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ORIGINAL ARTICLE

Decipherment of potential zones for groundwater occurrence: a study in Khatra Block, Bankura District, West Bengal, using geospatial techniques

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Abstract

Groundwater is considered as one of the most valuable natural resources as it supports human civilization. Freshwater is considered as an important natural resource which occurs partially on the surface and dominantly beneath the surface. The resource is declining drastically owing to the rapid increase in population and its management in an improper way. The occurrence of groundwater in hard rock terrain still behaves as enigmatic. Various terrain parameters control the movement and storage of groundwater. Accordingly geoscientists are using various techniques to explore the potential zone amongst which multi-criteria evaluation (MCE) technique seems to be more precise. Application of remote sensing and geographic information system (GIS) has come out as very effective tools in deciphering groundwater potential zone by modeling terrain features specially in hard rock arid regions. The present study is aimed to find out groundwater potential zones in Khatra Block of Bankura District, West Bengal, India characterized by hard granitic terrain and semi-arid climatic condition. In the present study various thematic maps viz., geomorphology, geology, lineament density, drainage density and slope have been prepared. For these, IRS Resources at LISS-4 with 5.8 m spatial resolution digital data, CARTOSAT-1 digital elevation model, CartoDEM with 2.5 m spatial resolution, along with other data sets such as Survey of India toposheets (73J/13, 73I/16, 73I/12), GSI Map have been used. Digitized vector maps relating to chosen parameters, were converted to raster data using 30 m × 30 m grid cell size. Different theme weight and class rank have been assigned to these raster maps. Each theme weight has been multiplied by its respective class rank and all the raster thematic layers have been summed up in a linear combination equation in Arc GIS Raster Calculator module. Similarly, the weighted layers have been statistically modeled to get the areal extent of groundwater prospects. This integrated approach, helped in classifying the groundwater availability in the study area into five categories, viz. very good, good, moderate, poor and very poor. Finally, it can be stated that the modeling assessment method proposed in this study forms an effective tool for delineating groundwater potential zones for proper development and management of groundwater resources in hard rock terrains.

Keywords Hydrogeomorphology · Lineament density · Automatic lineament extraction · Raster calculator · Arc GIS · Groundwater potential

Introduction

Water scarcity is a major problem in arid and semi-arid regions across the globe due to rainfall deficiency, which puts tremendous pressure on groundwater. This has caused a decline in the available resource during the past few decades. India also is approaching to a freshwater crisis. Groundwater constitutes the largest only freshwater resource in different parts of the world, and this becomes the main obstruction in providing sustainable water demands during continuous dry seasons (Assaf and Saadeh 2008). Moreover, the use of groundwater has increased and this has led to a water stress situation owing to unscientific exploitation of this natural resource. This has led to developing a technique which is cost and time effective for proper evaluation of this natural resource and its management. A groundwater development programme needs a huge volume of data from different sources. Integrated remote sensing and GIS study is the only

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way which can provide an appropriate platform for convergent analysis of huge volume of multi-disciplinary data and making decision for this.

The secondary porosity generated by fracturing of the underlying rocks in a watershed of a hard rock terrain are the main controlling factors in the occurrence and movement of groundwater (Srivastava and Bhattacharya 2006). Remote sensing and GIS is an effective tool in demarcating the groundwater potential zones as it provides a wide-range scale of the space–time distribution of observations, as well as saves time and money (Murthy 2000; Leblanc et al. 2003; Tweed et al. 2007). Further the technique is widely used to characterize the earth surface (such as lineaments, drainage patterns and lithology). Presently geoscientists are using high resolution satellite images in groundwater exploration only because of their usefulness in identifying different ground features indicating the presence of ground water (Krishnamurthy et al. 1996; Das et al. 1997; Ravindran and Jayaram 1997; Saraf and Choudhary 1998; Pratap et al. 2000; Harinarayana et al. 2000; Muralidhar et al. 2000; Sankar 2002; Bahuguna et al. 2003; Jaiswal et al. 2003; Jagadeeswara Rao et al. 2004; Kamal and Midorikawa 2004; Basudeo et al. 2005; Lokesha et al. 2005; Nag 2005; Sreedevi et al. 2005; Gustavsson et al. 2006; Jasrotia et al. 2007; Kumar et al. 2007; Singh et al. 2007; Ratnakar Dhakate et al. 2008; Corgne et al. 2010; Chenini et al. 2010).

The present study area is located on hard granitic terrain and in semi-arid climate zone. Over a long period of geological time due to the heterogeneous nature of the weathering this hard rock terrains give rise to complex hydrogeology. Fractured and weathered horizons in hard rock terrains are main sources of groundwater. Khatra Block is situated at western part of Bankura district where granite gneisses and their metamorphic equivalent rocks mostly covered the area, on the east recent alluvium occurs in few places. Strong massive bodies of hornblendic varieties run across the region in nearly east and west.

Cartosat-1 DEM of 30 m resolution was used for lineaments analysis and Resources at-1 (LISS-IV) was used for hydrogeomorphological studies for groundwater development works. In demarcating favourable sites for artificial recharging of groundwater, lineaments serve a major role as they reflect rock structures through which water can percolate and travel up to several kilometers (Krishnamurthy et al. 2000).

Groundwater potential zones can be delineated in a rapid and cost-effective manner through systematic integration of geomorphology, geology, slope, drainage data, lineament followed by hydrogeological investigation. For integrating various data, digital technique is used nowadays to delineate groundwater potential zones. These different data are used to prepare thematic maps using geographical information system (GIS) software (ARC GIS.10) tool. "Spatial Analyst" tool of Arc GIS.10 used to integrate these thematic maps and to prepare groundwater potential zones. The number and type of such themes used for the assessment of groundwater resources by Geoinformatics techniques vary considerably from one study to another. In most studies, for assigning weights to different thematic layers and their features, local experience plays an important role. Every year during summer, most surface water sources dry up, causing serious water shortages for both domestic and irrigation purposes. The availability of surface water cannot be ensured in the right quantity at the required time because of the unpredictable nature of the south-west monsoon in India. Groundwater collected from dug wells and tubewells are being extensively used in the majority of the irrigated area in the Khatra Block of Bankura District. However, the unplanned and excessive withdrawal of groundwater is the main reason for lowering of groundwater levels in some parts of the study area. Every year during the dry period, both dug wells and hand pumps also become inoperative, causing thereby the water problem in the study area to be crucial. The objective of the present investigation is deciphering groundwater potential zone in Khatra Block using Geoinformatics technology. In terrains of complex hydrological characters, both surface and subsurface indicators of groundwater are considered to obtain useful guidelines for the management of groundwater resource. This methodology can be applied effectively in areas such as South India having similar climate, geology and acute shortage of water. Under this scenario, the present study was carried out to delineate groundwater potential zones with proper management and sustainable use of groundwater.

