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Land Use/Land Cover Changes and Groundwater Potential Zoning in and around Raniganj coal mining area, Bardhaman District, West Bengal – A GIS and Remote Sensing Approach

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Abstract

The Raniganj area has a long history of coal mining starting from 1744. This has resulted in major change in land use pattern and high groundwater abstraction leading to drinking water crisis especially during the premonsoon period. In the present study, land use /land cover conversions in Raniganj area from 1972 to 1998 and groundwater potential zoning for future groundwater development has been delineated using the techniques of Remote Sensing and Geographic Information System (GIS). The study indicates that land covered by vegetation and settlement has decreased at the expense of mining activity, which is reflected in the increase in area of overburden dump, barren land, waste land and abandoned quarry filled with water. Land use/land cover conversion has taken place in about 99.6 sq km, which accounts for 34.9 % of the total area, over 26-year period. Overlay analysis using multi-criteria such as drainage texture, geomorphology, lithology, current land use and steepness of slope and frequency of lineaments has been utilized to understand the potentiality of groundwater for future development. The analysis indicates that the groundwater potentiality of Raniganj area is medium (yield: 25 –50 m^3/hr) with high potential (yield: >50 m^3/hr) in the stretch along the Damodar River and in small pockets in the northern part of the study area. The groundwater abstractions structures feasible in the each of the various potential zones have also been suggested.

Introduction

The study area is bounded between latitudes 23º43'00" and 23º30'00" and longitudes 87º05'00" and 87º15'00" and falling under the Survey of India Toposheet No.

73 $^{M}/_{2}$ in the central part of the Raniganj Coal field area (Fig. 1) and covering an area of 285.1 sq km. The area is characterized by a very gently undulating topography with height of ground level varying between 73m and 120m. However, in the vicinity of the colliery areas, abandoned quarry, large dumps of ash and other waste material mar to a great extent the otherwise picturesque landscape of the area.

The area is located in the interfluve of the Ajay and Damodar rivers both flowing from west to east. A large number of major and minor tributary rivulets and nalas join these rivers at various points. Khudia, Nonia *khal*, Singaran, Tamala *nala* are some of the significant tributaries of the Damodar, which contribute to the drainage system of the area. A large number of manmade village ponds/lakes are also present. Some of the important ones are 'Nupur *bil*' (at village Nupur), 'Raybandh *bil*' (near Raniganj town) and 'Sukho *bandh*' (near Ukhra). Several abandoned quarries have now been transformed into big pools of water.

The climate in this part of country is hot and tropical. During the summer month the mercury shoots up to 48 ºC, while during the winter minimum temperature goes down to about 10 ºC. Humidity is relatively low throughout the year. The annual rainfall varies between 1120 mm and 1180 mm, the major part of which takes places between mid June and mid October.

This area has a long history of coal mining starting from 1744. This has resulted in change in land use pattern and high groundwater abstraction leading to drinking water crisis in the pre-monsoon period. Keeping in view these problems, the objectives of the present work are:

- To understand the geologic and geomorphic set up.
- To understand the change of land use/land cover over the period of 26 years.
- To delineate the groundwater potential zones through integration and analysis of various thematic maps prepared with the help of remote sensing and GIS.

