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Delineation of Groundwater Potential Zones in Hard Rock Terrain in Kashipur Block, Purulia District, West Bengal, using Geospatial Techniques

S. K. Nag* **and Anindita Kundu**

Department of Geological Sciences, Jadavpur University, Kolkata-700032, India

***Corresponding author:** Nag SK, Department of Geological Sciences, Jadavpur University, Kolkata-700032, India, Tel: (33)-2237-1574; E-mail: nag_sk@yahoo.com

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Abstract

The rapidly increasing need for water has put tremendous pressure on groundwater resources in areas where it is the prime source of water. The objective of this study is to delineate groundwater potential zone in Kashipur Block, Purulia district, West Bengal with dry climate and hard rock terrain. In the present study, groundwater potential zones for the assessment of groundwater availability in Kashipur Block of Purilia District, West Bengal, has been delineated using remote sensing and GIS techniques. Survey of India toposheets and IRS-1C—LISS III satellite imagery. They are used to prepare various thematic layers, e.g., hydrogeomorphology, slope and lineament density. The maps were then transformed to raster data using feature to raster converter tool of software like MicroImages TNT mips pro 2012. The raster maps of these factors are allocated to a fixed score and weight computed from multi-influencing factor technique. Each weighted layer is statistically computed to get the groundwater potential zones. Weighted Index Overlay modeling technique was used to develop a groundwater potential zone map with three weighted and scored parameters. Although the area is characterized by hard rock, it has groundwater prospective zones due to fracturing, weathering and the presence of valley fills overlying a planation surface. The area has been categorized into four distinct zones- excellent, good, moderate and poor. Excellent groundwater potential zones constitute 1.5% of the total block area, good groundwater potential zones occupy majority of the block, covering approximately 53%, and the moderate potential zones occupy about 45% of the total block, poor potential zones occupy very small portion 0.5%. The results reveal that the modelling assessment method proposed in this study is an effective tool for deciphering groundwater potential zones for proper planning and management of groundwater resources in diverse hydrogeological terrains.

Keywords: Hydrogeomorphology; Slope; Lineament density; Weighted index overlay analysis (WIOA); Multi criteria analysis (MCA); Groundwater potential zone

Introduction

Groundwater is the purest form of water source from natural resources and meets the overall demand of rural and semi-urban people. Groundwater is considered to be the largest single fresh water source in many parts of the world that provides a risk buffer to sustain critical water demands during prolonged dry cyclical periods [1]. Over the years the importance of groundwater is continuously growing based on an increasing need has led to the unscientific exploitation of groundwater creating a water stress condition. 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. An integrated remote sensing and GIS study can 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 [2] in any area.

The competition for water resources has gained importance in recent years, not only in India but also in many places of the world [3-5]. Groundwater is the purest form of water sourced from natural resources and meets the overall demand of rural and semi-urban people. In recent years, many cities of developing countries are experiencing rapid demographic growth due to rural exodus. Urbanization and the unregulated growth of the population have altered the local topography and drainage system directly which affect both quality and quantity of the groundwater [6,7].

Hard rock terrains develop complex hydrogeology over long period of geological time due to heterogeneous nature of the weathering. Groundwater in hard rock aquifers is essentially confined to fractured and weathered horizons. The occurrence and movement of groundwater in a watershed of a hard rock terrain are mainly controlled by secondary porosity caused by fracturing of the underlying rocks [8]. In India, about 65% of the country is underlain by hard rocks [9].

Earlier, the crystalline rocks or so called hard rocks received less attention from groundwater point of view due to their low permeability and also difficulties in drilling. But during the last few decades, owing to the needs for safe drinking water for vast population, these crystalline rocks are being investigated in detail for groundwater development. Fractures often serve as major conduits for groundwater movement. The rock types commonly encountered in the study area are granite or granite gneisses overlain by a variable thickness of weathered material. The weathered material is a regolith produced by the *in-situ* weathering of the basement rock.

Satellite images are being increasingly used in groundwater exploration because of their utility in identifying various ground features, which may serve either as direct or indirect indicators of groundwater potential. Geospatial technology has come out as a rapid and cost-effective tool in deciphering groundwater potential zone. Many workers such as [10-18] have used remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. Researchers like [19-22] have used satellite imagery in identifying geomorphic features and lineaments applying various techniques that are helpful in groundwater studies. Jaiswal [23] have used the GIS technique for generation of groundwater potential zones towards rural development. Krishnamurthy [24-26] have used GIS to delineate groundwater prospect zone. Srinivasa [27] have applied GIS for processing and interpretation of groundwater quality data. GIS has also been considered for multicriteria analysis in resource evaluation. Shahid [28], in recent years different researchers have used different criteria for delineating groundwater potential zones. Srivastava [8,29,30] have integrated geophysical data with geospatial data. Nag [31], have used lineament, hydrogeomorphology and slope based approach in delineating groundwater potential zones.