Study area

The present investigating area, Khatra Block, is situated in the western part of Bankura district and lies between latitude 22°50′30″N–23°12′30″N and longitude 86°45′0″E–86°56′0″E with an area of 447 km^2. Survey of India toposheet nos. 73 I/12, 73 I/16, 73I/13 have been used in mapping the area (Fig. 1). The study area located 35 km from away from Bankura town. The area is mostly dominated by granite gnesis of Archean age, basically the extended part of Chota Nagpur Plateau. The studied area is characterized by semi-arid climate, and annual rainfall on average is 132 cm in the area; maximum rainfall occurs during June–September as the southwest monsoon onsets. During May when temperature exceeds 40 °C is the hottest month and in January the temperature sometimes goes down below 12 °C, is the coldest month. A gentle undulating sub-dendritic drainage pattern with seasonal flow is the characteristics of the area. Kangsabati River runs in west–east direction in the southern part of study area with several other streams and channels. The area is facing

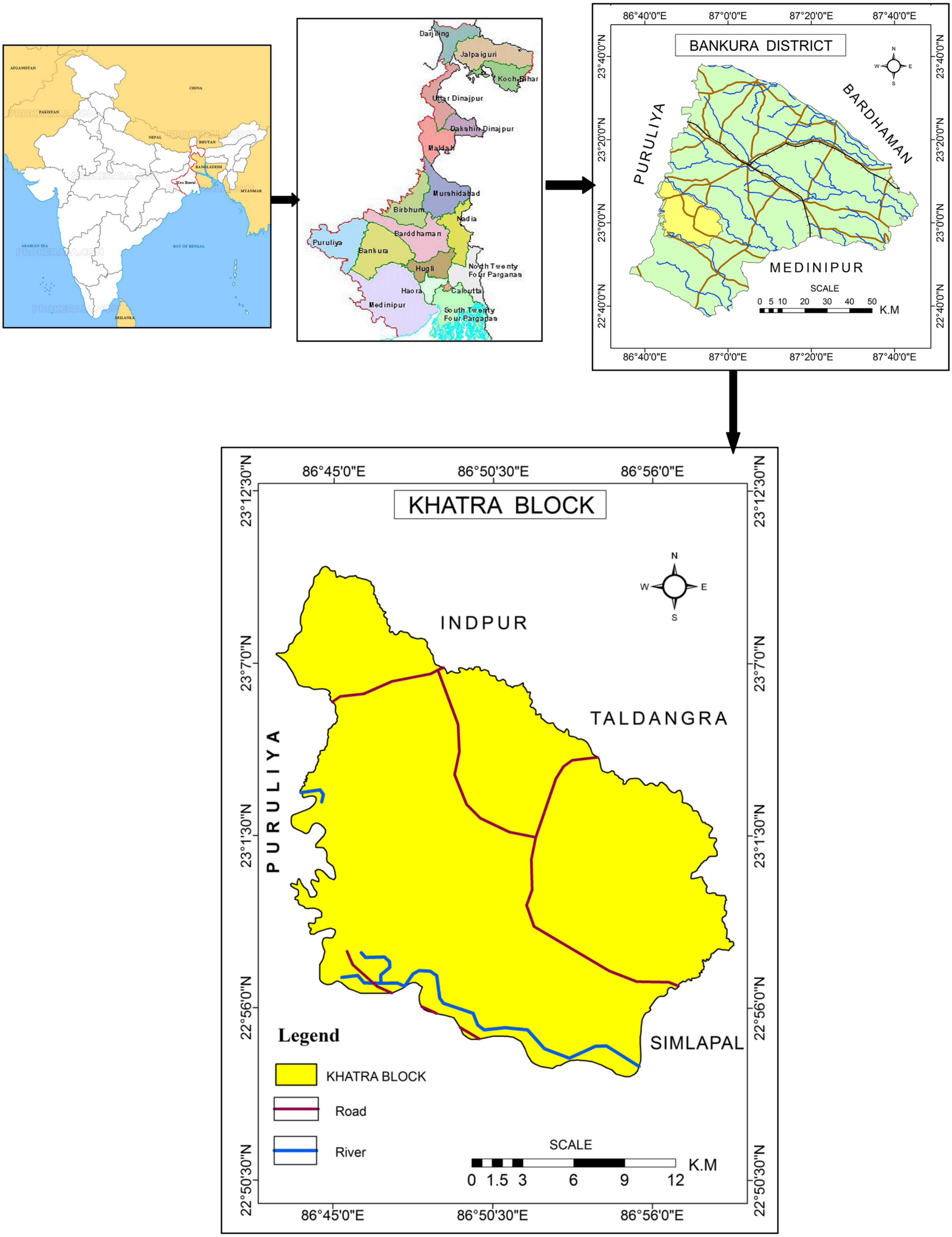

Fig. 1 Map of the study area

acute water scarcity problem due to rapid urbanization and absence of any perennial river. The area is composed mainly of granites of Archaean age and Precambrian include various types and grades of granite–gneisses, mica–schists and hornblende–schists, are the major rock types that cover the study area (Fig. 2).

Data used and methods

IRS Resources at LISS-4 data was used in the present investigation. The toposheets of Survey of India 73 I/12, 73 I/16, 73 I/13 with a scale of 1:50,000 have been used as a source of ancillary information. The satellite images have been visually interpreted to identify different hydro-geomorphologic units and in this process image interpretation elements such as tone, texture, shape, size, pattern, and association have also been taken into consideration. Geology map was prepared using Geological Survey of India existing map (1:250,000). The slope and drainage map have been prepared using Cartosat-1 DEM data in ArcGIS Spatial Analyst module. The drainage density map has been prepared using the ArcGIS line density analysis tool Lineaments were extracted from Cartosat-1 DEM of the study area. Lineament density map was also prepared using ArcGIS. The different thematic layers in vector format have been converted into raster format for loading into GIS environment. Weights have been assigned to individual themes (W_t) and for each feature within the theme, ranks have been given (W_i) based on the knowledge upon their significance to groundwater. Factor scores for each feature have been derived by multiplying theme weight (W_t) with feature rank (W_i). Similarly, scores were derived for all the themes. Subsequently, themes were converted into raster format and thus each pixel contained factor scores with respect to their potentiality to groundwater. Finally, all the thematic layers were integrated and the total factor scores for each pixel were calculated through raster calculation process in Spatial analyst extension of ArcGIS 10. Based on the derived scores, the final integrated map has been classified into five categories of groundwater prospect zones as (1) very good, (2) good, (3) moderate, (4) poor, and (5) very poor.

