



Application of remote sensing, GIS and MCA techniques for delineating groundwater prospect zones in Kashipur block, Purulia district, West Bengal

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Abstract

Demand of groundwater resources has increased manifold with population expansion as well as with the advent of modern civilization. Assessment, planning and management of groundwater resource are becoming crucial and extremely urgent in recent time. The study area belongs to Kashipur block, Purulia district, West Bengal. The area is characterized with dry climate and hard rock terrain. The objective of this study is to delineate groundwater potential zone for the assessment of groundwater availability using remote sensing, GIS and MCA techniques. Different thematic layers such as hydrogeomorphology, slope and lineament density maps have been transformed to raster data in TNT mips pro2012. To assign weights and ranks to different input factor maps, multi-influencing factor (MIF) technique has been used. The weights assigned to each factor have been computed statistically. Weighted index overlay modeling technique was used to develop a groundwater potential zone map with three weighted and scored parameters. Finally, the study area has been categorized into four distinct groundwater potential zones—excellent 1.5% (6.45 sq. km), good 53% (227.9 sq. km), moderate 45% (193.5 sq. km.) and poor ~ 0.5% (2.15 sq. km). The outcome of the present study will help local authorities, researchers, decision makers and planners in formulating proper planning and management of groundwater resources in different hydrogeological situations.

Keywords Remote sensing and GIS analysis · Multi-criteria analysis (MCA) · Weighted index overlay (WIOA) · Groundwater potential zone · Kashipur block · Purulia district

Introduction

The rapid development of this groundwater resource for many purposes has resulted in expansion of irrigation and overall economic development, and thereby improving the lifestyle in India. Groundwater is the main source for more than 85% of rural domestic supply and it is rapidly depleting in many areas owing to large-scale withdrawal. The significant contribution made for the Green Revolution has further accelerated the rapid decline in groundwater levels. This alarming situation calls for a cost- and time-effective technique for proper evaluation of groundwater resources and management planning. A groundwater development program requires a large volume of data from various sources.

Remote sensing and GIS study with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within a short time has come out as an efficient tool to provide the appropriate platform for convergent analysis of large volumes of multi-disciplinary data and decision making for groundwater studies. Geospatial technology is a rapid and cost-effective tool in producing valuable data on geology, geomorphology, lineaments and slope, etc., that plays a significant role in deciphering groundwater potential zone. The spatially complete and temporal nature of the remote sensing data provides excellent opportunities to hydrogeologists for improving the understanding of the hydrogeological system (Hoffmann and Sander 2007) in any area. Several factors such as geomorphology, land use/land cover, geological structures, fractures, groundwater table distribution, slope and drainage—all contribute in the movement and occurrence of groundwater in an area (Arkoprova et al. 2012).

Several conventional methods such as geological, hydrogeological, geophysical and photogeological techniques

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are being used to delineate groundwater potential zones (McNeill 1991; Lillesand and Kiefer 1994; Teeuw 1995; Meijerink 1996; Sander et al. 1996; Edet et al. 1997; Taylor and Howard 2000; Shahid et al. 2000; Srivastava and Bhattacharya 2006; Sharma and Kaur 2012; Fashae et al. 2013; Selvam et al. 2014; Jhariya et al. 2016). In recent times, digital techniques come out as a rapid and cost-effective tool, and are being used to integrate different data to decipher groundwater potential zones. In recent times, many workers have used the approach of RS and GIS for delineation of groundwater potential zones and artificial recharge sites (Chatterjee and Bhattacharya 1995; Teeuw 1995; Krishnamurthy et al. 1996; Saraf and Choudhary 1998; Shahid and Nath 1999; Goyal et al. 1999; Murthy 2000; Obi et al. 2000; Pratap et al. 2000; Shahid et al. 2000; Jaiswal et al. 2003; Srinivasa and Jugran 2003; Kamal and Midorikawa 2004; Nag 2005; Sener et al. 2005; Sreedevi et al. 2005; Gustavsson et al. 2006; Srivastava and Bhattacharya 2006; Singh et al. 2007; Jasrotia et al. 2007; Kumar et al. 2007; Chenini et al. 2010; Machiwal et al. 2011; Talabi and Tijani 2011; Kuria et al. 2012; Gumma and Pavelic 2013; Nag and Ghosh 2013; Nag and Saha 2014; Olutoyin 2014; Nag and Ray 2015). Furthermore, GIS is also being used for multi-criteria analysis for groundwater resource evaluation (Saraf et al. 2004; Rao and Jugran 2003). Multi-criteria analysis (MCA) process provides an optimum solution in which the uncertainties associated with evaluating criteria are ranked on the basis of overall performance of various input with respect to the multiple objectives (Aher et al. 2013). In MCA, each and every criterion is given a weightage to represent its genuine importance (Chow and Sadler 2010). The integration of GIS and MCA techniques provides efficient spatial analysis functions (Yu et al. 2009). In recent times, GIS-based MCA technique has gained importance because of its capacity to integrate a large quantity of data (Chen et al. 2010; Feizizadeh et al. 2012; Kumar and Jhariya 2015).

The present study aims to contribute towards systematic groundwater studies utilizing Remote Sensing, Field Studies, Digital Elevation Modeling (DEM) and GIS in developing effective guidelines for groundwater resource management in similar hydrological terrains. The specific objective of the study is to delineate groundwater potential zones. Since the area comprised crystalline basement, groundwater occurs mostly in shallow weathered residuum and in fractured bedrock. Owing to the failure of public/municipal water supply scheme, the people had to depend on the groundwater resources and consequently the water level is gradually declining. To arrest this gradual and continued declining of water level, indiscriminate use of groundwater by putting dug cum bore wells, it is of utmost importance to have a proper understanding of the hydrogeological situation as well as groundwater potentiality of the area. This methodology can also be applied effectively in the areas with similar

climate and geology such as southern India, which suffers from acute shortage of water leading to severe suffering of farmers.