Integration of remote-sensing data brings out areas that have favorable rock types, such as coarse grain gneiss, lineament intersection, lineament density and favorable geomorphic units such as valley fills, buried pediments etc. Field data integration brings out the favorable areas on the basis of seasonal water level, its fluctuation, thickness of weathered zone (buried pediments), etc. On overall analysis it emerges that the areas where two or more sets of lineaments intersect, covered with valley fills, are potential areas for groundwater prospecting.

The present study provides effective guidelines for groundwater resource management in complex hydrological terrains. This methodology can also be applied effectively in the areas with similar climate and geology like southern India, which suffers from acute shortage of water leading to severe suffering of farmers. Keeping this scenario into consideration, the present study to delineate groundwater potential zones was carried out to have proper management for sustainable use of groundwater in such a complex hydrological terrain.

Study Area

The study area, Kashipur block, is a part of Puruliya district. It is situated in the northern part of this district. The district is mainly a hard rock terrain comprising of cryatalline basement occurring at very shallow depth. 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 falls between latitude 23˚18′ N - 23˚30′ N and longitude 86˚35′ E - 86˚52′ E (Figure 1). It is about 280 km far from Kolkata.

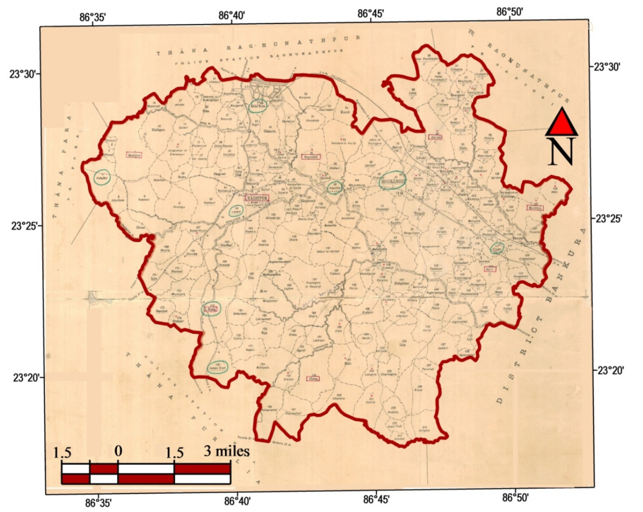

Figure 1: Map of the study area.

Data Used and Methodology

In the present paper, the database used for the study purpose includes:

(i) Contour data of Survey of India Topographical maps No. 73 I/11 and 73 I/15

(ii) Geological map of the study area.

(iii) Satellite Imagery of Indian Remote Sensing (IRS 1C LISS III, path and row 106-55 respectively on 1:50,000 scale) data to identify different hydrogeomorphological units, mapping of lineaments; these data were collected and registered to Survey of India topographical maps at 1:50,000 scale. These satellite images have been georeferenced and merged using TNT mips pro 2012 version Image Processing Software and contour maps have been prepared using SURFER 7.0 version.

(iv) 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, curvilinear ties and rectilinear ties [32,33]. 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.

To determine the lineament density in the study area, the total study area is subdivided into a number of grids of dimension 1 × 1 km. Density of the lineaments of a single grid is 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 value of L/A for each grid, the value is plotted at the centre of each grid. Lineament density contour map is prepared by joining the fields of equal density values. 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 θ.

(v) Digital elevation modelling.

(vi) 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 existing literature. 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.

No.	Criteria	Score	Classes	Weightage
1	Hydrogeomorphology	5	Valley fills	4
			Burried Pediments Moderate	3
			Burried Pediment Shallow	2
			Residual Hills	1
2	Lineament Density	3	< 0.1	1
			– 0.2	2
			– 0.3	3
			>0.3	4
3	Slope	2	0 - 50	4
			5 - 100	3
			10 - 200	2
			>200	1

Table 1: Weightage of different parameters for groundwater prospect zonation.

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 2 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 [9,14,31]. Researchers like [34-40], also have applied this GIS modelling technique for delineation of groundwater potential zones in their research study area.