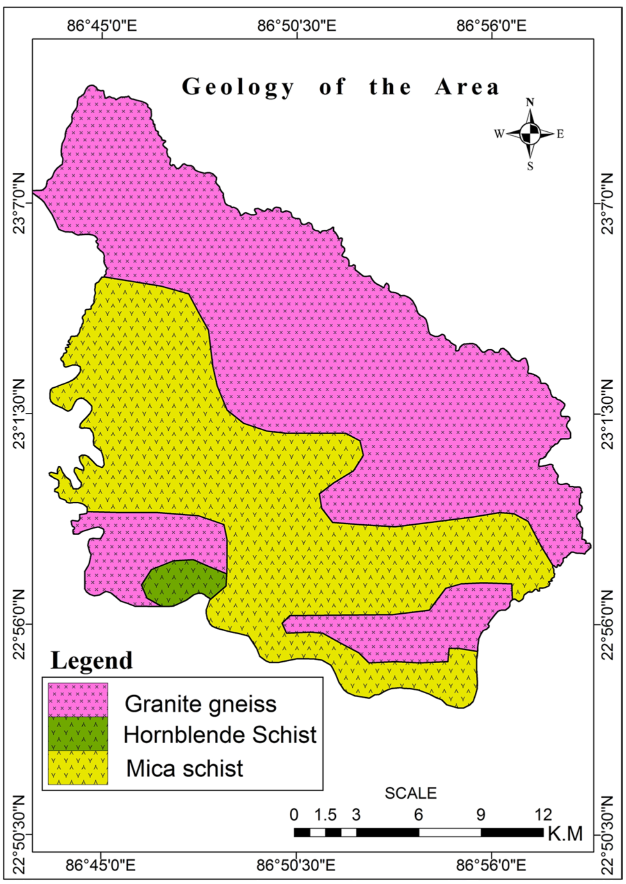

Fig. 2 Geological map of the study area

Geology

Most diversified rock types belonging to Precambrian sediment & metasediments cover the area (Table 1; Fig. 2). Precambrian include various types and grades of mica–schists and gneisses, hornblende–schists, amphibolites. Mica–schist covers most of the area. Geologically, granite gneiss belonging to Archean age dominate over the area which are basically the extended part of Chota Nagpur Plateau. The present geological map has been extracted from the geological map prepared by the Geological Survey of India. The granite-gneiss rocks are widespread over the study area covering about 260 km^2 (58%) and schist/metasediments covering 180 km^2 (40.26%) and quartzites are limited in few parts. Granite gneiss occurs mostly in the northern part with the southwestern and eastern fringe of the studied area. Mica schist covers central part of the

Table 1 Geological units and their groundwater prospects

Sl. no	Rock types	Rock characteristics	Area (km^2)	Area (%)	Ground water prospects
1	Mica schist	Highly fractured weathered form	180	40.26	Good
2	Hornblende schist	Fractured weathered form	6	1.36	Moderate to good
3	Granite gneiss	Massive occasionally traverse by joint	260	58	Moderate to poor

study area. Hornblende–schist also present in the southwestern fringe of the study area covering 6 km^2. Usually, massive lithologic units in basement setting are devoid of fractures and have little influence on the groundwater availability. The development of secondary porosity in weathered overburden and fractured bed-rock units forms potential groundwater zones. Granite gneiss and mica schist are the major geological structures in the present study area. Depending on the occurrence of weathered regolith units and fracture systems, appropriate weights have been assigned to the different rock units in the study area. The weightage that has been given in terms of increasing groundwater potentiality is in the order of granite gneiss to hornblende schist and mica schist.

Geomorphology

Geomorphology of an area constitutes the most important features in deciphering the groundwater potential of an area (Kumar et al. 2008). In hard rock area, lithology and structures of the underlying rock units greatly influence the geomorphology. The area is characterized by a dominant rocky undulating terrain along with a number of erosional/depositional hydro-geomorphic units manifested by hills, uplands and undulating surfaces. Remote-sensing studies provide an opportunity for better observation and more systematic analysis of various hydrogeomorphic units/landforms/lineaments, features owing to its synoptic, multispectral repetitive coverage of the terrain (Horton 1945; Kumar and Srivastava 1991; Sharma and Jugran 1992; Chatterjee and Bhattachaya 1995; Tiwari and Rai 1996). The different hydrogeomorphological units are shown in Figure-3.

Structural hills/residual hills/denudational hills

Structural hills

The structural hills are in linear as well as arc shapes in the study area. They exhibit many definite trend lines and act mostly as runoff zones. Massive structure and high resistance to erosion are characteristics of linear ridges. From groundwater potentiality, they act as very poor zones. This unit covers 17 km^2 (4%) of the study area. Numerous joints, fractures and lineaments occur in this unit which facilitates some infiltration and mostly act as runoff zones. Dark green tonal variation and thick vegetation help in interpreting this geomorphic unit from the satellite imagery and also in height verification of DEM data. Therefore, groundwater recharge is poor and limited only along the joints, fractures, and faults.

Residual hills

These are described as isolated hills. Residual hills occur in a scattered mode on the southwestern part of the study area. In imagery, they exhibit dark greenish in false color composite. Granite gneisses occur as residual hills restricted to some area. The residual hills stand out as resistant formation from differential erosion and weathering. At lower altitudes, this unit occurs as isolated patches, in a linear or curvilinear manner indicating their structural control. The residual hills occur as inselbergs, tors, linear and curvilinear ridges, exfoliated domes with partially debris cover at the footslope (Tripathy et al. 1996). Most of the rainwater is washed off immediately without much infiltration due to its steep slope and this causes very poor groundwater prospect in this unit is very poor.

Denudational hills

These hill ranges are formed by differential erosion and weathering. They occur at very few places in the northern and central part of the studied area. In the satellite imagery, they are identified by their dark greyish green color. In contrast to structural hills, these hills are characterised by big boulders and sparse vegetation. Owing to its moderate to steep slope (5°–20°), this landform, generally, acts as high runoff zone. The groundwater prospect in this zone is also considered as very poor.

