factors concerning the groundwater potential zone in Birbhum, West Bengal

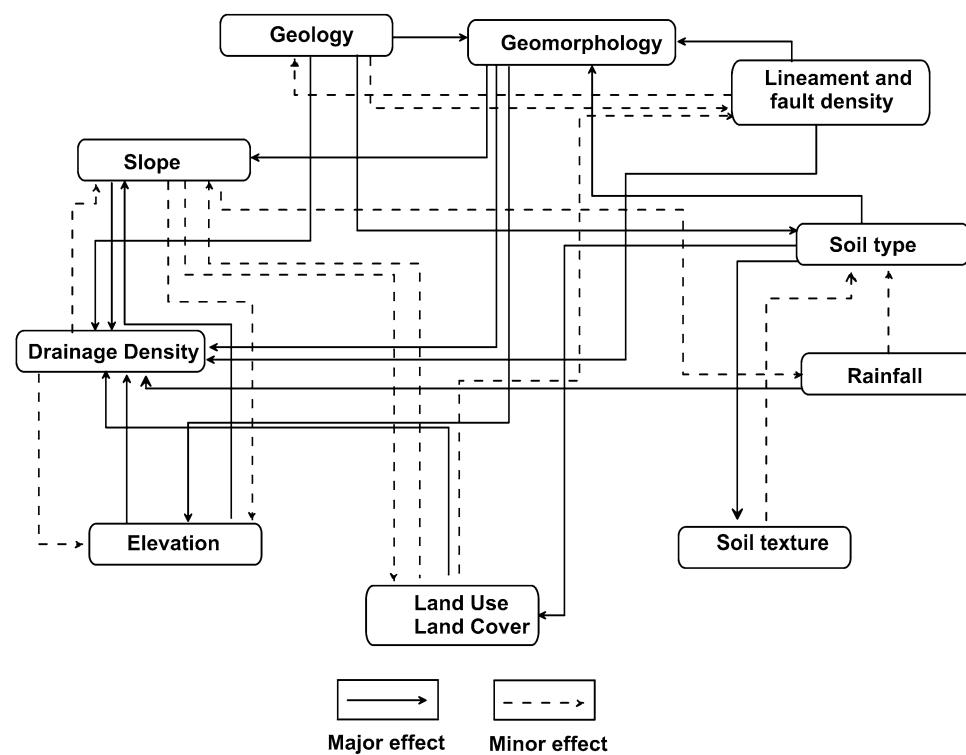


Table 1 Effect of influencing factor, relative rates and score for each potential factor (Magesh et al. 2012)

Factor	Major effect (A)	Minor effect (B)	Proposed relative rates ($A + B$)	Proposed score of each influencing factor
Geology	3	0.5	3.5	17
Lineament and fault density	2	0.5	2.5	12
Geomorphology	3	0	3	14
Drainage Density	0	1	1	5
Slope	1	1.5	2.5	12
LULC	1	0.5	1.5	7
Elevation	2	0	2	10
Rainfall	1	0.5	1.5	7
Soil type	3	0	3	14
Soil texture	0	0.5	0.5	2
Total			$\Sigma 21$	$\Sigma 100$

sediment cover, sand, silt, clay bed, etc. governs the infiltration and percolation of water flow. Shaban et al. (2006) referred that groundwater recharge is greatly influenced by the rocks types, exposed to the surface. In the study area, hard clay with impregnated caliche nodule, granite-gneiss complex (Chotanagpur Gneissic), laterite, an alternating band of sand, silt and clay encompassed an area of 1760 km² (38%), 712.58 km² (15%), 1116 km² (24%) and 833.39 km² (18%), respectively, as represented in Fig. 4a. Rajmahal trap (basalt), Gondwana Supergroup, pegmatite and unclassified metamorphism account for a very small portion of the study area encompassing an area of 141.63,

49.39, 0.69 and 7.08 km² accounting for 3, 1, 1.5 and 0.15%, respectively.

Geomorphology

Geomorphology and its features are essential components for understanding landforms evolutions controlling the movement and occurrence of groundwater. Geology provides crucial information about the underlying geological setup and the topographic feature hence widely used in groundwater-related studies (Machiwal et al. 2011). Weathered and fractured hard rock terrains with higher

Table 2 Classification of weighted factors influencing the potential zones in the study area

Factor	Subclass	Weight	Rating
Geology	Alternating band of sand, silt and clay	17	17
	Gondwana Super Group		14
	Granite Gneiss with enclave of metamorphites		7
	Hard Clay impregnated with caliche nodules		4
	Laterite and lateritic soil		5
	Pegmatite		3
	Rajmahal trap—Basalt		10
	Unclassified metamorphics		1
	Old floodplain	14	14
Geomorphology	Upper mature deltaic plain and parodeltic fan surfaces		10
	Hills and valleys of Rajmahal trap		5
	Pediplain/peneplain		7
	Rural settlements	7	2
LULC	Urban settlement		1
	Industrial land		1
	Wasteland		2
	water bodies		7
	Forest		5
	Cultivated land		6
Elevation	0–35 m	10	10
	35–48 m		9
	48–63 m		8
	63–80 m		6
	80–100 m		3
	100–158 m		2
Drainage Density	Very low	5	1
	Medium		4
	Low		2
	High		5
	Very low	7	1
Rainfall	Low		3
	Medium		5
	High		6
	Very high		7
	Red loamy	14	2
Soil type	Red sandy		8
	Younger alluvial		14
	Laterite		12
	Old alluvial		14
	Clay loam	2	1
Soil texture	Loam		2
	Clay		1
	Sandy		2
	Sandy loam		2
	Sandy clay loam		2
	High	12	12
Lineament and fault density	Medium		7
	Low		5
	Low	12	12
Slope	Moderate		8
	High		4