Study area

The study area falls between latitude 23° 18' N–23° 30' N and longitude 86° 35' E–86° 52' E (Fig. 1). It is a part of Purulia district. It is about 280 km far from Kolkata. Physiographically, the entire region of the block belongs to upper catchment of Dwarakeswar, Damodar and Sali river basins. The study area is characterized by gently to moderately rolling plain with lateritic uplands, valley cuts and terraced banks. Regionally, the drainage pattern of the area is sub-parallel and/or dendritic.

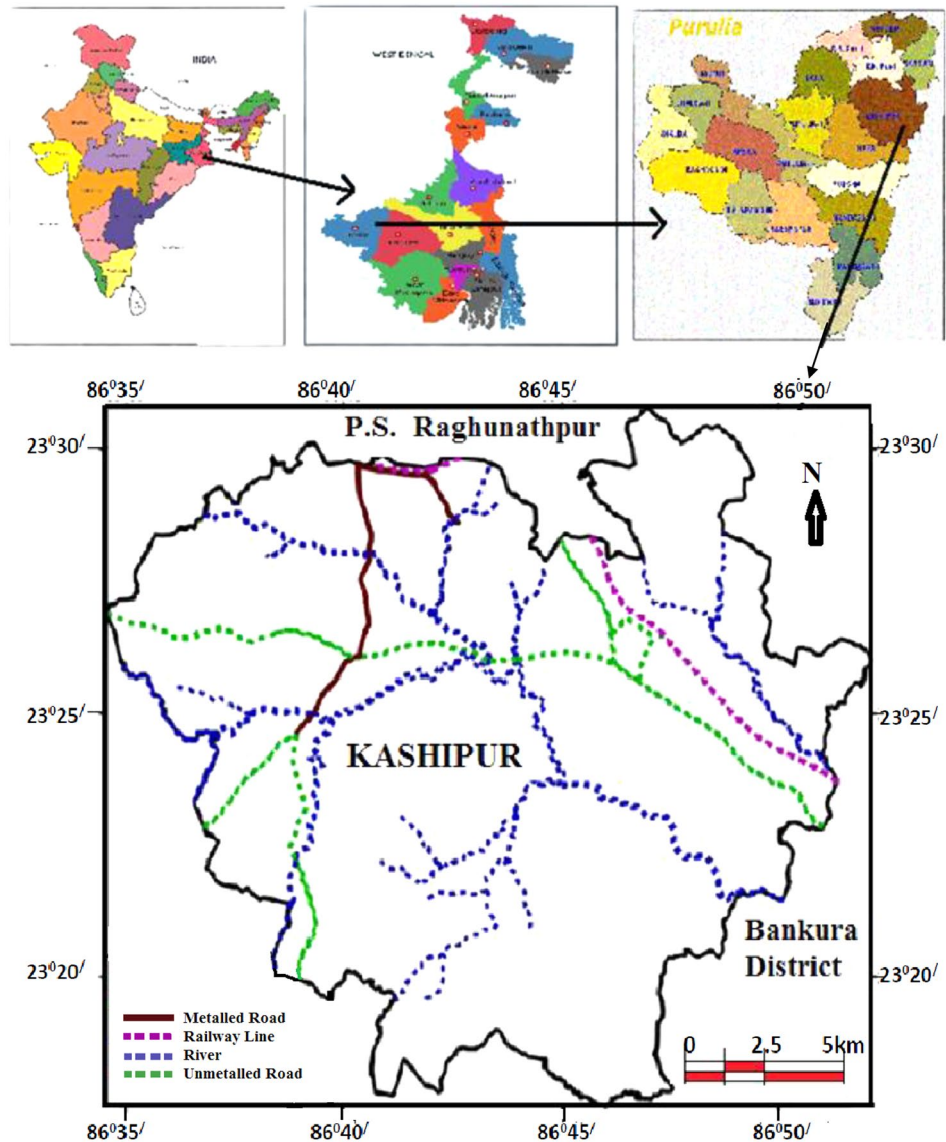
The study area generally consists of granite-gneiss, which is hard and foliated type rocks belonging to the Chotanagpur Gneissic Complex. Beside this, mica schist is also present as band-like formation and very small amount of amphibolite is also found in this area (Fig. 2). Granite-gneisses are hard and compact but having fracture zones which act as conduit for surface water percolation. Mica schists are intensely foliated, fractured and have good groundwater potentiality. Amphibolites are rather weathered, decomposed and can transmit water. The area receives annual rainfall to the tune of 1100 ~ 1500 mm, the bulk of rain coming in the months of June to September.

Data used and methodology

Various thematic maps such as geomorphology, slope and lineament density maps have been generated to determine the groundwater potential zones in the study area. The steps followed include:

- i. Preparation of district and village boundary maps.
- ii. Preparation of hydrogeomorphological map.
- iii. Preparation of Slope map.
- iv. Preparation of Lineament map.
- v. Preparation of Lineament density map.
- vi. Assignment of weights according to their respective importance in groundwater occurrence and,
- vii. Finally, the thematic layers are integrated using TNT mips pro2012 software to generate groundwater potential zone map of the study area. Accordingly, four different zones, namely 'very good', 'good', 'poor', and 'very poor' have been identified.
- viii. Initially from satellite images and toposheets, lineament map, hydrogeomorphological map, contour map and slope map were prepared. By visually interpreting the satellite imagery, the lineaments of the study area are picked up and traced on the basis of tonal, textural, soil, vegetation, topographic and drainage linearity,

Fig. 1 Map of the study area



curvilinear ties and rectilinear ties (Lilesand 1989; Drury 1990; Gupta 1991). In the study area, major lineaments are identified from the satellite data interpretation, which are surface manifestation of some structural features in the bedrock as fracture and joints developed due to tectonic stress and strain. Fracture and joints are usually visible in rock exposures though not all are always identified at every outcrop. Joints may develop in more than one set and with varying frequency in exposures.

