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Study of Groundwater Prospect Zones in Metamorphic Rocks in Purulia District, West Bengal- An Approach From Remote Sensing and Geographical Information System

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Abstract — Groundwater being a valuable resource in today's world needs proper evaluation and management for overall development within a region for its judicious use. Delineation of groundwater potential zones in crystalline rocks is a challenge in the present day research. The Balarampur and Barabazar blocks of Purulia district, West Bengal is within the hard rock terrain of Chhotanagpur Gneissic Complex and Singhbhum Group of rocks. Groundwater in this region is confined within the fracture zones and weathered residuum. Analysis has been carried out for locating groundwater potential zones in the study area. This study introduces the procedure of identifying linear features and their interpretation with respect to different hydrogeologic phenomena. The lineament map has been prepared from visual interpretation of the satellite imagery and then digitized for the present study. From this the lineament density contour map and lineament intersection density contour map have been prepared. An integrated remote sensing and Geographic Information System (GIS) based methodology has been used for delineating groundwater prospect zones in the study area. Here the lineament density map, lineament length density map, lineament intersection density map, lithology map are overlaid following the Weighted Index Overlay Method, which delineates groundwater potential zones. Each theme was assigned a weightage depending on its significance to groundwater occurrence. All the themes are overlaid and integrated with the help of Geographical Information System (GIS). The resultant composite coverage is a map classified into five groundwater prospect categories.

Keyword — Geographical Information System (GIS), Groundwater, Lineament, Weightage

1. INTRODUCTION

Groundwater is a valuable resource in present day but of limited extent, particularly in metamorphic rocks. Exploration of groundwater potential zones is a major problem in metamorphic crystalline terrain. No permanent solution has been found so far. Water supply problems in metamorphic crystalline rocks have resulted for three reasons – (i) secondary porosity of the rocks, (ii) underlying heterogeneous characteristics and iii) problem of identification of suitable fractures. Only through geophysical methods which consumes more time, alone it is not an easy task to delineate ground water potential zones of a large area. With the advent of remote sensing techniques, identification of the locales for occurrence of groundwater has become a rapid and cost effective natural resource survey (Nag 2005, Ravindran 1997, Tiwari and Rai 1996, Chatterjee and Bhattacharya 1995, Sharma and Jugran 1992, Horton 1945). The remote sensing data helps in fairly accurate lithological analysis and identification and delineation of locales (Kumar and Srivastava 1991). On the other hand Geographical Information Systems (GIS) has added new vistas in the field of groundwater resources mapping and management. It helps in integrating remotely sensed derived data with ancillary data to have more precise and correct information about various factors involved in the ground water resources management. Studies are being targeted in this direction by many authors (Prakash 1993, Roy & Ray 1993, Chaudhary et al 1996 and Ravindran & Jeyram 1997). Groundwater occurrence being subsurface phenomenon, its identification and location is based on indirect analysis of some directly observed terrain features like geological features and their hydrologic characters.

Linear features on the surface of the earth have attracted the attention of geologists for over one hundred years and the interest in this study has grown most rapidly since the introduction of aerial photographs and satellite imageries into geological studies. Lineaments are natural, linear surface elements, interpreted directly from satellite imagery and have been called linears, fracture traces, and many other names (Garza and Slade 1986). Geologists have showed that lineaments perceived in remotely sensed images are reliable indicators of geologic structures (Caran et al. 1982). Sometimes lineament mapping, regardless of geologic environment, is believed to be the panacea for successful groundwater exploration. Hydrogeologists made use of lineaments to locate high-yielding wells describing these structures as subsurface expression for governing recharge, migration, and discharge of groundwater (Brown 1994).

Balarampur is known as drought prone area and falls within the semi – arid region of the state of West Bengal. This region has a sub tropical climate, the temperature varying over a wide range during the year 7ºC to 46ºC in summer in average. The area experiences a marked seasonal variation with pronounce variability of rainfall and occurrence of drought condition due to its interior location i.e. approximately 300 km away from the sea. Hence an integrated approach, including studies of lithology, hydrogeomorphology and lineament, has been taken up, using remote sensing and GIS techniques, for a proper assessment of groundwater potential zones in Balarampur Block, Purulia District West Bengal.