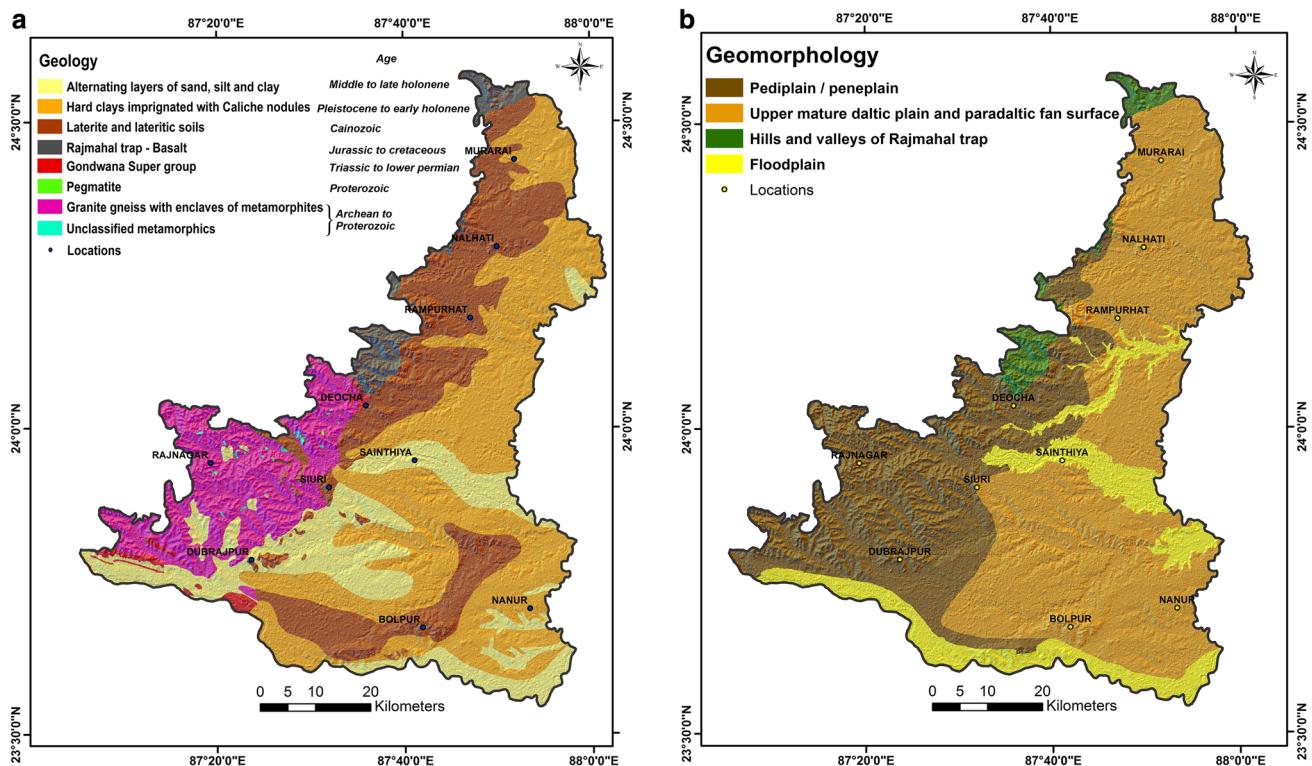
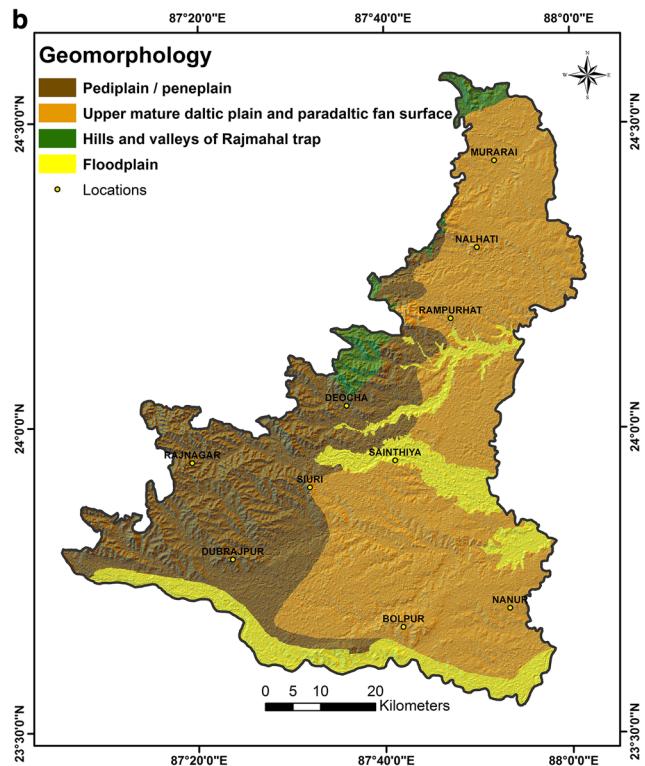


Fig. 4 Various input parameters **a** Geology of the study area, **b** geomorphology map of the study area, **c** Soil type of the study area, **d** land use land cover of the study area, **e** drainage density of the study

elevations and steeper topography have medium to low groundwater potential, whereas floodplain zones are usually associated with good groundwater potential due to the high infiltration rates of the alluvium deposits. In the study area, upper mature deltaic plain and old flood plain, covering an area of 2375.29 and 621.25 km², account for 51.41 and 13.45%, respectively, of the total study area. Rajmahal trap accounts for 144.74 km², which is about 3.13% of the study area and pediplain (1479.27 km²) represents 32.02% of the total area (Fig. 4b).