- ix. The slope or gradient of a line describes its steepness, incline, or grade. A higher slope value indicates a steeper incline. The slope is defined as the ratio of the “rise” divided by the “run” between two points on a line, or in other words, the ratio of the altitude change to the horizontal distance between any two points on the line. The angle θ of a line makes with the positive

x axis is closely related to the slope m via the tangent function: $m = \tan \theta$.

- x. For preparing slope map of the area digital elevation model (DEM) Cartosat – 1 (30 m) resolution is used and developed by TNT mips spatial analysis tools.
- xi. All the maps were converted into raster format and georeferenced to common reference point in the Universal Transverse Mercator plane coordinate system. All the themes were integrated using “Spatial Analyst Module” of TNT mips pro 2012. Each theme and its individual class were assigned weight and rank (Table 1) based on the existing literature (Saraf and Choudhary 1998; Rao and Jugran 2003; Prasad et al. 2008; Jha et al. 2010; Machiwal et al. 2011; Mukherjee et al. 2012; Singh et al. 2013). Individual themes have been assigned weights (W_t) and based on the knowledge upon their significance to groundwater, dif-

Fig. 2 Geological map of the study area

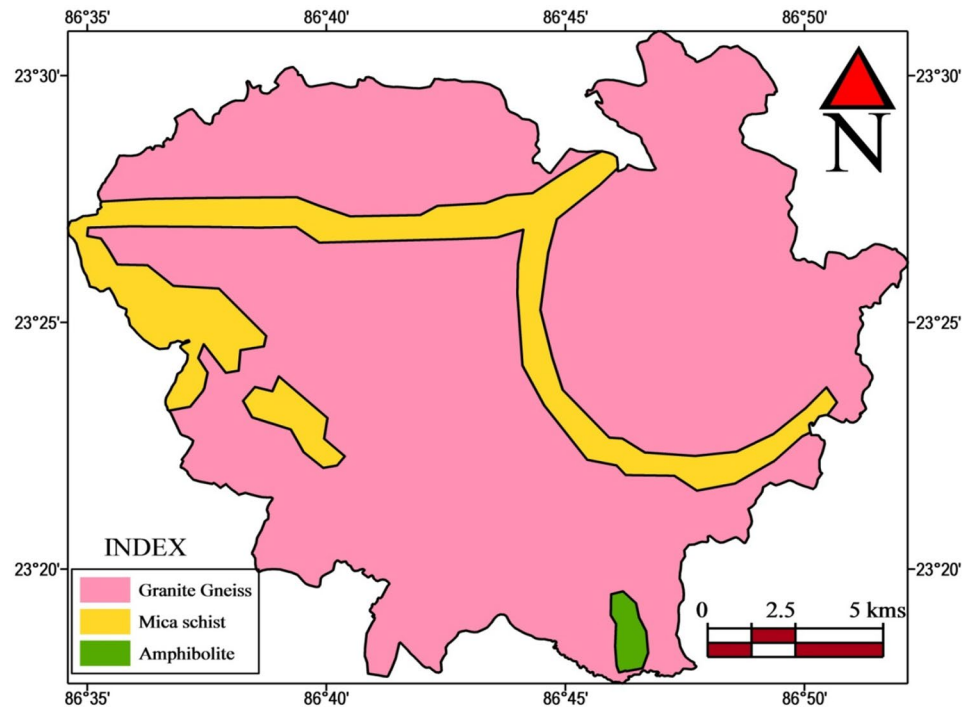


Table 1 Weightage of different parameters for groundwater prospect zonation

Sl. no.	Criteria	Weight (W_i)	Classes	Ground water prospects	Rank (R_i)
1	Hydrogeomorphology	40	Valley fills	Excellent	16
			Buried pediment moderate	Good	12
			Buried pediment shallow	Moderate	8
			Residual hills	Poor	4
2	Lineament density	30	0.5–0.65	Very good	8
			0.4–0.5	Good	7
			0.3–0.4	Moderate	6
			0.2–0.3	Poor	4
			0.1–0.2	Very poor	3
			0.0–0.1	Very poor	2
3	Slope	20	0°–5°	Very good	8
			5°–10°	Good	6
			10°–15°	Moderate	4
			15°–20°	Poor	1.5
			> 20°	Very poor	0.5
4	Geology	8	Mica schist	Good	4
			Amphibolite	Moderate to good	3
			Granite-gneiss	Moderate to poor	1
5	Drainage density	2	0.20 km/km ²	Good to moderate	2

ferent ranks were given (W_i) to each features within the theme. Then factor scores were derived for each feature by multiplying theme weight (W_t) with feature rank (W_i). In the same way, scores have been derived for all the themes. Subsequently, themes have been converted into raster format so that each pixel con-

tains factor scores with respect to their potentiality to groundwater. Finally, all these thematic layers have been integrated and the total factor scores for individual pixel have been calculated through raster addition process in Spatial Analyst Extension of TNT Mips.

Based upon derived scores, the final integrated map was prepared.

The resultant composite coverage was classified into four groundwater potential zones: (1) excellent, (2) good, (3) moderate and (4) poor. The output map was correlated and validated with the field groundwater data.

All these thematic maps are weighted and scored through GIS overlay to find suitable zonation for groundwater potential. Weighted Index Overlay Analysis (WIOA) method takes into consideration the relative importance of the parameters and the classes belonging to each parameter. Figure 3 shows the flow chart of the procedure for determining potential zone delineation for groundwater prospects. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis are defined and each parameter is assigned importance (Saraf and Choudhury 1997, 1998). Researchers, such as Sarma and Saraf 2002; Khan and Moharana 2002; Nag 2005; Rokade et al. 2007; Muthukrishnan and Manjunatha 2008; Prasad et al. 2008; Chowdhury et al. 2009; Dar et al. 2010; Rashid et al. 2011; Magesh et al. 2012, Pandian and Kumanon 2013 also have applied this GIS modeling technique for delineation of groundwater potential zones in their research study area.