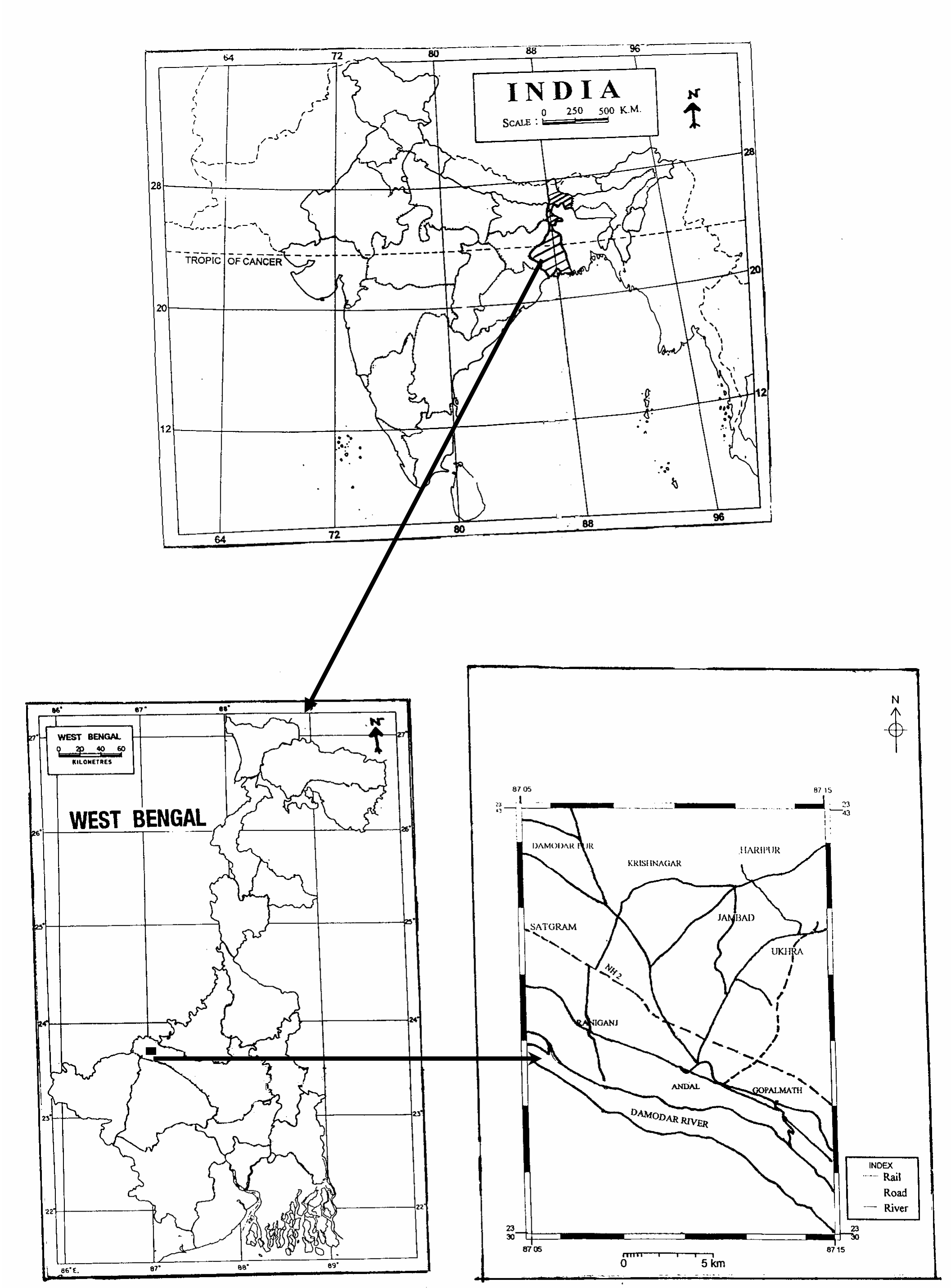

Fig.1 Location Map of Raniganj area

Data source and methodology.

Satellite imagery IRS-ID LISS-III geocoded FCC of 1998 on 1:50,000 scale, the corresponding Survey of India Toposheet (73 $^{M}/_{2}$) and geological map of the Geological Survey of India were used for the study.

The methodology used consists of following steps.

- Visual interpretations of satellite imagery to delineate the geology, drainage, geomorphologic units, lineament and land use/land cover.
- Field verification of interpreted units.
- Preparation of various thematic maps using GIS (ILWIS 3.0 Academic version).
- Preparation of slope map using Digital Elevation Model (DEM).
- Preparation of land use/land cover change map over the period of 26 years.
- Preparation of groundwater potential zone map using overlay analysis.

Geological set up

The area is underlain by consolidated Gondwana sedimentary formations. In the northern part of the study area the rock type exposed belongs to Barren Measure Formation. The rocks of Panchet Formation are exposed in the southeastern part of the study area. The Panchets are represented by medium to coarse-grained sandstones, yellowish in colour. These sandstones are generally feldspar bearing and are inter layered with red clays (Mehta, 1957). The rest of the area is underlain by Raniganj Formation. The lithology of Raniganj Formation consists of fine to medium grained buff coloured sandstone, greyish to greenish micaceous shale, coal seams and siltstones. (Fig. 2).