Soil type

The permeability of the soil is directly related to the effective porosity of the soil and is greatly influenced by grains shape, size grains, adsorbed water, voids ratio, the degree of saturation and impurities present (Punmia et al. 2005). The soil is an important factor for delineating the groundwater potential zones. The analysis of the soil type reveals that the study area is covered with different soil types namely, red loamy, red sandy, younger alluvial, laterite and old alluvial occupying area of about 829 km² (17%), 261 km² (6%), 318 km² (7%), 2236 km² (48%) and 977 km² (21%), respectively (Fig. 4c).



area, **f** slope of the study area, **g** elevation in the study area, **h** spatial distribution of rainfall in the study area, **i** lineament and fault density of the study area, **j** soil texture of the study area

Land use/land cover (LULC)

Land use/cover plays a crucial role in groundwater recharge. Shaban et al. (2006) mentioned that vegetation cover influences the groundwater recharge by preventing water loss by absorbing water. The major land use type of study area are rural settlements, urban settlements, industrial land, wasteland, water bodies, forest and cultivated land occupying area of 466 km² (10%), 43 km² (1%), 46 km² (1%), 42 km² (1%), 113 km² (2%), 168 km² (4%) and 3743 km² (81%), respectively (Fig. 4d).

Drainage density

Drainage density is characterized as the closeness of spacing of stream channels. Krishnamurthy et al. (2000) mentioned that natural drainage systems are the indicator of terrain's higher permeability and porosity. According to drainage density, the study area is divided into four subclasses, i.e., very low, low, medium and high, covering an area of 144.38, 1331.14, 1995.77 and 1149.42 km² accounting for 3, 28.81, 43.19 and 24.90%, respectively, of the total area (Fig. 4e).