All of the groundwater storing controlling feature layers, i.e., hydrogeomorphology, slope and lineaments were converted into raster format. Raster classification was performed for all the layers to demarcate six classes of lineament density (0–0.1, 0.1–0.2, 0.2–0.3, 0.3–0.4, 0.4–0.5, 0.5–0.65),

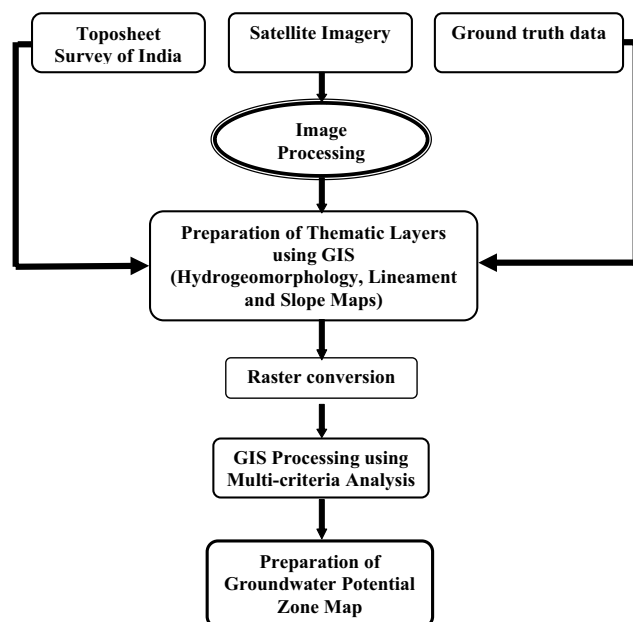


Fig. 3 Flow chart showing the steps followed in delineating groundwater potential zone map

four classes of hydrogeomorphology [buried pediment moderate (BPM), buried pediment shallow (BPS), residual hill (RH) and valley fills (VF)], five classes of slope (0° – 5° , 5° – 10° , 10° – 15° , 15° – 20° and $> 20^{\circ}$). The individual layers and also their classes are assigned by weightage and score ranging from 1 to 4. The higher value of weightage and score indicate the most favorable sites for groundwater potential. GIS modeling technique of index overlay method was then used to produce groundwater potential map. The average score is defined by Bonham-Carter 1994 as follows:

$$S = \frac{\sum S_{ij} W_i}{\sum W_i},$$

where S is the weight score of an area object (polygon, pixel), W_i is the weight for the i th input map and S_{ij} is the rating score of the j th class of the i th map.

Results and discussion

Different thematic maps describing favorable sites for groundwater potentiality have been prepared. These maps were then integrated with the help of GIS software TNTmips pro 2012, into a single map showing groundwater potential zones in the study area.

Hydrogeomorphology

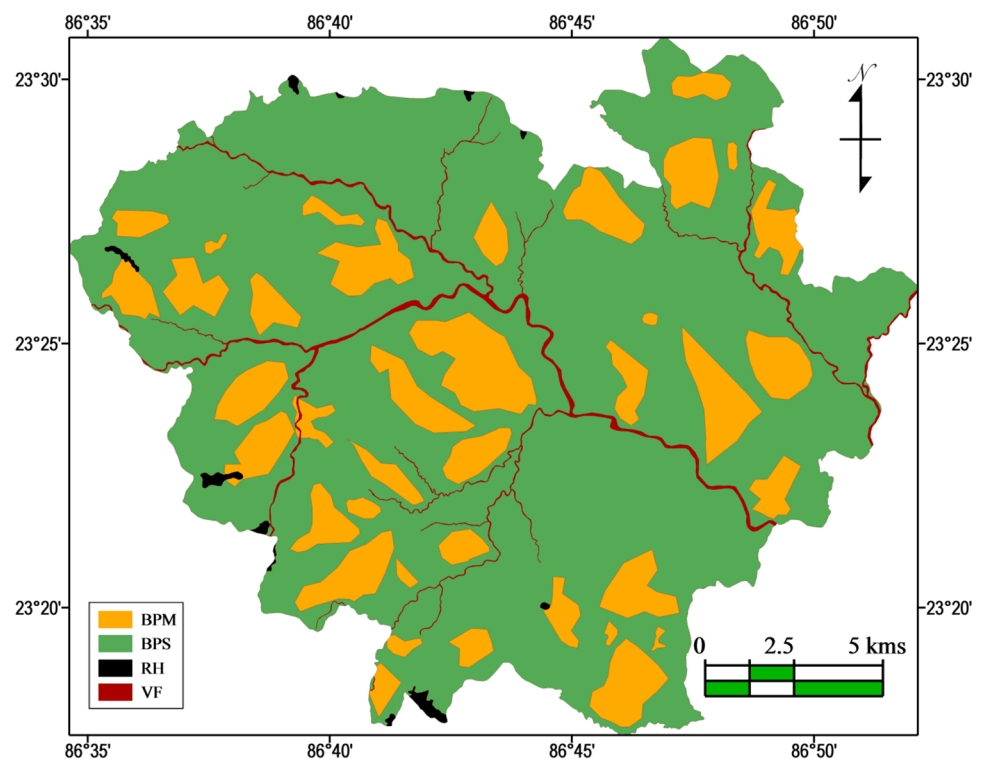
Hydrogeomorphological studies include identification and mapping of different landforms that have a direct control on the occurrence of groundwater. Based on the interpretation of the satellite image and SOI Toposheet, different hydrogeomorphological units have been delineated. The probability of occurrence of groundwater depending upon its morphological characteristics has been listed in Table 2 (Fig. 4). Geomorphology of an area is one of the most important features in evaluating the groundwater potential and prospect (Das et al. 1997; Kumar et al. 2008). Remote-sensing studies provide an opportunity for better observation and more systematic analysis of various hydrogeomorphic units/landforms/lineaments, features following the synoptic, multispectral repetitive coverage of the terrain (Horton 1945; Kumar and Srivastava 1991; Sharma and Jugran 1992; Chatterjee and Bhattacharya 1995; Tiwari and Rai 1996). The geomorphic evolution of the hard rock terrain is controlled by mainly tectonic–lithologic features and denudational processes.