Pediment

Pediments are gently sloping erosional surfaces of low relief developed on bedrock. They occur in a wide variety of lithologic and climatic settings. It is caused by erosion and develops when sheets of running water wash over it in intense rainfall events. Pediments (Fig. 3) have been classified into two types (a) Buried pediment moderate (BPM) and (b) Buried pediment shallow (BPS).

Buried pediment moderate

It is nearly flat to smooth surface, comprising of relatively thick overburden derived from weathered material spreading over large area. The buried pediment moderate is a major hydrogeomorphic unit in the study area. This thickness of this unit varies from 5 to 20 m. It is clayey to fine loamy soils and is well distributed throughout the region of the study area. This unit is interpreted by its light to moderate red color in the satellite imagery. This unit spreads over 300 km^2 and occupies 67% of the study area. Groundwater prospects in this unit are considered as moderate to good although,

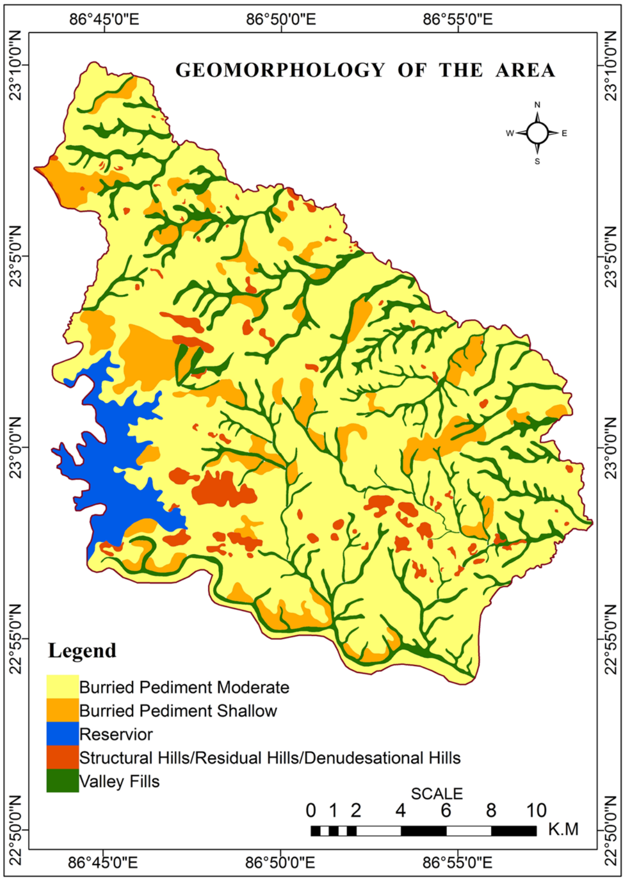

Fig. 3 Geomorphological map of the study area

higher yields are expected because of its association with lineaments. Table 2 shows the different geomorphic units, their characteristic features and groundwater potentiality.

Buried pediment shallow

This unit is characterized by very gently sloping inclined bedrock surface. They are covered by shallow weathering materials up to 5 m. Medium grey tone on the imagery is observed due to its low moisture content. This unit covers 49 km^2 (~11%) of the study area. Groundwater prospect is supposed to be moderate to poor. The area occupied by this hydrogeomorphological unit can be used for groundwater resource in terms of open wells after monsoon (Subba Rao et al. 2001).

Valley fills

Rivers coming out from hilly terrain brings loads of unconsolidated materials and deposit them along their courses. Generally, coarser materials are deposited at the young stages of rivers which comprises of pebbles, gravels and sand. These forms the bulk materials of valley fills. The

Table 2 Different hydrogeomorphological units, their characteristics, area covered and groundwater prospects

Hydrogeomorphological units	Description	Characteristics	Area km^2	Association	Groundwater prospects
Valley fills	Accumulation zone of colluvial materials derived from surrounding uplands; shallow to deep; fine loamy to clayey soils	Moderately deep to deep, fine textured moderately well drained soils. Moderate limitation of wetness	58.11	Stream course	Good to very good
Buried pediment (moderate)	Gently sloping topography; very deep, clayey to fine loamy soils	Moderately deep to deep, fine textured loamy skeletal to coarse loamy soil. Single crop area with marginal	300	Agricultural land	Good
Buried pediment (shallow)	Nearly flat to gently sloping topography, shallow to moderately deep	Very shallow to shallow coarse `textured soil with occasional weathered outcrops of country rocks. Wastelands with or without scrub. Shallow to moderately deep	49.17	Hill and stream course	Moderate to poor
Rocky outcrop (Structural Hills/ Residual Hills/ Denudation Hills)	Broad uplands of considerable elevation, steeply sloping on all	Very shallow, coarse loamy soil on moderately steep to very steep hill slopes	18	Hill and stream course	Poor to very poor

valley fills deposits vary in composition and texture (Agarwal and Garg 2000) depending upon the parent rock. The drainage pattern is by and large controlled by the lineaments and is parallel to sub-parallel. This unit occupies 58 km^2 (~ 13%) in the study area. Groundwater prospects in this unit are found to be excellent to good because of its location at the bottom of the hill and geology comprising highly porous materials. Valley fills also act as good to excellent subsurface water potential (Murthy and Venkateswara Rao 1999).

Slope

Slope controls subsurface infiltration of groundwater and acts as an indicator for groundwater prospect. In areas having gentle slope, the surface runoff is slow and gets more time for percolation of rainwater. High slope area allows high runoff, gets less residence time for rainwater percolation. To generate the slope, digital elevation model (DEM) Cartosat-1 (30 m) resolution is used and developed by ArcGIS Spatial Analysis tools. Slope of the area ranges from 0°–35°. The study area has been divided into five slope categories: 'Very good' category area with 0°–1° slope, 'good' category area with 1°–3° slope, moderate 3°–6° slope, poor 6°–12° slope, and finally very poor with 12°–35° slope. The southern and entire central portion (~ 67% of the total area) is considered as good category. These areas are hilly with rocky outcrop having steep slope, where amount of infiltration negligible but runoff is maximum (Table 3; Fig. 4).