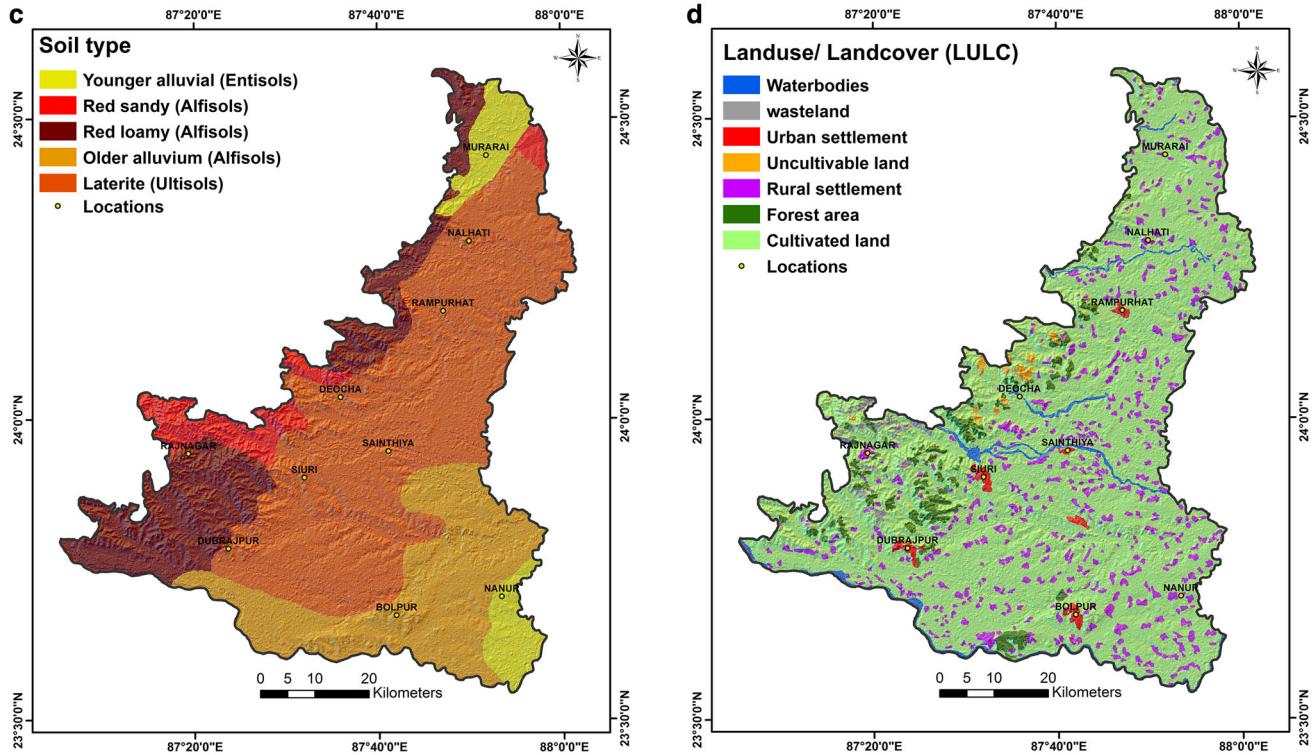


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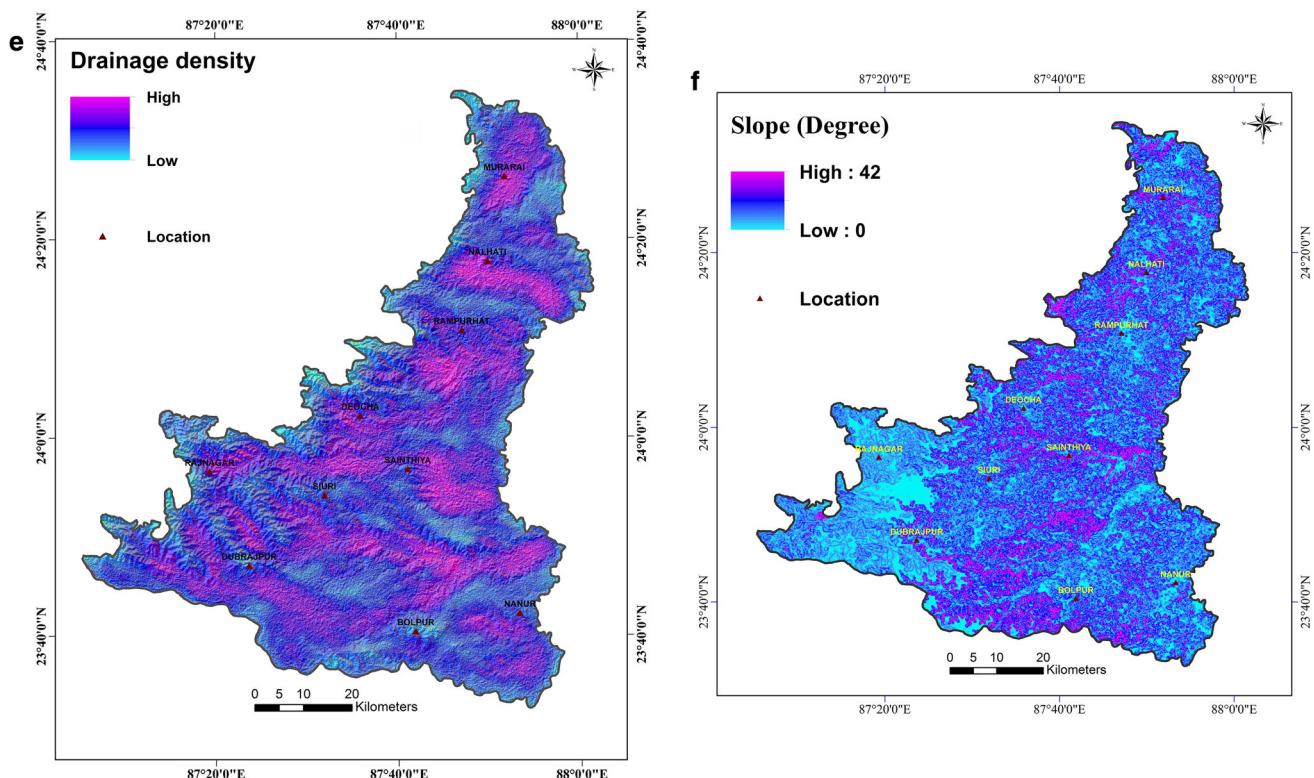