Soil

Soil is the most important natural resources for agricultural activities as well as human habitation. Soil of the area is laterite mostly, originated from granite-gneiss. The soil

Table 2 Different hydrogeomorphic units, their characteristic features along with groundwater potentiality

Hydrogeomorphological units	Characteristics	Ground-water potentiality
Valley fills (VF)	Accumulation zone of colluvial materials derived from the surrounding uplands; shallow to deep; fine loamy to clayey soils	Excellent
Buried pediment moderate (BPM)	Gently sloping topography; moderately deep, clayey to fine loamy soils. Because of low relief shallow depressed area, infiltration is moderate to good	Good
Buried pediment shallow (BPS)	Nearly flat to gently sloping topography, shallow to moderately deep, loamy soils followed by regolith zone. Intermediate zone between pediments and deep pediments, infiltration is moderate	Moderate
Residual hills (RH)	Elevated portions of the hill but steeply sloping on all directions below plateau level. Mostly run-off, but along fractures/joints moderate to poor; dug wells along fractures/joints may be made	Poor

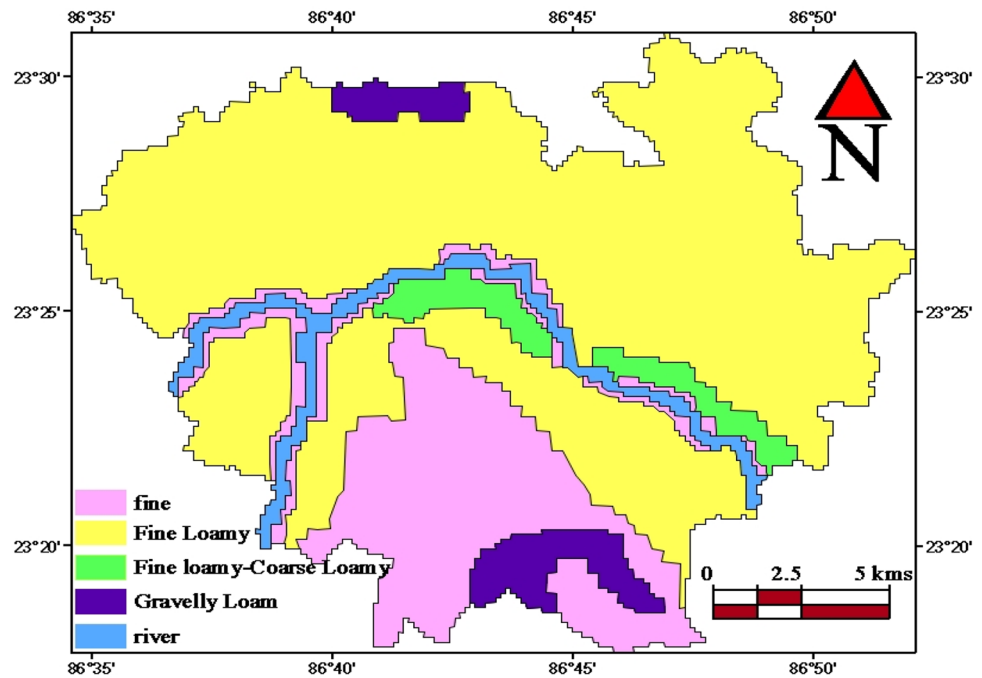
Fig. 4 Hydrogeomorphic units of the study area

of this region is mainly controlled by undulating topography, climate, vegetation and obviously the parent materials granite-gneiss. The area is covered by residual soil, which is formed due to disintegration and decomposition of the rocks by weathering process. Geologically, this soil is older but immature. Soil in the region is primarily lateritic with acidic in nature and low phosphorous content. Figure 5 represents that four types of soil are found in the study area, namely fine, fine loamy, fine loamy-coarse loamy and gravelly loam. In these types, fine loamy is the dominant type of soil in the study area.

Drainage density

Drainage network analysis is important for geo-hydrological studies. Drainage pattern reflects the characteristic of surface as well as subsurface formation. The study area is traversed by a number of rivers. The Dwarakeswar river is one of the largest river in the study area and flows from northwest to south east. Drainage density is defined as the closeness of spacing of stream channels. It is a measure of the total length of the stream segment of all orders per unit area. The drainage density is an inverse function of

Fig. 5 Soil map of study area



permeability. If a rock is less permeable, the lesser is the infiltration of rainfall, which conversely means high surface run-off. In the present study, since the drainage density can indirectly indicate the groundwater potential of an area due to its relation to surface run-off and permeability, it was considered as one of the indicators of groundwater occurrence. The drainage density of the study area has been calculated as 0.20 km/km^2 .

Slope

Slope plays an important role in groundwater infiltration as well as its prospects. A higher slope value indicates a steeper inclination. The slope is defined as the ratio of the altitude change to the horizontal distance between any two points on the line. Generally, flat and gently sloping areas promote infiltration and groundwater recharge, and steeply sloping grounds encourage run-off and little or no infiltration. Groundwater potentiality is expected to be greater in the flat and gently sloping area (Subba Rao 2006). Flatter topography then will give more chance for groundwater accumulation. Topographic data is a vital element in determining the water table elevations (Sener et al. 2005). The combination of fractures (lineament) with topographically low ground can also serve as the best aquifer horizon (Subba Rao 1992). The slope map (Fig. 6) of the study area has been prepared from digital elevation model (DEM) in TNTmips pro 2012. The slope of the area ranges 0° and $> 20^\circ$. Eventually, the study area has a gentle slope and favors low discharge of overland flow and high rate of infiltration.