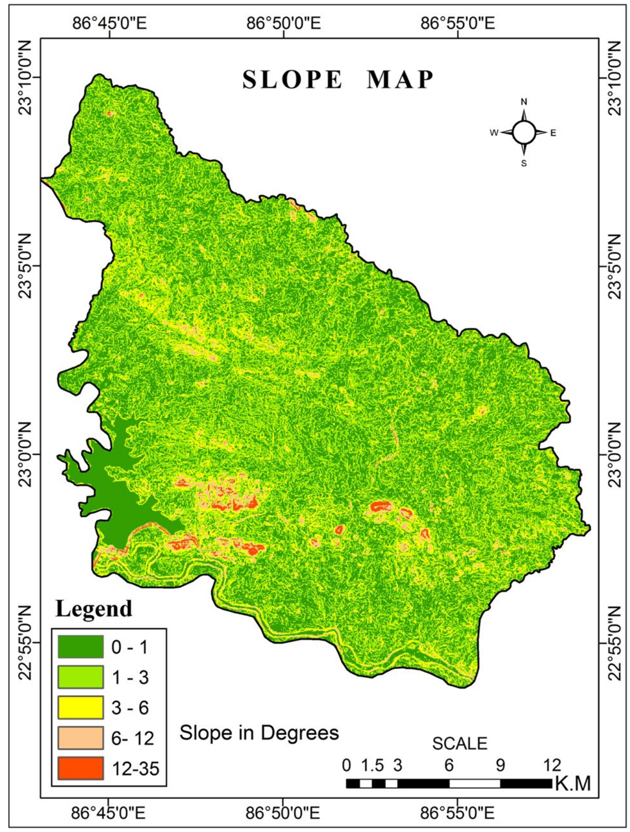

Fig. 4 Slope map of the study area

Drainage network

Analysis of drainage network is important in hydrogeological studies. The characteristic of surface and subsurface formation is reflected in the drainage pattern. "The study area is well drained by" a number of rivers. Kangshabati is the main river flowing through the southern side of the study area and originates from hills of Chota Nagpur Plateau. Silabati flows northern part of study area. The rivers occurring in the study area classified following Horton's law of stream order. Streams up to 5th order have been delineated. Only two types of drainage patterns viz. dendritic, parallel to sub parallel have been identified in the study area. The high-resolution Digital Elevation Model of 30 m resolution Cartosat-1 has been used to extract drainage pattern of the study area. Here, we have used "Spatial Analysis" tool of Arc GIS. 10 to develop stream orders (Fig. 5). Lithology mainly controls the stream flow pattern in the study area. The total Kangsabati river basin comprises of two varieties of rocks of belonging to different geological period. Relatively older rock mica-schist of Precambrian period occupy the western part is while pliestocene laterite formation occurs in the eastern part. Strong structural control is observed due to the presence of hard base of granite and gneiss in the area.

Table 3 Slope values and their groundwater prospects

Sl. no.	Altitudinal zones	Area (km^2)	Area (%)	Associated land use/land cover	Ground water prospects
1	0°–1°	188	42	Agricultural land	Very good
2	1°–3°	192	43	Agricultural land with sparse vegetation	Good
3	3°–6°	54	12	Scrubland with sparse agriculture	Moderate
4	6°–12°	11	2.42	Barren rocky land	Poor
5	12°–35°	3	0.7	Hilly areas with exposed rocks	Very poor

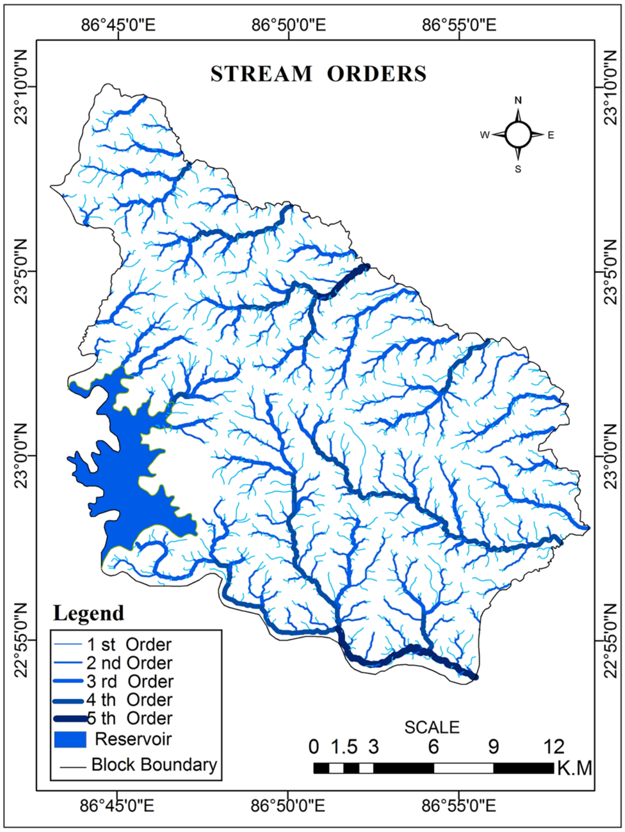

Fig. 5 Drainage map of the study area

Drainage density

Drainage density defines how closely stream channels are spaced. It measures the total length of the stream segment of all orders per unit area. The drainage density is an inversely related to permeability. The less permeable rock allows less rainfall infiltration. The drainage density has a relation with surface run-off and permeability and indirectly indicates the groundwater potential of an area. Hence, drainage density is considered as one of the criteria for the occurrence of groundwater. Drainage density (expressed as km/km^2) indicates the characteristics of surface material. The drainage density is directly proportional to runoff. So, it can be stated that if the drainage density becomes less, higher will be the recharge probability and also the groundwater potential zone. The study area has been classified into five categories. These categories have been assigned as 'very low' (< 1 km/km^2), 'low' (1–2 km/km^2), 'moderate' (2–3 km/km^2), 'high' (3–4 km/km^2) and 'very high' (4–5 km/km^2) (Table 4; Fig. 6). Presence of low network of drainage is indicative of the occurrence of highly resistant and permeable rock. On the other hand, the presence of a high network of drainage indicates impermeable and highly weak rocks (Karanth 1999). Accordingly, a high value of rank has been given to low drainage density zones and a low value of rank to a high drainage density zone.