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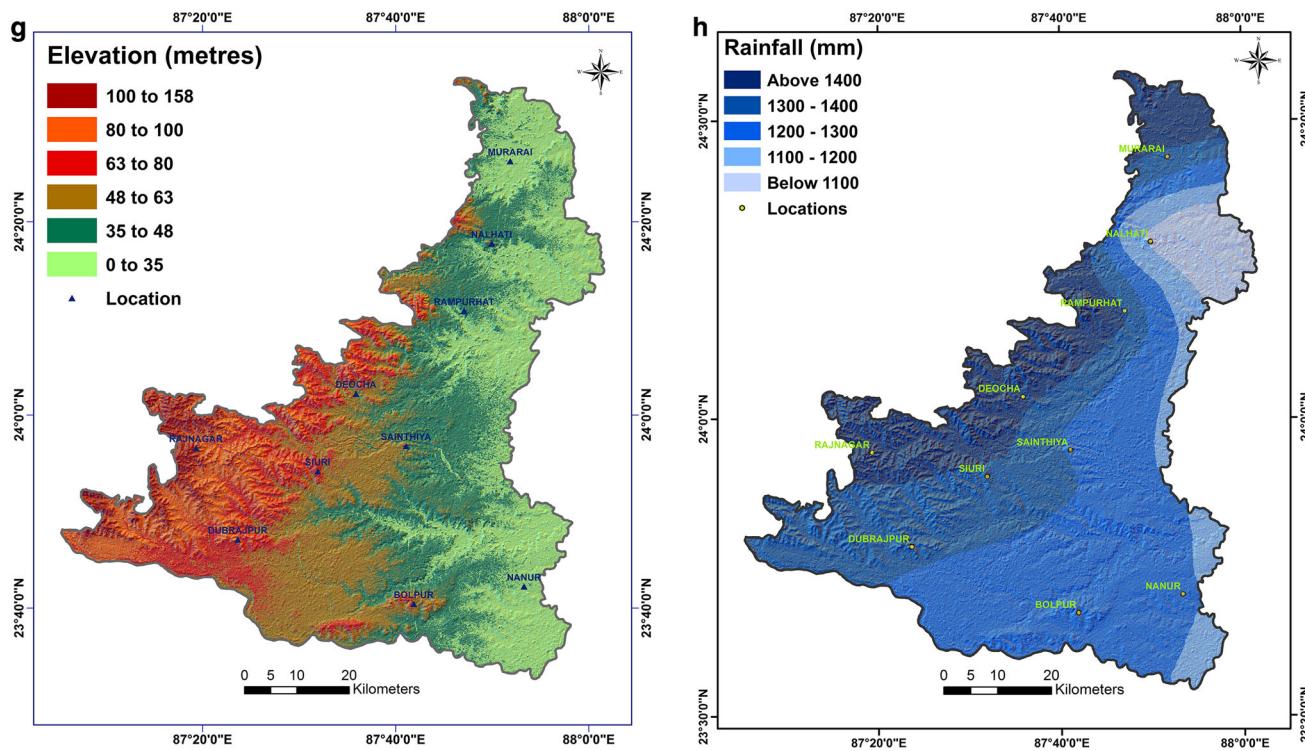
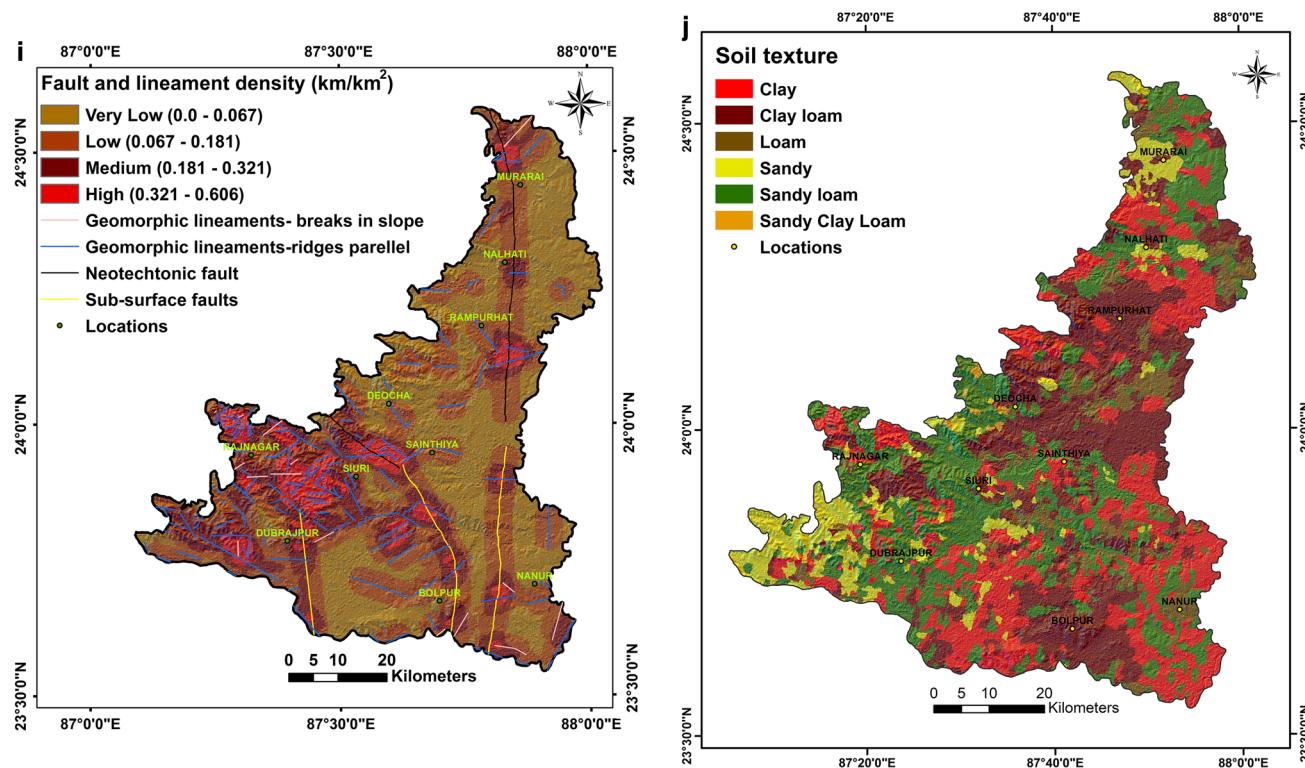