All of the groundwater storing controlling features layers, i.e., hydrogeomorphology, slope and lineaments, were converted into raster format. Raster classification was performed for all the layers to demarcate four classes of lineament density (0–0.1, 0.1–0.2, 0.2–0.3, 0.3–0.66), four classes of hydrogeomorphology [buried pediment moderate (BPM), buried pediment shallow (BPS), residual hill (RH) and valley fills (VF)], four classes of slope (0–5, 5–10, 10–20, and >20). 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 favourable 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:

$$S = \frac{\sum SS_{i\,j} W_i}{\sum W_i}$$

where S is the weight score of an area object (polygon, pixel), Wi is the weight for the ith input map and Si j is the rating score of the j th class of the i th map.

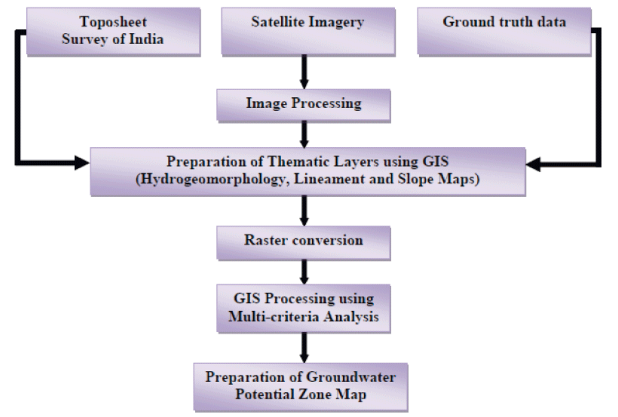

Figure 2: Flow chart showing the steps followed in groundwater potential zone delineation.

Results and Discussions

Delineation of groundwater resources are being increasingly implemented in the recent years because of increased demand for water. The indicators of groundwater occurrence are related to rainfall distribution, land use, geology, topographic elevation, slope and drainage features of the area. Satellite data have come out to be very useful for surface study, especially in detecting surface features and characteristics such as lineaments and geology. In order to predict the groundwater potential zones, different thematic maps were prepared. These include hydrogeomorphology, slope and lineament density. Integrated assessment of thematic maps using weighted index overlay method, developed based on GIS techniques has been found to be suitable for delineating groundwater potential zones.

Hydrogeomorphology

Hydrogemorphology of an area constitute the most important parameter in evaluating groundwater potential and prospect zonation [41,42]. The integrated uses of satellite image coupled with field survey have been used to distinguish various hydrogeomorphic units in the study area. The hydrogeomorphology in the hard rock terrain is highly influenced by the lithology and structures of the underlying formations. The area is characterized by a dominant rocky terrain and a number of erosional and depositional hydrogeomorphic features, which are 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 following the synoptic, multispectral repetitive coverage of the terrain [10,43-46]. The geomorphic evolution of the hard rock terrain is controlled by mainly tectonic–lithologic features and denudational processes. A number of hydrogeomorphic units have been identified in this terrain using IRS 1C LISS III image (Figure 3).

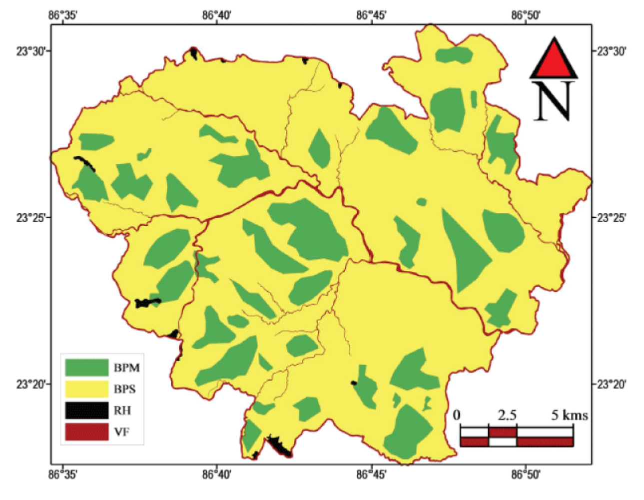

Figure 3: Hydrogeomorphological map of the study area.

Residual hills: These are broad uplands of considerable elevation, steeply sloping on all directions. Very shallow, coarse loamy soil on moderately steep to very steep hill slopes and escarpments having different degrees of hardness are characteristic features, open to dense forest and plantation, not suitable for agriculture/pasture/orchards. From the groundwater point of view, the structural hills serve as high run-off zones. The recharge is poor and restricted mainly along the joints, fractures, and faults. Therefore, groundwater occurrence is limited only along the joints, fractures and fault planes. Residual hills occupy an area of 2.1 km2 along the borders of the study area.

Valley fills: Valley fills are generally unconsolidated alluvial materials consisting of sand, silt, gravels and pebbles deposited along the floor of a stream valley. Valley fills with an area of 61.7 km2 are found in central parts along the stream network of the study area. The area is mainly covered by coarse sediments with good vegetation cover, and groundwater potential of this unit is described as very good.