Table 4 Drainage density and their groundwater prospects

Sl. no	Drainage density (km/km^2)	Area (km^2)	Area (%)	Ground water prospects
1	< 1 very low	105	23	Very good
2	1–2 low	121	27	Good
3	2–3 moderate	109	24.32	Moderate
4	3–4 high	80.61	18	Poor
5	4–5 very high	31.29	7	Very poor

Lineament study

Mapping of lineament is considered as important criteria in solving the problem of hydrogeological research. Over several decades, extensive research is going on the regional study and automated extraction of linear features (e.g., faults, joints, folds, dikes, crustal fracturing, and lithological contacts) from satellite images. The groundwater occurrence

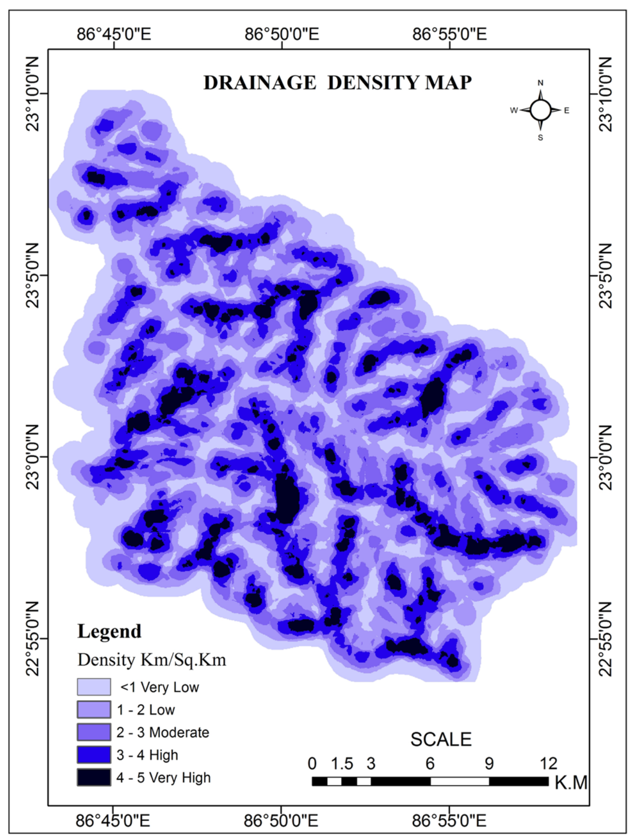

Fig. 6 Drainage density map of the study area

in hard rocks terrain is dependent on rock types as well as the intensity of the tectonic activity.

Mapping of lineament has been used earlier in different geological applications and the term lineament was first used in geology was probably by Hobbs (1904, 1912), and is defined as significant lines of landscape generated from joints, faults and the architecture of the basement rock. Later O'Leary et al. (1976) developed its definitions. Now, lineaments are defined as extended mappable linear or curvilinear features of a surface whose parts align in straight or nearly straight relationships that may be the expression of folds, fractures or faults in the subsurface.

A close relationship between lineaments and groundwater flow and yield has been established by several workers (Mabee et al. 1994; Magowe and Carr 1999; Fernandes and Rudolph 2001). Therefore, it is essential in a groundwater survey, its development and management to map the lineaments as they are closely related to occurrences of groundwater and its yield. Groundwater potentiality of an area is directly related to its lineament density as the presence of lineaments normally denotes a permeable zone(Kumar et al. 1999). In hard rock terrain fractures/lineaments behave as master conduits in movement and storage of groundwater (Ramasamy et al. 2005; Chandra et al. 2010). Since the remote-sensing data provide synoptic view of large area and helps in understanding and mapping the lineaments both on regional and local scale, important information can be achieved on subsurface fracture, which directly controls the movement and storage of groundwater.

For automatic extraction of lineament, LINE module of the PCI Geomatica (Hung et al. 2005) is most commonly used software. The same has been used here. Here Lineaments have been extracted from CARTOSAT DEM data of 30 m resolution and finally developed by Arc GIS.10 (Fig. 7).

A total of 462 lineaments have been mapped through analysis of satellite data in the study area, varying in length from minimum 0.0422 to maximum 3.12 km. Measurement of length also forms a significant parameter as fractures with a greater length affects the groundwater flow in a more dominant way than those of smaller length. In the present area, three sets of joints/fractures have been delineated and joints trending ESE–WNW/E–W conform with the regional trend of the axial plane foliation of folding phase F1. The analysis on the orientation of the lineaments forms an important role for delineating its trend and this is done by constructing rose diagrams.

A bimodal oriented structural trend is observed in the present area. The main class strikes NW–SE while other strike NE–SW. A rose diagram (Fig. 8) has been prepared by plotting the major directions of the lineaments. It is observed that majority of the lineaments arc oriented in NW–SE (100–280). The lineament density, their

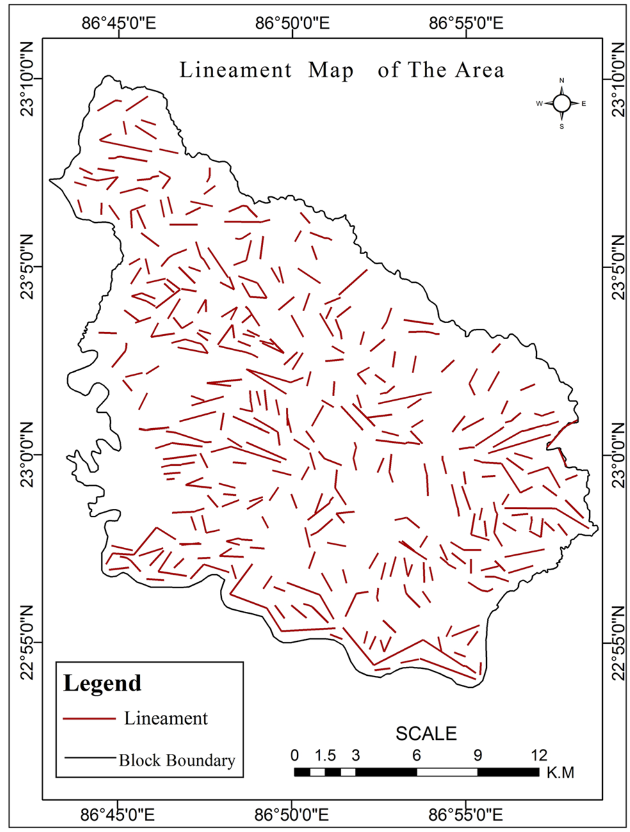

Fig. 7 Lineament map of the study area

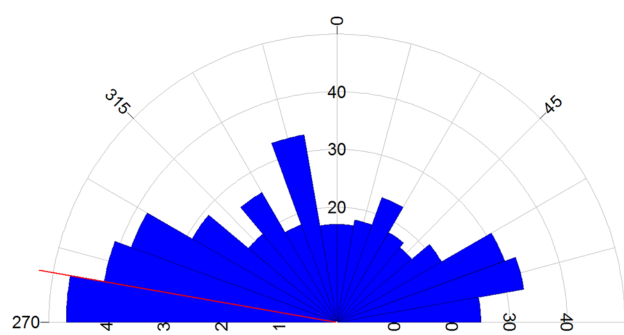

Fig. 8 Rose diagram showing orientation of the lineaments of the study area

groundwater prospects and area occupied by them have been presented in Table 5.