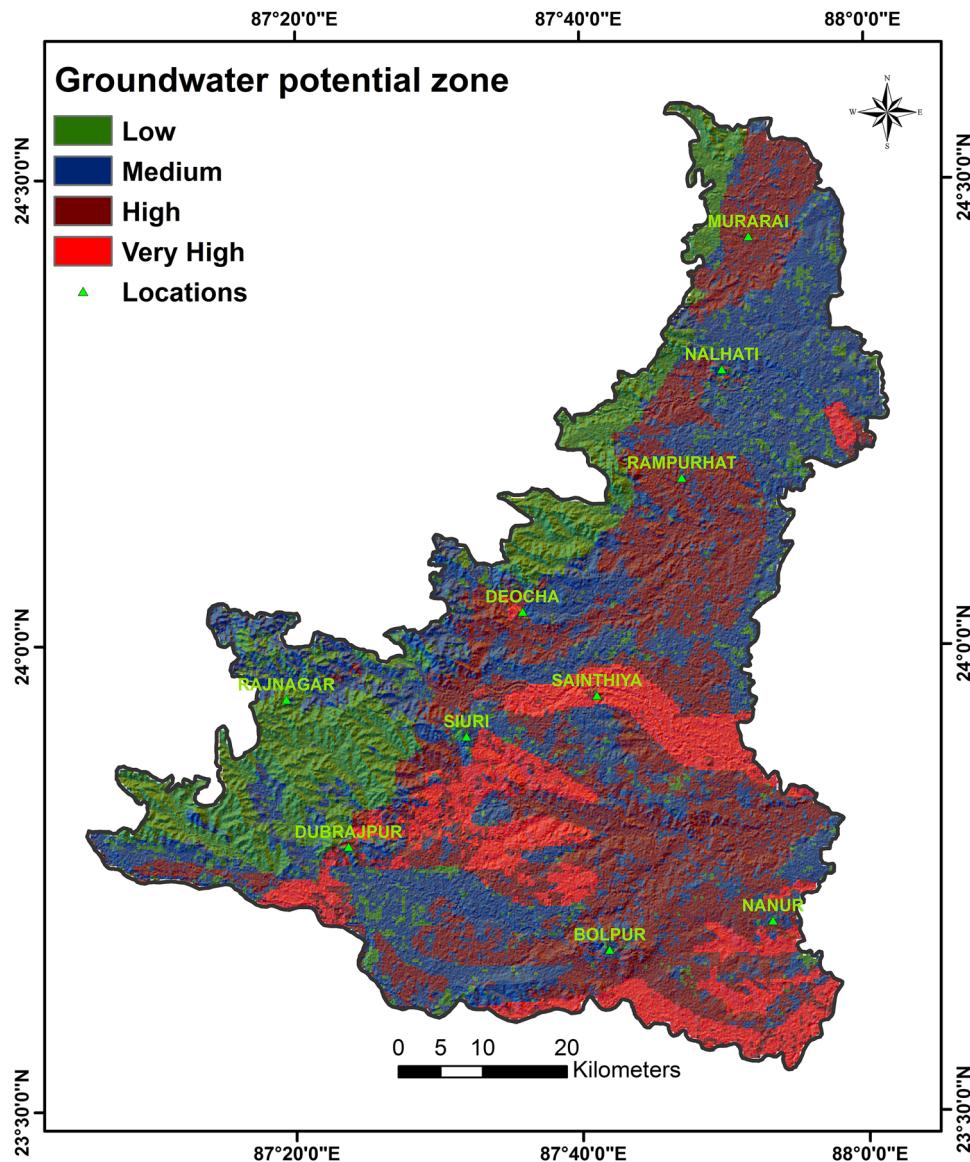
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Fig. 5 Groundwater potential zonation in the Birbhum district, West Bengal