Major lineaments in the study area were identified from the satellite data interpretation. These are surface manifestations of some structural features in the bedrocks such as joints, fractures and faults, developed due to tectonic stress and strain. The lineaments were initially categorized into water bearing and non water-bearing depending on their mode of occurrence and the water bearing lineaments were plotted in Figure 3. The water bearing lineaments are mainly concentrated in the northern, western and eastern parts of the study area. In the northern part of the study area the lineaments trend in NW-SE, N-S and NE-SW directions. In the western part the lineaments trend in

NW-SE direction and in the eastern part the lineaments trend in N-S and NW-SE directions (Fig. 3). The lineament density map (Fig. 4) indicates relatively higher density in the northern part compared to the southern part of the study area.

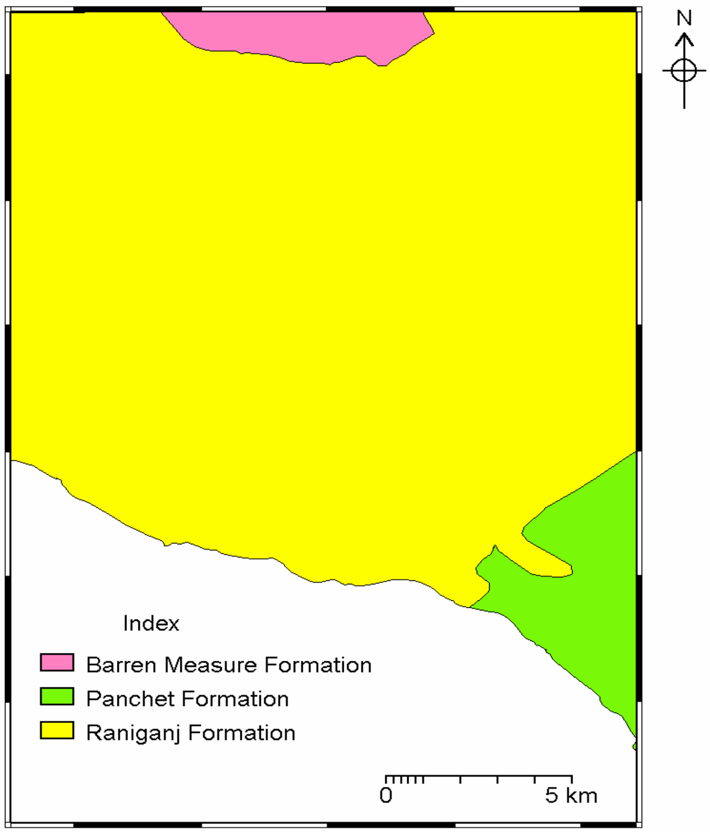

Fig.2 Geological map of Raniganj area

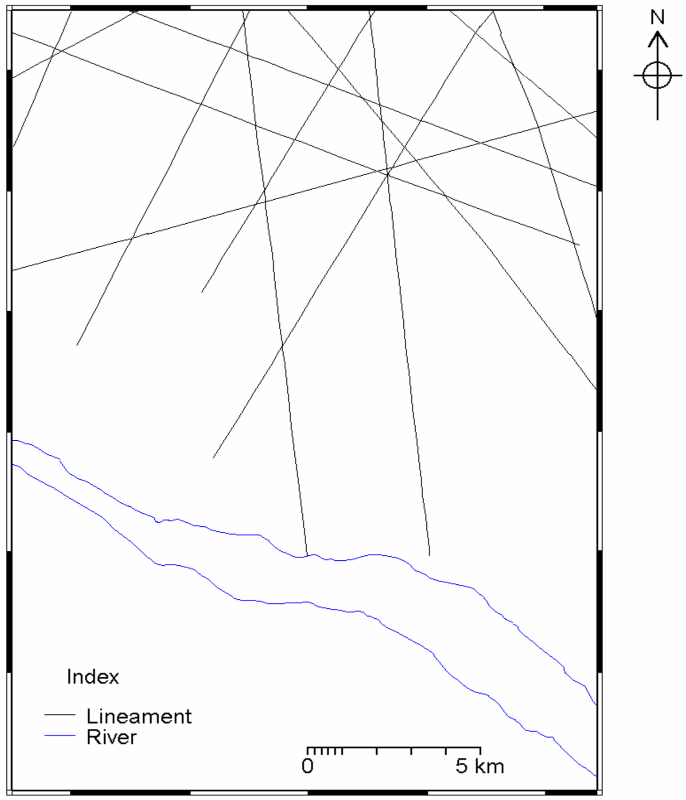

Fig. 3 Lineament map of Raniganj area

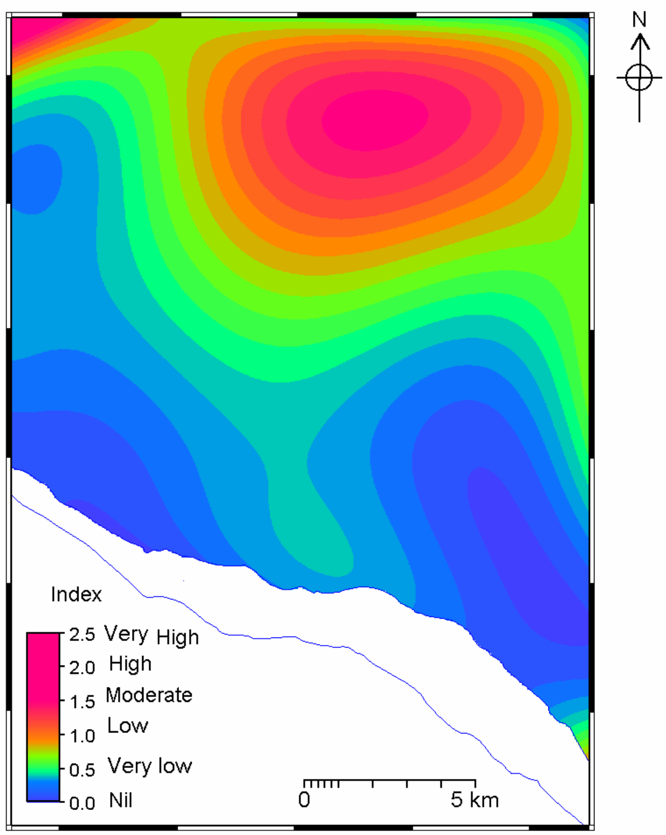

Fig. 4 Lineament density map of Raniganj area

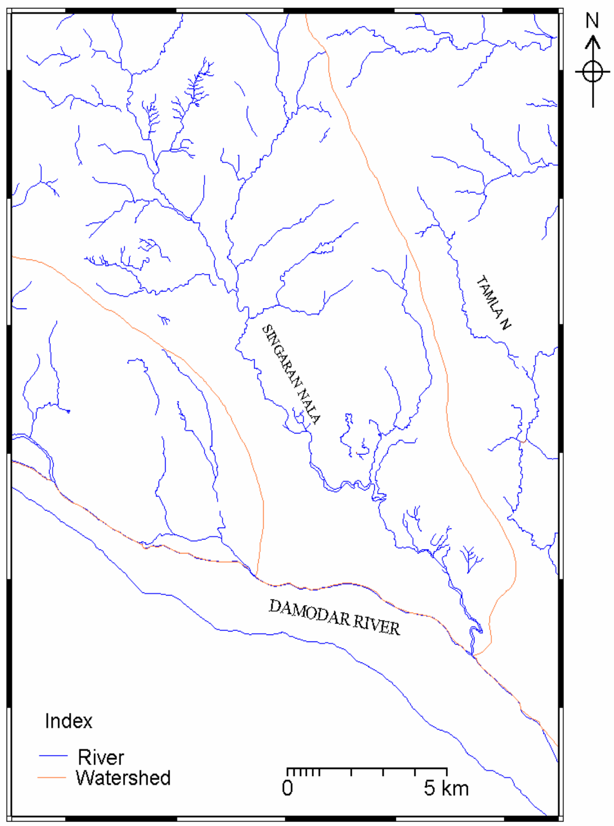

Fig. 5 Drainage map of Raniganj area (1998)