Lineament and lineament density

Lineaments are topography of the underlying linear structural features. Lineaments play an important role in groundwater recharge in hard rock terrains; groundwater potential is high near lineament zones Srivastava and Bhattacharya (2006). In hard rock terrains, lineaments represent areas and zones of faulting and fracturing, resulting in increased secondary porosity and permeability and are good indicators of groundwater (Kumar et al. 2007). Well-developed fractures/lineaments intersecting with each other can hold appreciable quantity of groundwater. Lineaments provide pathways for groundwater movements and are hydrogeologically very important. The lineaments intersections are considered as good groundwater potential zones.

The lineament map of the basin shows that regionally there are bimodal-oriented structural trends striking NE–SW and NW–SE (Fig. 7). Lineaments have been identified throughout the area but from the groundwater occurrence point of view, the lineaments occurring in the pediplain or valley fills area are considered significant. Those across the high slope area, or in the area of less significance as there could be high run-off along them and these may act only as a conduit to transmit infiltrated rain water.

Lineament density is the total length of all the lineaments present in the basin/watershed divided by the area of basin/watershed. Lineament density map was prepared by dividing the study area into $1 \text{ km}/1 \text{ km}$ grids, and the lineament density values of each grid was then obtained from the values of the ratio of total length of the lineaments in a single grid (L) and the area of that single grid (A). By calculating the

Fig. 6 Slope map of the study area

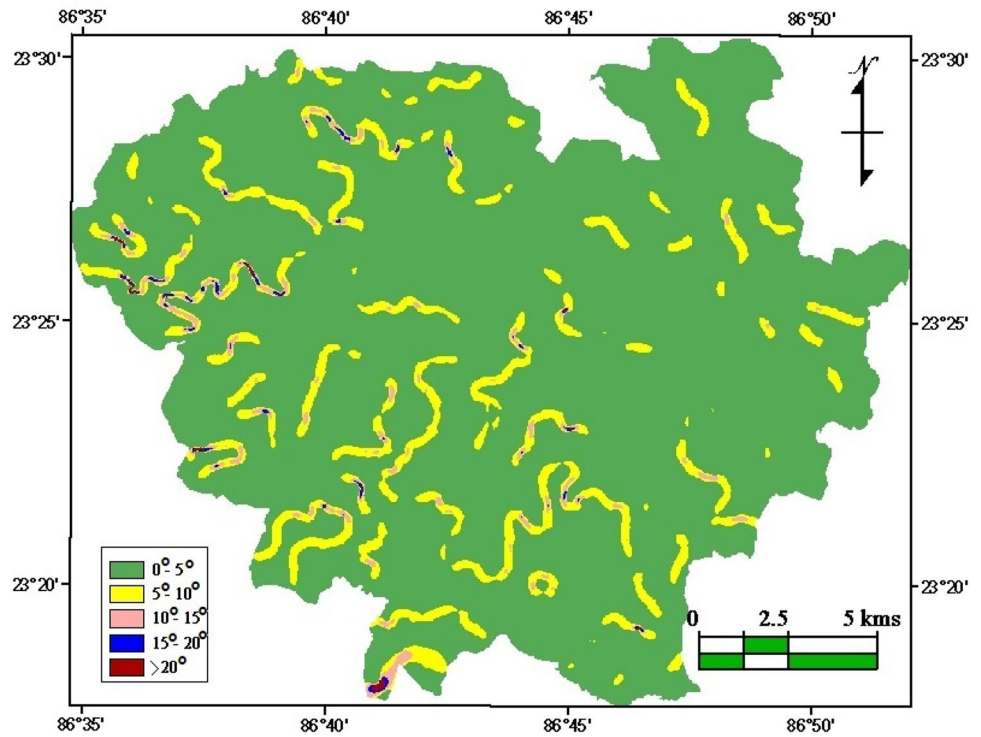
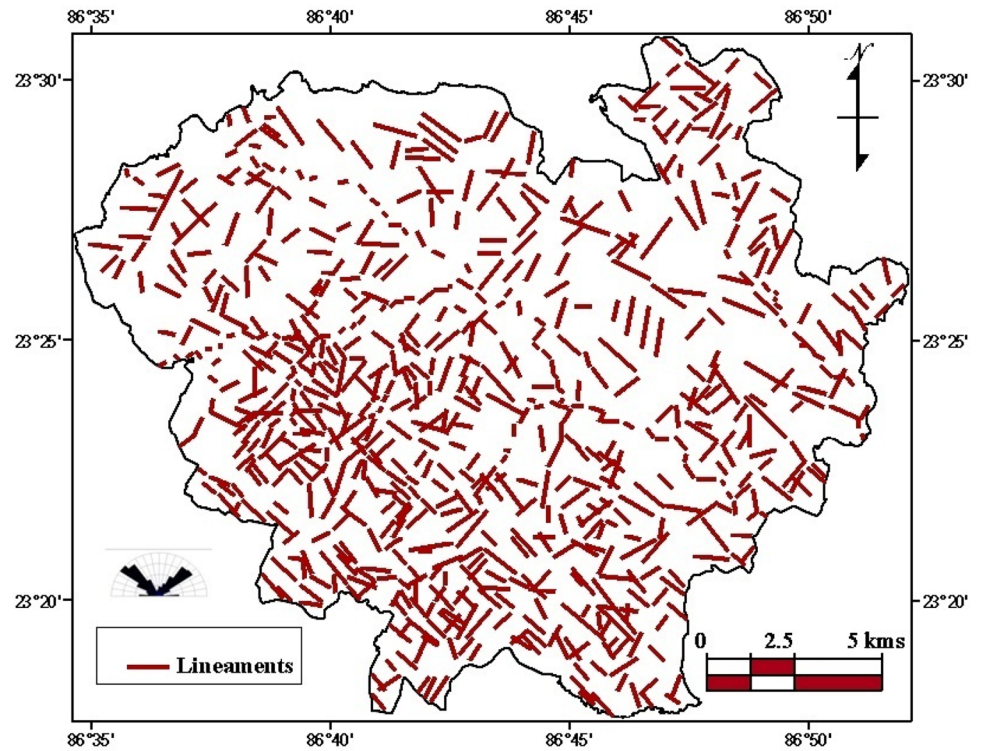