Buried pediment moderate (BPM): These units are moderately weathered with their thickness greater than that of the shallow pediments. A flat and smooth surface of buried pediment consists of moderately thick overburden of weathered derivative material. In the study area, buried pediments (moderate) [covering a total area of 92.1 km2] Groundwater prospects are also good to moderate.

Buried pediment shallow (BPS): These are the areas of nearly flat to gently sloping terrain with low gradient. These are covered with shallow weathering material ranging from 0 to 5 m. The top soil is generally red soil. Most of the study area is occupied by this unit (covering an area of 291.1 km^2). Groundwater prospects are moderate to poor, but open wells yield a good amount of potable water after monsoon.

Slope: 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. 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 [47,48]. Flatter topography then will give more chance for groundwater (Figure 4) accumulation [47].

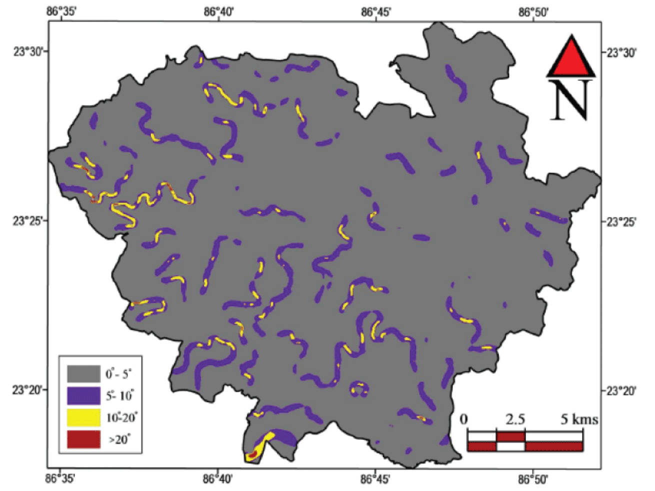

Figure 4: Slope map of the study area.

Lineament study

Lineaments are natural, linear surface elements, interpreted directly from satellite imagery. Lineament analysis using satellite imagery has an advantage in that a regional area can be investigated synoptically with high accuracy. Lineaments usually appear as straight lines or "edges" on the images, which in all cases are contributed by the tonal difference within the surface material. Lineaments are evaluated to extract further information on the distribution and nature of the lineaments. In the hard rock areas, the movement and occurrence of groundwater depends mainly on the secondary porosity and permeability resulting from folding, faulting, fracturing, etc. The most obvious structural features that are important from the groundwater point of view are the lineaments.

The lineament map of the basin shows that regionally there are bimodal oriented structural trends striking NE–SW and NW–SE (Figure 5). Although lineaments have been identified throughout the area, it is the lineaments in the pediplain or valley fill which are considered significant from the groundwater occurrence point of view. Those across the high slope area, or in the area of less significance as there could be high runoff along them and these may act only as a conduit to transmit infiltrated rain water.

Lineament delineated using satellite imageries, with azimuth sector size is 5 degrees were converted into zones of different lineament density, 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.

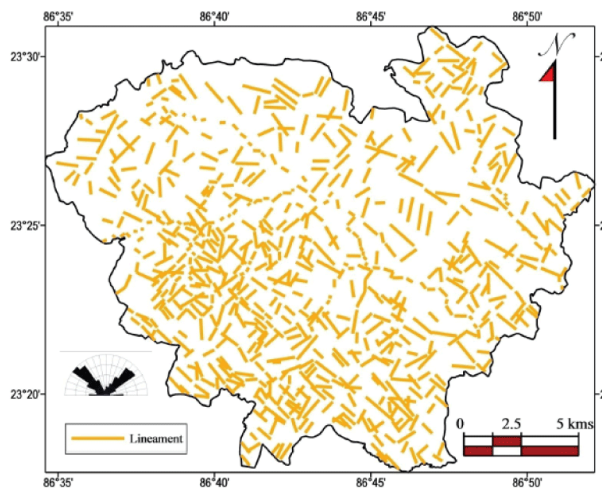

Figure 5: Lineament map of the study area.

Lineament density

To determine the lineament density in the study area, the total study area is subdivided into a number of grids of dimension 1 km x 1 km. Density of the lineaments of a single grid is 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 value of L/A for each grid, the value is plotted at the center of each grid. Lineament density contour map (Figure 6) is prepared by joining the fields of equal density values. Lineaments provide important clues on subsurface structures that may control the movement and storage of groundwater. Good to moderate prospects are expected depending on nature and intensity of lineaments and lineament intersection density. The peaks in the lineament density contour maps are the places of interest for groundwater resource development.