2. General Geology Of The Area

The study area comprises a part of the eastern Chhotonagpur plateau in the Eastern India Shield. This area of Precambrian hard rock terrain bears the evidence of polyphase deformation resulting generations of structural elements (both planer and linear) on different tectonic phases.

The study area is located at the junction of Chhotanagpur Granite Gneissic Complex (CGGC) and the Singhbhum Group of rocks (SG), exposing metamorphic rocks of Proterozoic age (Gupta and Basu 2000) (Figure. 1).

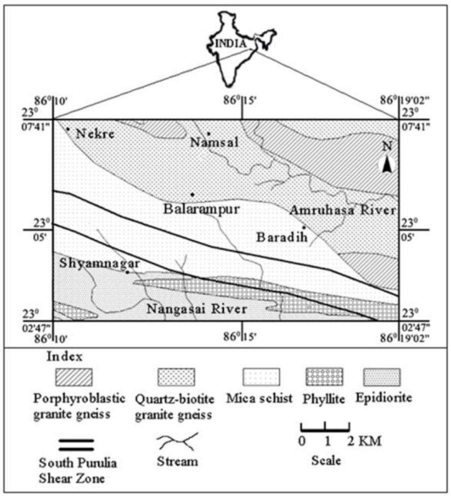

Fig 1.Geological map of the study area in Purulia district, West Bengal, India.

At the north the CGGC is a part of the Chhotanagpur craton consisting varieties of granite gneisses, such as quartz-biotite granite gneiss and porphyroblastic granite gneiss. The SG rocks, exposing at the south belongs to Singhbhum orogenic belt and comprises chiefly mica schist and phyllite. NW-SE foliations are well developed both in the CGGC and in the metasedimentaries of Singhbhum Group (Geological quadrangle map 73 I, 1948). The foliations in the area statistically dip high (> 57°) towards north. The metasediments of SG are interlayered with basic bodies, locally described as epidiorite sills, which may have a strong genetic connection with the Dalma Volcanics (Geological quadrangle map 73I, 1948).

The basement for the older metasedimentes is not recognized but petromineralogy of the Sediments indicates an older granitic provenance. A sequence of dominantly shale and impure limestone, with some intercalated sandstone bodies existed prior to folding and metamorphism (Baidya, 1992). The calcmagnesian sediments are now transformed into calc-silicate rocks. Metasomatic effect of the Granites on these calc-silicate rocks caused some skarn rocks which are principally composed of quartz, diopside, microcline and calcite with accessories like epidote, sphene and plagioclase. The older basic rocks comprising amphibolites mainly and some hornblende schist occur as elongated patches, lenses and bands concordant with the metasediments and are co-folded with them. Granitic rocks vary considerably in composition, structure and texture. The composite gneiss representing the oldest unit among the granitoids, comprises mainly of some migmatites and biotite-granite gneisses. The composite gneiss shows continuity of all structural elements found in the adjacent metasedimentary rocks and amphibolites. The porphyroblastic biotite-granitoid is relatively coarse grained and crudely foliated having more or less sharp contact with the metasediments and composite gneiss. Complex folds within the metasediments and composite gneiss are absent in the porphyroblastic biotite granitoid. Pegmatites, aplite and hydrothermal quartz bodies occur as nearly east – west trending lenses and veins closely associated with granitoids.

From the study of satellite imageries and photographs, the area displays a prominent east – west lineaments which are intercepted by a system of north-south lineament and occasionally by NW – SE lineaments. Some elongated patches of metabasics like amphibolites are entrapped within the phyllite zone.