Fig. 7 Map showing lineaments of the study area

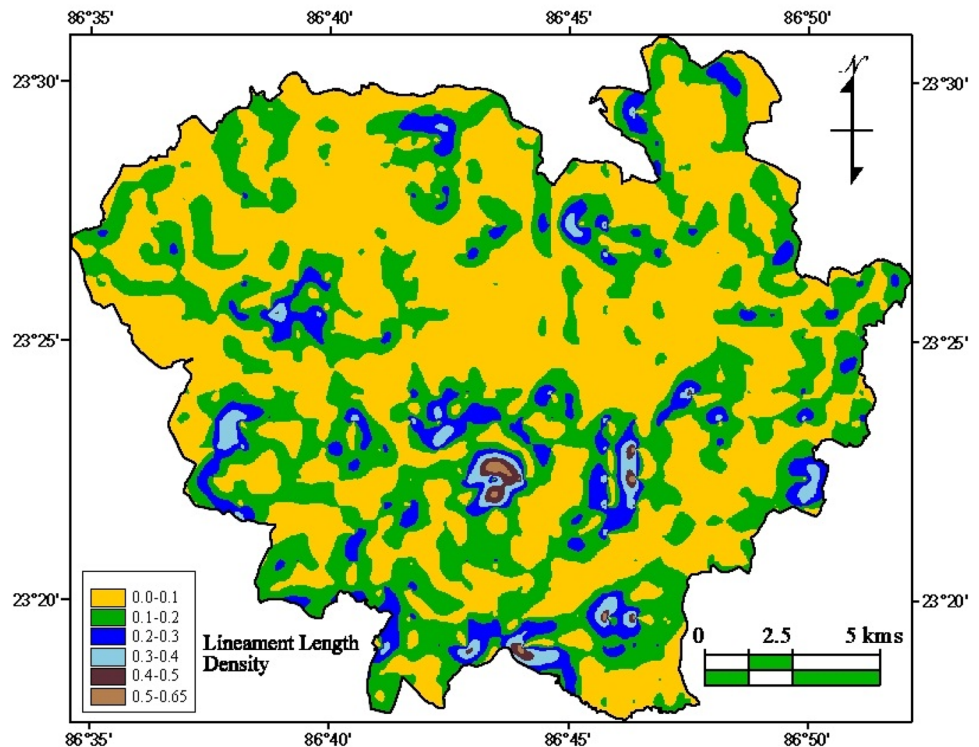


value of L/A for each grid, the value is plotted at the centre of each grid (Fig. 8).

Lineament delineated using satellite imageries, with azimuth sector size is 5° were converted into zones of

different lineament densities, viz. very high to high (1) weightage factor, high to moderate (2), moderate to low (3), and low to very low (4) using spatial density analysis in GIS domain.

Fig. 8 Lineament length density map of the study area



Groundwater potential zone delineation

A multiparametric approach (Skankar and Mohan 2006) has been considered for delineating groundwater potential zone (GWPZ). The parameters or factors used for GWPZ consist of three main influencing factors, such as hydrogeomorphology, slope and lineament. Each factor has been assigned a weighted according to its strength.

The output being largely dependent on the assignment of appropriate weightage, determination of weightage of each class is the most crucial in integrated analysis. A better representation of the actual ground situation (Choudhury 1999) is obtained by considering the relative importance of each factor. There is no standard scale for a simple-weighted overlay method (Saraf and Choudhury 1997, 1998; Nag and Ghosh 2013; Nag and Saha 2014). Researchers such as Sarma and Saraf (2002); Ganapuram et al. 2008 and Muthukrishnan and Manjunatha (2008) also have applied this GIS modeling technique for delineation of groundwater potential zones in their research study area. In the present study, groundwater prospective zones have been delineated considering the hydrogeomorphic condition of the area. Weighted index overlay (WIO) has been done (Table 1) considering only three parameters, namely geomorphology, soil, slope and lineaments (Fig. 9).

Groundwater table distribution

The depth of water level has an important effect on use of the land surface and on the development of water supplies from unconfined aquifers. Ground water level, as measured in borewell, reflects the amount of water in storage in the monitored aquifer. Comparisons of measured groundwater levels with long-term averages provide an indication of state of groundwater resources within an aquifer. During the field work, it was observed that a single aquifer is the source of groundwater in the study area and the aquifer is unconfined by nature as weathered layers of rocks present on the top soil layer. Apart from draft of ground water for various purposes, quantum of rainfall and its component being recharged to the ground water is major controlling factor of the depth to water levels and its annual, seasonal or decadal fluctuations. Thus, the study of rainfall pattern is very important for understanding spatial and temporal variations in water levels (CGWB 2007). In the study area, the groundwater level ranges from 1.97 to 7.55 m bgl in the post monsoon session, while in pre-monsoon session it falls and ranges from 2.85 to 14.31 m bgl. Figure 10 represents hydrograph depicting variation in water tables in meters for sampling locations in both sessions.