Slope

Infiltration of surface water is directly influenced by the slope gradient. Steep slopes result in rapid downward water flow resulting from insufficient time to infiltrate. Flat areas provide higher retention time for infiltration of rainwater. The majority of the portion of the study area falls under gentle slope category with a slope less than 10°. On the basis of slope angle, the entire study area is divided into three sub-classes, i.e., slope <10°, 10°–20° and 20°–80°, respectively, covering an area of 3897.02 km² (84.34%), 598.29 km² (12.15%) and 125.40 km² (2.71%) (Fig. 4f).

Elevation

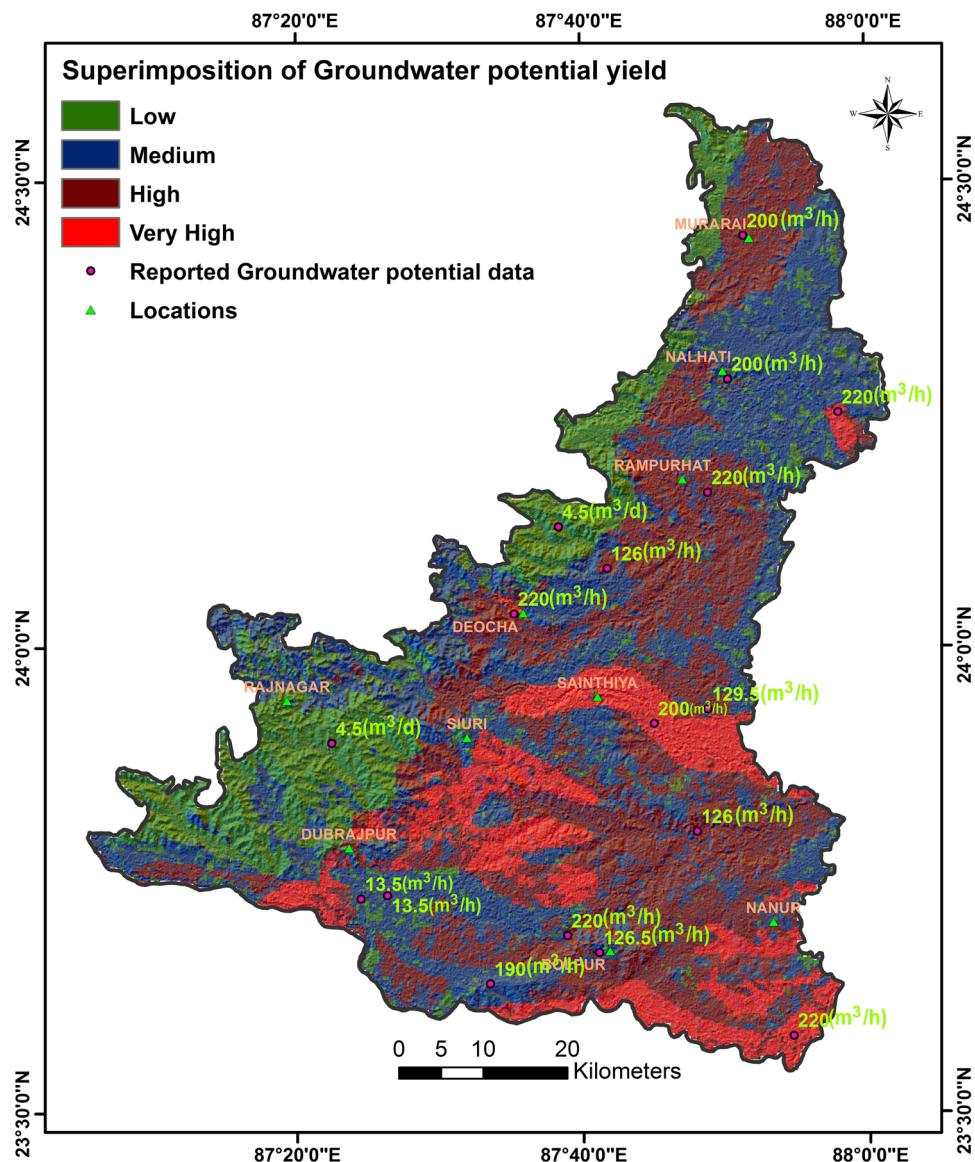
Elevation of the study area has a major role in groundwater potential. Plainer areas, having lower elevation tend to

retain water longer inducing greater infiltration of recharge of water. A large amount of runoff and a smaller amount of infiltration are associated with areas with steep elevation angle. It is subdivided into six subclasses namely 0–35, 35–48, 48–63, 63–80, 80–100 and 100–158 m (Fig. 4g).

Rainfall

Rainfall is one of the most important sources of groundwater recharge through percolation in the groundwater system. The average annual rainfall in the study area is grouped into five classes namely very low (below 1100 mm), low (1100–1200 mm), medium (1200–1300 mm), high (1300–1400 mm) and very high (above 1400 mm), covering the area of about 240 km² (5%), 383 km² (8%), 1867 km² (40%), 1199 km² (26%) and 931 km² (20), respectively (Fig. 4h). Rainfall

Fig. 6 Superimposition of groundwater potential data reported by CGWB over the final derived groundwater potential zonation map



distribution along with the slope gradient directly affects the infiltration rate of runoff water hence, increases the possibility of groundwater potential zones.

Lineament and fault density

Higher fault and lineament density can be used to speculate secondary porosity as most of the faults or fracture system serves as conduits for movement and storage of groundwater. Krishnamurthy et al. (2000) pointed out that a buffer zone of 300 m around fracture system of faults and lineaments are treated as appropriate groundwater recharge and availability zone. The lineament and fault density map in the study area was categorized into four, i.e., very km^{-2} area, respectively (Fig. 4i).