3. Structure of the Area

The southern Purulia shear zone occurs in the study area. The South Purulia Shear Zone trends almost E-W and passing through just to the south of Balarampur. This shear zone contains important phosphate mineralisation including apatite. The area under study comprises the so-called "southern Purulia shear zone" (Baidya, 1992). Filed checking of the satellite imagery revealed the presence of a prominent E-W trending or nearly so pervasive zone of structural weakness which is characterized by the development of very prominent schistisity or cleavage or mylonitic foliation. The abrupt orthogonal turns of different E-W flowing streams like Nangasai, Kumari, Amruhasa etc. is mainly the effect of

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N-S younger fracture system transgressing the schistosity. Photogeological study also reveals that water bodies like ponds and tanks are much more frequent in the region of metasediments than in the granitic terrains. Evidences of shear forces acting along some E-W trending nearly vertical weak planes during the third tectonic period are practically very scanty in region of southern Purulia shear zone. In this area such structural elements are mainly represented by some shear-joints and fractures in the granitic rocks, pegmatites and quartz veins. These shear joints, fractures and faults strike E-W, in general, with 60° to nearly vertical dips.

4. DATA USED

False color composite of IRS-P6 (LISS III) was used for lineament study, the toposheets no 73 I/4, 73 I/8 on 1:50,000 scales are used in the preparation of base maps onto which the interpretation details are transferred.

5. METHODOLOGY

Locating groundwater potential zone in the study area involves the preparation of lithological and lineament thematic maps. Visual interpretation of imageries exhibits several tonal types along with characteristics draining pattern indicating different litho-units. Visual interpretation of IRS-P6 LISS III imageries have been carried out to extract the lineaments from the imageries. Ground verification of the lineament map results the preparation of 'geologic lineaments' after exclusion of the non-geologic or man-made lineaments. Lineaments map has been prepared by detecting and tracing lineaments from satellite imageries on the basis of tonal, textural, soil tonal, vegetation, topographic and drainage linearities (Lillesand 1989, Drury 1990, Gupta 1991). The non-structural and "false" lineaments have been isolated and eliminated after comparing lineaments map with the corresponding toposheets (73 I/4, 73 I/8). The figure 2, shows the lineament map of the study area.

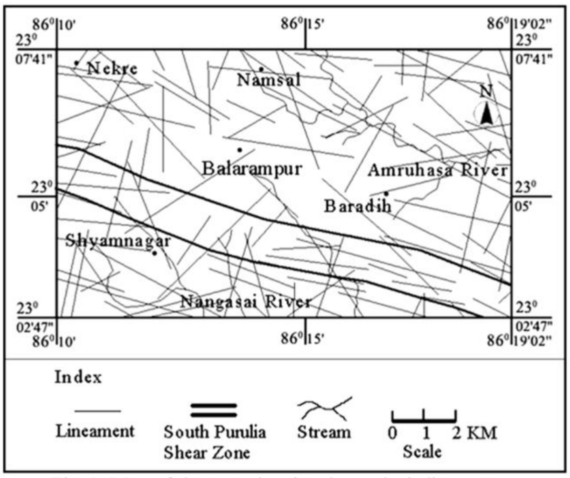

Fig. 2. Map of the area showing the geologic lineaments.

To determine the lineament density, lineament length density and lineament intersection density in the study area the total study area is subdivided in 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 total number of the lineaments in a single grid (ΣN) and the area of that single grid (A); density of the length of the lineaments of a single grid is obtained from the values of the total length of the lineaments in a single grid (ΣL) and the area of that single grid (A) and density of the lineament intersection of a single grid is obtained from the values of total lineament intersection points (ΣP) and the area of the single grid (A). Calculation of the density of the lineaments, lineament-length and intersecting-lineaments in the area involves the ratio of ΣN to A, ΣL to A and ΣP to A respectively. By calculating the value of $\Sigma N/A$, $\Sigma L/A$ and $\Sigma P/A$ for each grid and locating the value at the centre of that grid the density of the lineaments, lineament length and the intersecting-lineaments of the study area is calculated. The maps of lineament density (see figure 3), lineament length density (see figure 4) and intersecting–lineament density (see figure 5) are prepared with the help of the software Surfer.