Drainage

The drainage of the area is mainly controlled by the Damoder River and its tributaries such as Khudia n*ala*, Nonia k*hal,* Singaran n*ala* and Tamla n*ala.* The area can be divided into three watersheds (Fig.5). They are eastern part of Nonia watershed in the western part, Singaran watershed in the central part and Tamla watershed in the eastern part. Drainage density is one of the important parameters to understand the groundwater potential of a watershed. Lower the drainage density higher the groundwater potential. In the present study area the drainage density of the three watersheds are 0.77, 0.86 and 0.64 km per sq. km. Thus, drainage texture of the study area can be classified as moderate to fine (Fig. 6)

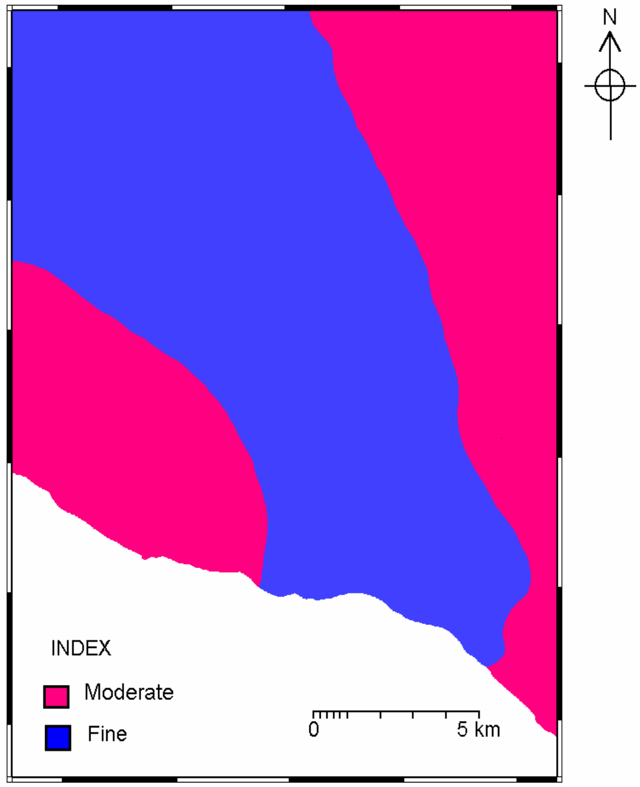

Fig. 6 Drainage texture of the Raniganj area

Geomorphology

The geomorphology of the area is highly influenced by the lithology and structure of the underlying formations. Based on visual interpretation of IRS- ID LISS III, 1998 the following units have been delineated and a geomorphological map prepared (Fig. 7)

- Dissected Gondwana Upland
- Dissected Lateritic Upland (Upper)
- Valley Fill
- Alluvial Plain (Lower)

Detailed description and groundwater prospect of the geomorphologic units are presented in Table 1.

The area is characterized by a very gently undulating topography with average height of the ground level varying between 73 m and 120 m. A digital elevation model (DEM) has been created using the method of interpolation of contours. The contours at 20 m interval and the spot heights were traced out from the Survey of India Toposheet.

This map was then geo-referenced, digitized, edited and rasterised using ILWIS 3.0 Academic version software to generate the DEM. On the generated DEM, DfDx and DfDy filters were applied to generate the slope percentage map. A slope map in degrees was then constructed from the DEM. The different classes of slope in degree and their description are shown in Table 2. In the present area the slope varies between 0^o to 15^o i.e. very gentle to moderate (Fig. 8).