Fig. 9 Map showing groundwater potential zones of the study area

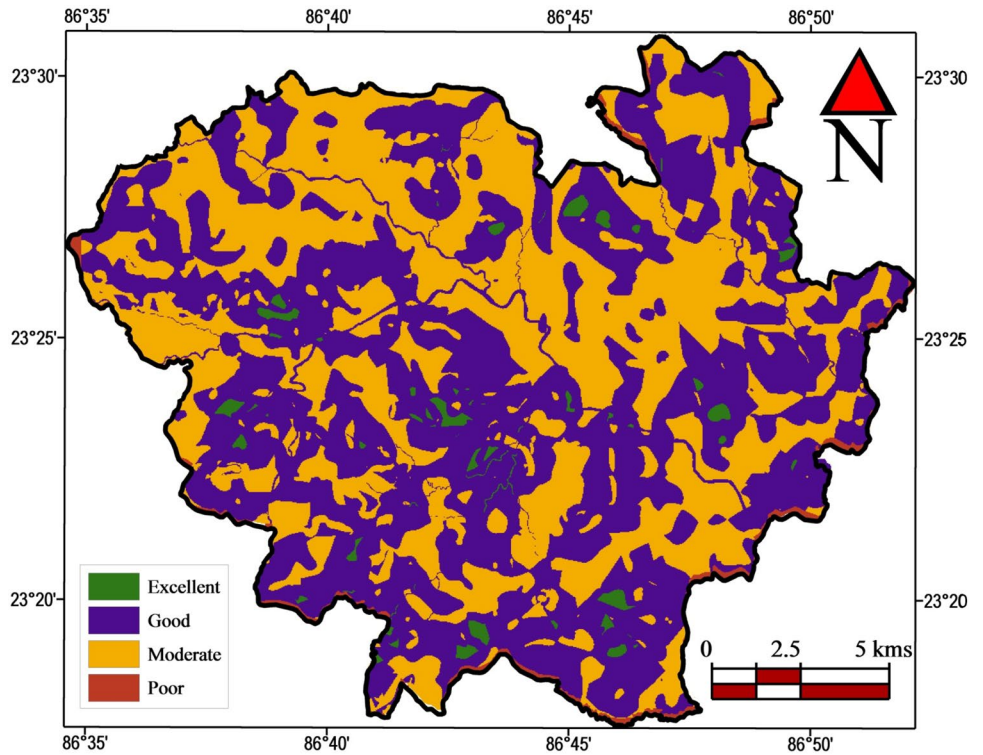
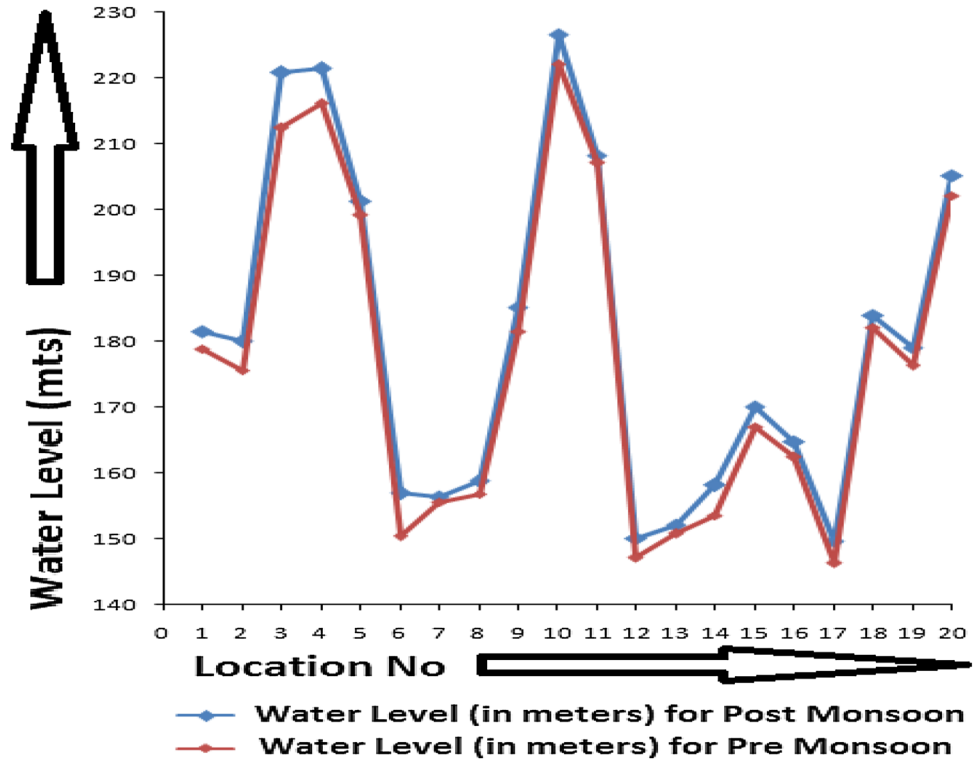


Fig. 10 Hydrograph representing variation in water tables (meters.) for both sampling sessions



Conclusions

Groundwater potential zones have been delineated in Kashipur block of Purulia district, West Bengal, using Remote Sensing and GIS approach which seems to be very constructive. All the thematic maps were converted into grid (raster format) and analyzed by weighted overlay method (rank and weightage wise thematic maps). From the results of the groundwater potential zone map, Kashipur block of Purulia district has been categorized into four different zones, namely very good (6.45 sq. km that covers only 1.5% of the total block area), good (227.9 sq. km that occupy majority of the block about 53%), poor (193.5 sq. km of the block that occupy about 45% of the total block), and very poor (2.15 sq. km area that is only 0.5%).

To validate the groundwater potential zones delineated through Remote Sensing, GIS and MCA Techniques, data on existing borewells collected from State Water Investigation Directorate (SWID) and Central Ground Water Board (CGWB) of the study area. The results revealed a good correlation with respect to derived groundwater potential zones. High yielding ($> 130 \text{ m}^3/\text{day}$) borewells are located in 'Excellent' and 'good' groundwater potential zones. Low yielding ($< 60 \text{ m}^3/\text{day}$) borewells are typically found in low groundwater potential zones.

The map thus prepared can serve as guidelines for planning future artificial recharge projects in the study area to ensure sustainable groundwater utilization. Concerned decision makers can formulate an efficient groundwater utilization plan for the study area so as to ensure long-term sustainability.

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