Figure 3. Lineament density contour map

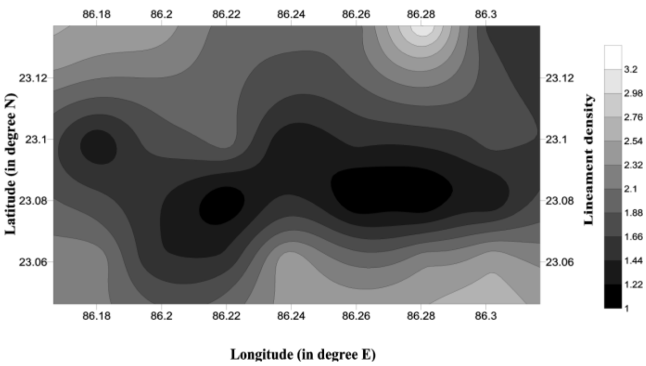

Figure 4. Lineament length density contour map

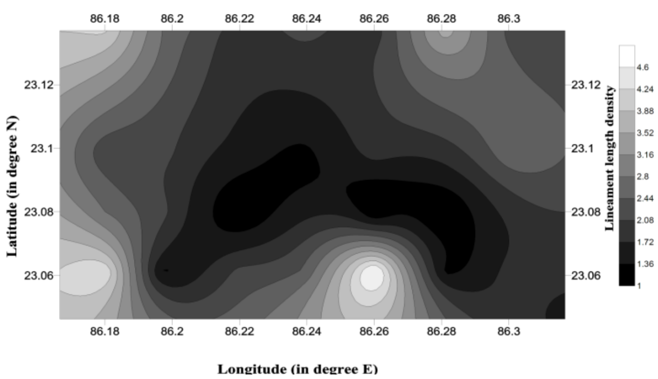

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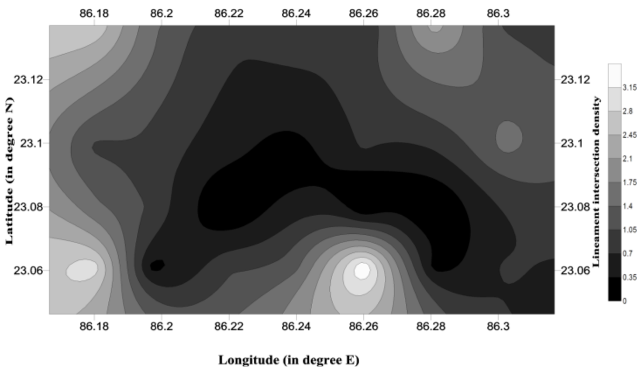
Figure 5. Lineament intersection density map



The high values of lineament density are found to be present in the north-eastern part of the study area. In the north-western and southern parts of the study area also the lineament density is moderately high. Low lineament density is found in the centrally east-west elongated part of the study area. Lineament density are designated as very low (1-1.44), low (1.441-1.88), moderate (1.881-2.32), high (2.321-2.76) and very high (>2.76). The high values of lineament length density are found to be present in the southern part of the study area. In the south-western and north-western parts of the study area also the lineament length density is moderately high. Low lineament length density is found in the central portion of the study area. Lineament length density are designated as very low (1-1.72), low (1.721-2.44), moderate (2.441-3.16), high (3.161-3.88) and very high (>3.88). The high values of lineament intersection density are found to be present in the southern part of the study area. In the western part of the study area also lineament intersection density is moderately high. Low lineament intersection density is found in the central part of the study area. Lineament intersection density are designated as very low (<0.7), low (0.7-1.4), moderate (1.41-2.1), high (2.11-2.8) and very high (>2.8). Lineaments provide important clues on subsurface structures that may control the movement and storage of groundwater. Good to moderate prospects depending on nature and value of inverse gradients of lineament density and lineament intersection density. The very high value of the lineament density, lineament length density and lineament intersection density are the places of interest for groundwater resource development.

Weighted Index Overlay Analysis (WIOA) is a simple and straightforward method for a combined analysis of multi-class maps. A weight represents the relative importance of a parameter vis-à-vis the objective. WIOA method takes into consideration the relative importance of the parameters and the classes developing to each parameter. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis should be defined and each parameter should be assigned importance (Saraf and Chowdhury, 1998).

6. Data Integration

Table 1 shows the criteria for groundwater potentiality in crystalline rocks. The groundwater potentiality in the present study has been delineated with the help of the software Surfer following the calculation exhibited in the table 1.