Lineament density

The main purpose of fracture/lineament density analysis is to get an idea of the frequency of fractures/lineaments present per unit area. A map has been prepared to show concentrations of the lineaments over the study area. Areas having higher lineament density are expected good for groundwater

Table 5 Lineament density and their groundwater prospects

Sl. no	Lineament density (km/km^2)	Area (km^2)	Area (%)	Ground water prospects
1	1.431–2.245	44	10	Very good
2	1.043–1.431	94	21	Good
3	0.689–1.043	112	25	Moderate
4	0.318–0.689	116	26	Poor
5	<0.318	81	18	Very poor

development. Lineament density is defined as the summation of all the lineament lengths present study area divided by its total study area. The entire study area has been divided into 1 km/1 km grid. The highest value of lineament density, 1.431–2.245 km/km^2, is observed in southwestern and eastern parts as well as upper central part of the study area. On the basis of lineament density, the area was divided into five different (very high, high, moderate, low, very low) zones. Since groundwater potential is directly proportional to lineament density, hence, high rank was assigned to high lineament density zones and low rank to low lineament density zones (Fig. 9).

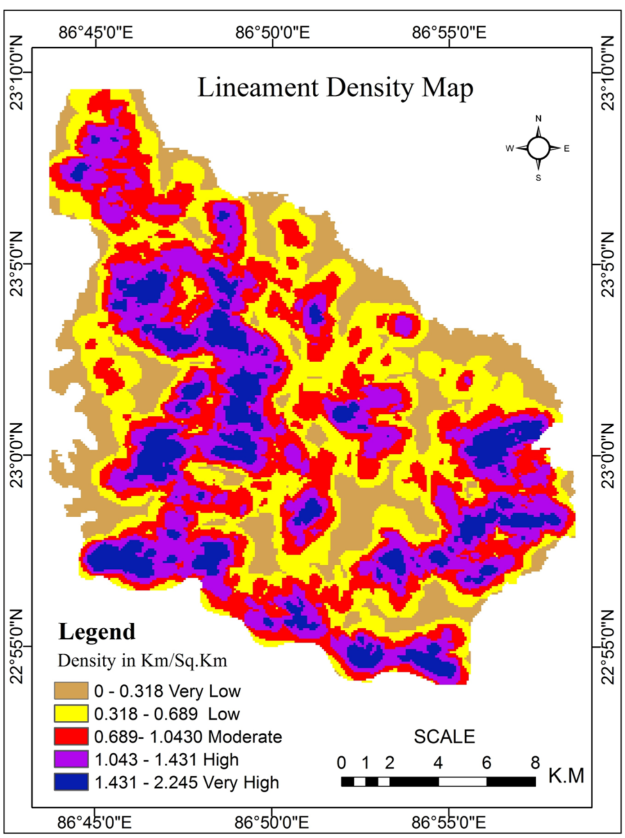

Fig. 9 Lineament density map of the study area

Results and discussion

Different thematic layers showing groundwater potentiality have been integrated into a single map showing favourable groundwater potential zones with the help of Arc GIS10. Satellite imageries, topographical maps along with collateral data have been taken into consideration while preparing various thematic layers viz., geology, geomorphology, slope, drainage density and lineament density maps of the area. The different thematic layers have been given due weightage with the help of MIF technique followed by integration in the GIS environment to produce the map showing groundwater potentiality (Krishnamurthty et al. 1996; Saraf and Choudhary 1998). The results thus obtained from the present study will serve as guidelines to plan artificial recharge projects in future in the area having similar conditions for ensuring sustainable groundwater utilization. The information on geology, geomorphology, slope, drainage density and lineament density was gathered from Cartosat DEM data, GSI map, LISS-IV and toposheets of scale 1:50,000. Further, GIS platform have been utilized for integrating different thematic layers. The composite map thus generated has

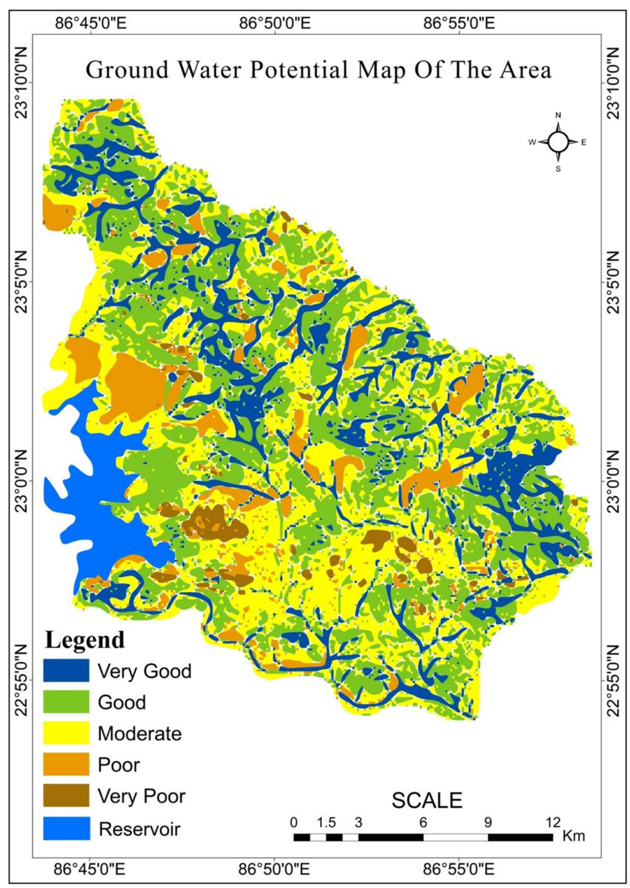

Fig. 10 Map showing Groundwater Potential Zone of the study area

been further classified according to the spatial distribution of groundwater potential.

All these thematic maps have been converted into raster format followed by superimposition by weighted overlay method (rank and weight wise thematic maps and integrated with one another through Arc GIS environment). During assignment of the weight, the hydrogeomorphology, lineament density and slope were given higher values, and the drainage density and geology have been given lower values. This is followed by individual rankings for different sub-variables. In this way, the different GIS have been studied carefully and ranks have been given to their sub variable (Butler et al. 2002; Asadi et al. 2007; Yammani 2007).