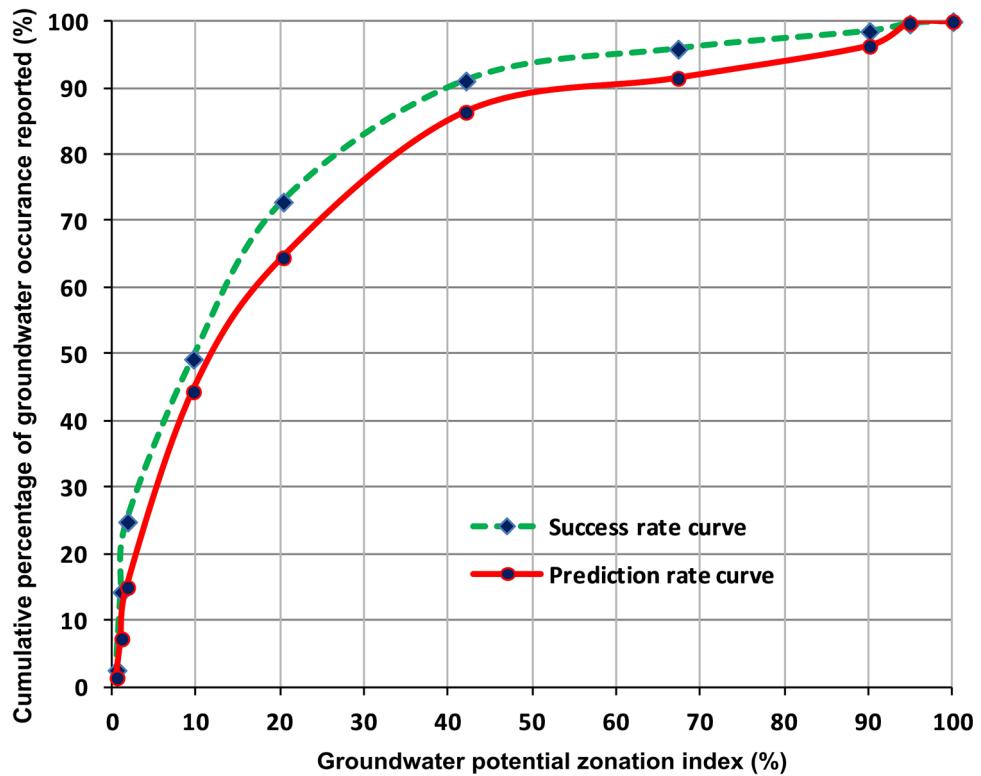
Soil texture

Soil texture has a valuable role in groundwater potential. High permeability levels are observed in gravels and coarse sand; fine sand and loamy soils exhibit moderate permeability whereas lowest permeability is shown by clay and silt soils (Saunders 2001). Soil texture in the study area is subdivided into six subclasses namely, clay loam, loam, clay, sandy, sandy loam and sandy clay loam, occupying area about 1330 km^2 (29%), 339 km^2 (7%), 1140 km^2 (25%), 408 km^2 (9%), 1389 km^2 (30%), 14 km^2 (0.5%), respectively (Fig. 4j).

Potential groundwater zone

On the basis of the pixel arrangement in the histogram, the final output map has been classified into “low”,

Fig. 7 Success and prediction rate curve for groundwater potential zones in Birbhum district, West Bengal



“medium”, “high” and “very high” by means of selecting ‘natural breaks/Jenks’ in ArcGIS software (Fig. 5). About 18.41% of the total area covering an area 836.86 km² falls under ‘low’ zone, 34.41% (1563.98 km²) falls under ‘medium’ groundwater potential zone, about 35.23% of the study area encompassing an area of 731.89 km² falls under ‘high’ zone and 542.98 km² (11.95%) of the total study area represents high groundwater potential area. The model generated output shows a mirror reflection of the principal factors like geomorphology, slope and geological formations underneath in controlling the potential groundwater zone. Southern and south-eastern parts of the study area including Sainthiya and Deocha region bear high groundwater potential zone due to the distribution of alluvial plains and agricultural land with high infiltration ability. Southwestern and western part of the study area represents low groundwater potential due to the presence of granite and basaltic hard rock underneath which have little influence on groundwater availability due to the low water holding potential and the absence of fracture/lineament density of the formation.

Validation of the model

The model generated output map of groundwater potential zone is further validated with the data related to yield potentialities of different borehole/tube well (CGWB report 1985) in the district. The pictorial representation of

the reported location points is overlaid upon final groundwater potential zonation map and is represented in Fig. 6. The reported boreholes/tube wells data show good correlation with the final output map. Wells in Murarai, situated at northern extremities of the study area and Nalhati have a yield of 200 m³/h. Some of the observation wells situated in Noapara, towards east along Murshidabad district, Benigram near Rampurhat and Dangapara have a yield of around 220 m³/h. In the south-east region of the study area particularly near Ilam Bazar, the water level is quite shallow and yield is around 180–200 m³/h. Heavy duty tube wells, located at Bara Dibur, Indradanga, Santiniketan, Mustal, etc. have a yield of about 72.7–179.7 m³/h. The yield capacity in the hard rock terrain in the western and south-western part is very low (~4.5 m³/d).

Prediction and success rate (Chung and Fabbri 2003) is a widely used method for model validation. In the present study, this method of validation is implemented as the goodness of fit and success rate can be visualized distinctly (Klose et al. 2014). Initially, the reported groundwater potential yield inventory is divided into two datasets, i.e., modeling and validation set. To establish model’s statistical robustness, 15% of reported groundwater potential data were randomly classified into validation group as suggested by Neuhäuser et al. 2012. The susceptible index values generated are divided into 100 equal classes each having a cumulative interval value of 1%. Cumulative percentage of susceptible areas is plotted on the x-axis and the cumulative

percentage of groundwater potential yield in the training dataset on the y-axis to generate the success rate curve (SRC) (Chung and Fabbri 2003; Van Westen et al. 2003; Sterlacchini et al. 2011). The SRC represents the prediction rate and lacks any information about the prediction accuracy hence to evaluate the future prediction accuracy, prediction rate curve (PRC) is also estimated. For generating of prediction rate curve (PRC), a method similar to SRC was followed except that on y-axis the groundwater potential yield in the test dataset was plotted (Chung and Fabbri 2003). The area under the curve (AUC) is measured for comparative and easier understanding of SRCs and PRCs generated. Assuming that the model is ‘correct’, success rates depict goodness of fits whereas prediction rates account for validation of the prediction. The area under the curve (AUC) for success rate (Fig. 7) indicates an accuracy of 83.03% whereas the prediction rate accounts for an accuracy of 78%.

Conclusion

In this research work, combined application of remote sensing, GIS and MIF techniques are found an efficient tool in the delineation of groundwater potential zones in Birbhum district, West Bengal with respect to costs, efficiency, manpower and time involved in conversational exploration. Approximately, 47% of the total area falls from ‘high’ to ‘very high’ zones indicating that about half of the study area have good groundwater potential. The outcomes of the research will be helpful as first-hand information planners and local authorities for assessment, planning, management, administration, sustainable utilization and artificial recharging in near future.

Acknowledgements The authors express their heartiest gratitude to the DST (project No. SB/ES-687/2013 dated 11.11.2014), Government of India for financial support to the project. The author would also like to thank Central Ground Water Board, Survey of India, and Geological Survey of India for their help and support.

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