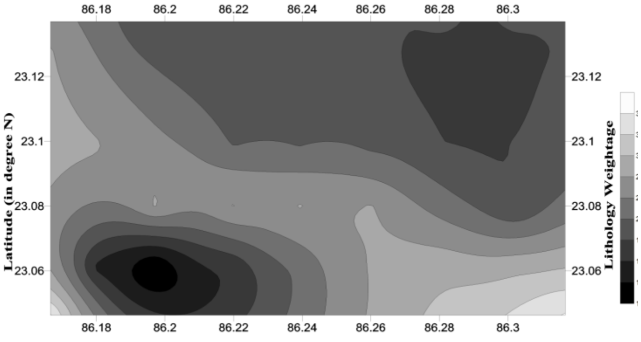
Table – 1. Criterion Table – Crystalline Rock Environs

Theme	Rank 1	Rank 2	Rank 3	Rank 4	Weightage
	4 x weightage	3 x weightage	2 x weightage	1 x weightage	
Lineament Intersection Density	High	Moderate	Less Moderate	Low	40%
Lineament length Density	High	Moderate	Less Moderate	Low	30%
Lineament Density	High	Moderate	Less Moderate	Low	20%
Lithology	Phyllite	Mica Schist	Epidiorite	Granite Gneiss	10%
TOTAL					100%

7. Results And Discussion

The main advantages in using remote sensing and GIS techniques for ground water exploration on a scientific basis are : quick and inexpensive technique for getting information on the occurrence of ground water, aids to select promising areas for further ground water exploration thus reducing field work and provides information on prospects, depth and quality in one map. This type of information is very helpful in the areas where there is scarcity of ground water for the irrigation and drinking purposes such as Purulia District West Bengal. Nag (2005) showed the application of lithology and lineament density for locating groundwater potential zone. The visual interpretation of IRS P6 LISS III data provided information pertaining to lithologic features is very useful in understanding the nature and water potentiality of different lithologic units. The integration of lithological and lineament information on a GIS platform is important in preparing groundwater potential map. The information generated on prospects in a map will help the planners and decision-makers for devising sound and feasible groundwater development plans. The resultant groundwater prospect map of the study area (see figure 6) shows five classes, viz., excellent (>360), very good (295.1-360), good (230.1-295), moderately good (165.1-230) and poor (100-165).

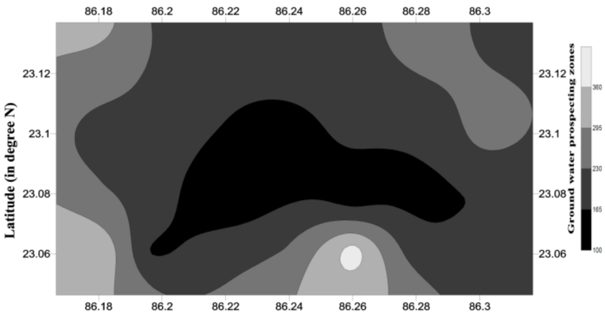
Figure 6. Contour map showing the lithological weightage in the study area



8. Conclusion

The main objective of this work is to find the suitable groundwater potential zones by overlaying the lineament density map, lineament length density map, lineament intersection density map and lithological map of the study area, using weighted overlay index method (Nag 2005). 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 (Choudhury, 1999). Weighted indexing method has been adopted to delineate ground water prospective zones considering mainly four parameters namely Lineament Intersection Density, Lineament length Density, Lineament Density and Lithology.

Figure 7. Map of the area showing the potentiality of ground water prospect.



The final map (see Figure 7) shows that the prominent lineament length density and high value of lineament intersection density associated with phyllite and an isolated pocket of gneissic rock are classified into relatively high prospect zones (very good and excellent), while the low values of lineament density, lineament length density and lineament intersection density underlain dominantly by granite gneiss and epidiorite are demarcated under poor prospect areas. The area underlain by epidiorite and mica schist, but traversed by good numbers of lineaments are classed under moderately good to good prospects.

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