Groundwater potential map indicates that valley fills associated with lineaments are highly promising area for groundwater extraction. The structural hills, denudational hills and residual hills are considered as poor to very poor groundwater potential zone. However, these land landforms are found to act as run-off zones because of their steep slope. Lineaments particularly joints, fractures and their intersections enhances the potentiality of hydrogeomorphic units. Buried Pediment (moderate, shallow) region have been identified as a good to moderate favourable zone. The region of structural/ denudational/ residual hills with low lineament density has been identified as the least favourable site for groundwater exploration and development in the study. At a glance, it reveals that the southern part of the study area have excellent groundwater potential as compared to the extreme northern part of the study area. Thus, the generated groundwater potential map be utilized as a baseline information for future exploration.

Weight assignment and geoinformatics-based modeling

Relevant weights have been given to the five themes and their individual sub-folders considering their importance in making potential groundwater occurrence in the study area. The Thematic layers are integrated in the GIS environment to generate groundwater potential index (GWPI) (Malczewski 1999).

All these thematic maps have been given respective theme weight and their class rank. The individual theme weight was then multiplied by its respective class rank and then all the thematic layers were converted to raster format and reclassified with individual preference (R_i), aggregated in a linear combination equation in ArcMap GIS Raster Calculator format.

The equation used for analysis:

$$\mathrm{GWPI} = \sum W_i \times R_i,$$

where W_i is the map weight, R_i is the ranking for each layer, GWPI is the Groundwater Potential Index, $\mathrm{GWPI} = W_{\mathrm{Geom}} \times R_{\mathrm{Geom}} + W_{\mathrm{Slope}} \times R_{\mathrm{Slope}} + W_{\mathrm{lineament\ Density}} \times R_{\mathrm{lineament\ Density}} + W_{\mathrm{Drainage\ Density}} \times R_{\mathrm{Drainage\ Density}} + W_{\mathrm{Geology}} \times R_{\mathrm{Geology}}$.

Table 6 Different thematic layers, their groundwater prospects and their weights and ranks

Thematic layers	Weight (W_i)	Features	Ground water prospects	Rank (R_i)
Hydrogeomorphology	40	Valley fills	Very good	16
		Buried pediment moderate	Good	12
		Buried pediment shallow	Moderate to poor	8
		Structural hills/denudation hills/residual hills	Poor to very poor	4
Lineament density	20	1.43–2.24 km/km^2	Very good	8
		1.04–1.43 km/km^2	Good	6
		0.68–1.043 km/km^2	Moderate	4
		0.3–0.6 km/km^2	Poor	1.4
		< 0.31 km/km^2	Very poor	0.6
Slope	20	0°–1°	Very good	8
		1°–3°	Good	6
		3°–6°	Moderate	4
		6°–12°	Poor	1.4
		12°–35°	Very poor	0.6
Drainage density	10	0–1 km/km^2	Very good	4
		1–2 km/km^2	Good	3
		2–3 km/km^2	Moderate	2
		3–4 km/km^2	Poor	0.7
		4–5 km/km^2	Very poor	0.3
Geology	10	Mica schist	Good	5
		Hornblende schist	Moderate to good	3
		Granite gneiss	Moderate to poor	2

The cumulative final cumulative map has been generated by applying the above equation. Finally, the cumulative effect of the weighted multi influencing factors through overlay analysis in Arc GIS platform revealed the mapping of groundwater potential zones in the study area (Fig. 10).

The potential zones have been differentiated into five categories: (1) very good, (2) good, (3) moderate, (4) poor and (5) very poor. About 3% of the total area falls under the 'very poor' zone, 11% falls under 'poor' zone, 30% falls under 'moderate' groundwater potential zone, 38% of the study area falls under 'good' zone and finally 18% of the area falls under 'very good' zone (Tables 6, 7; Fig. 11). The groundwater potential map demonstrates that the excellent groundwater potential zone is concentrated in the south–western, central and eastern portion of the study area owing to the distribution of valley fills, high lineament density making fractured network, low drainage density and low slope.

Table 7 Different categorisation of groundwater potential zones and their respective area coverage with areal percentage

Sr. no	Potential zones	Area (km^2)	Area (%)
1	Very good	80	18
2	Good	172	38
3	Moderate	135	30
4	Poor	48	11
5	Very poor	14	3

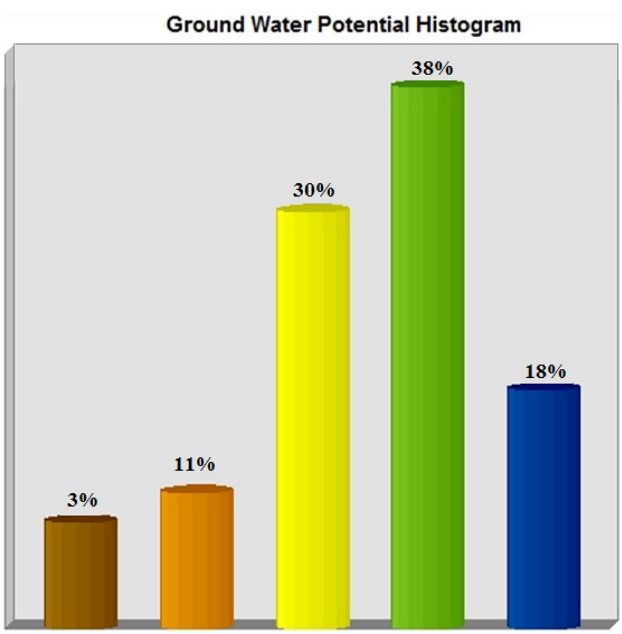

Fig. 11 Histogram showing Groundwater Potentiality of the study area

Conclusion

In the delineation of groundwater potential zone in parts of Bankura District of West Bengal, remote sensing and GIS studies has come out as the most powerful and cost-effective tool. In the present study, five thematic maps (e.g., geology, geomorphology, slope, drainage density and lineament density) have been integrated using ArcGIS 10 tool. Various thematic layers have been assigned proper weightage through MCE technique and then integrated in the GIS environment to prepare the groundwater potential zone map of the study area. To demarcate the groundwater potential zones within each thematic layer, an innovative statistical modeling was done using Arc GIS 10. The results reveal that the area falls in five groundwater potential zones ranging from very poor to very good. The poor zone is indicative of the least favourable region for groundwater prospecting, while the good to very good zone indicate the most favourable region.

The results obtained can be used for sustainable management of groundwater resources in the area. This gives first-hand information to local authorities and planners about the areas suitable for groundwater exploration and management. Concerned decision makers can formulate an efficient groundwater utilization plan for the study area so as to ensure long-term sustainability. This study is beneficial to conduct groundwater exploration mapping faster and more efficiently at the same time.

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