Groundwater potential zone delineation

The delineation of groundwater potential zone (GWPZ) consists in identifying areas favourable for the occurrence of groundwater, based on a multiparametric approach [49]. The parameters or factors used for GWPZ are composed of some influencing factors. Three main influencing factors, such as slope, lineament, and hydrogeomorphology have been identified to delineate the groundwater potential zones. Each factor is weighted according to its strength. The representative weight of a factor of the potential zone is the sum of all weights from each factor. A factor with a higher weight value shows a larger impact and a factor with a lower weight value shows a smaller impact on groundwater potential zones. Integration of these factors with their potential weights is computed through weighted overlay analysis in TNT mips pro 2012.

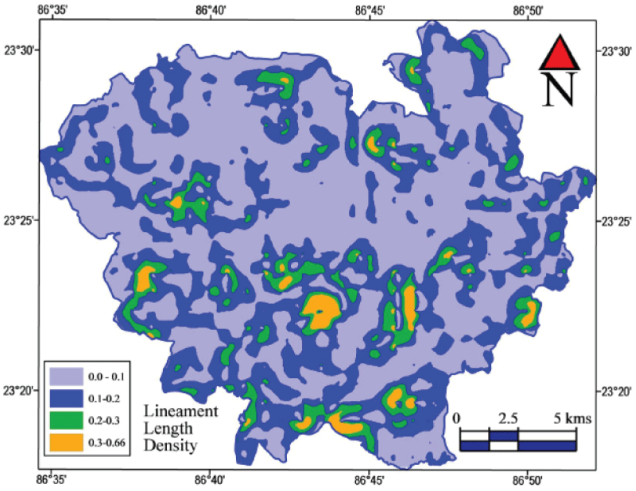

Figure 6: Lineament density map of the study area.

Determination of weightage of each class is the most crucial in integrated analysis, as the output is largely dependent on the assignment of appropriate weightage. Consideration of relative importance leads to a better representation of the actual ground situation [50]. 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 [9,14,17,18]. Researchers such as [35,39,51] also have applied this GIS modeling technique for delineation of groundwater potential zones in their research study area. Considering the hydrogeomorphic condition of the area, weighted indexing has been adopted (Table 1) to delineate groundwater prospective zones considering three parameters namely geomorphology, slope and lineaments (Figure 7).

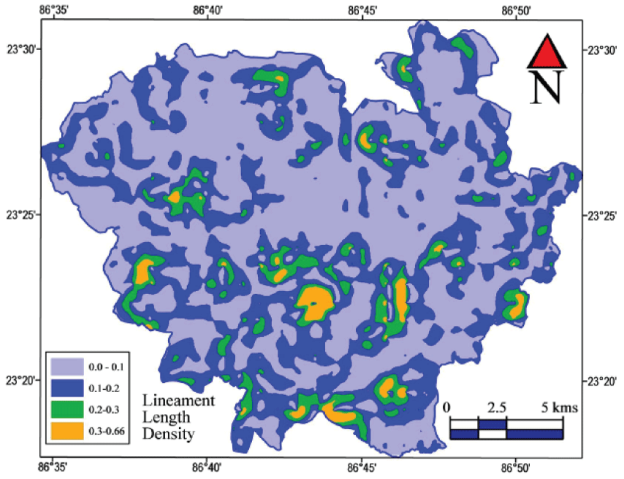

Figure 7: Groundwater potential zone map of the study area.

Conclusions

Delineating the groundwater potential zones in Kashipur block of Purulia district, West Bengal using remote sensing, GIS and MCA techniques is found efficient to minimize the time, labor and money and thereby enables quick decision-making for sustainable water resources management. Satellite imagery, topographic maps and other conventional data were used to prepare the thematic layers of hydrogeomorphology, lineament density and slope. The various thematic layers are assigned proper weightage through MCA technique and then integrated in the GIS environment to prepare the groundwater potential zone map of the study area. According to the groundwater potential zone map, Kashipur block of Purulia district has been categorized into four different zones, namely 'very good', 'good', 'poor', and 'very poor'. The results of the present study can serve as guidelines for planning future artificial recharge projects in the study area in order to ensure sustainable groundwater utilization. This is an empirical method for the exploration of groundwater potential zones using remote sensing and GIS, and it succeeds in proposing [52-55] potential sites for groundwater zones. This method can be widely applied to a vast area with hard rock terrain for the exploration of sites suitable for groundwater exploration.

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