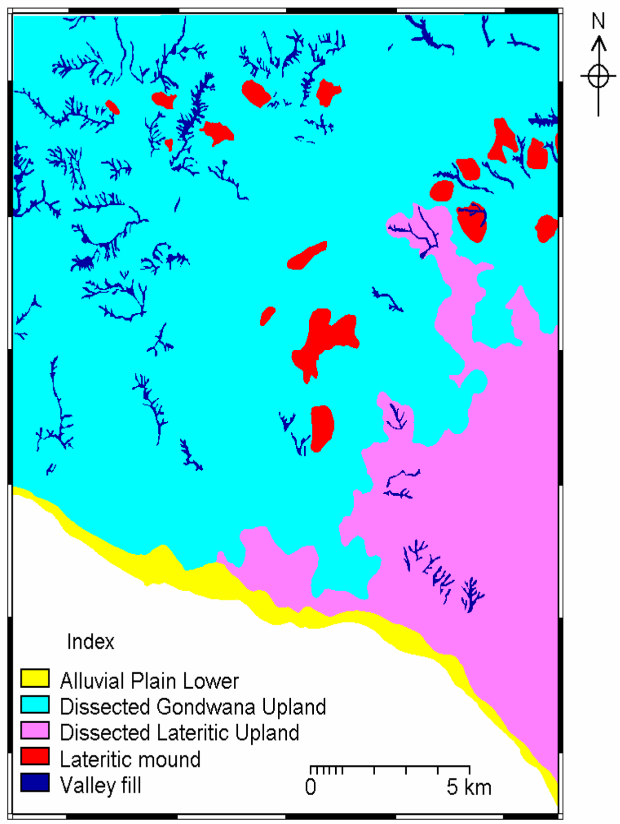

Fig. 7 Geomorphological map of Raniganj area

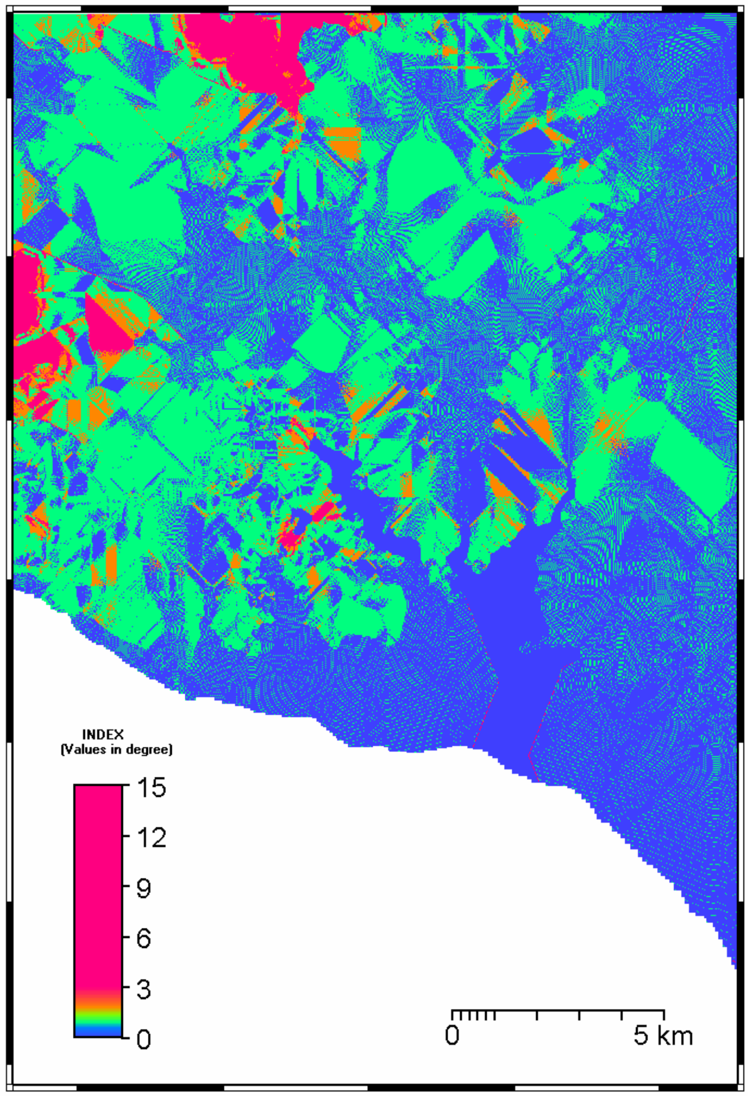

Fig.8 Slope map of Raniganj Area

Table 1 Hydrogeomorphology and ground water prospect of the study area.

Geomorphic units	Description	Ground water prospect
Dissected Gondwana Upland	Undulating terrain with/without duricrust; lateritic mounds at places; active coal mining area (both under ground and opencast). Zone of land subsidence – identified from 'Geomorphic anomalies' and drainage deflection; dusky red-to-red skeletal soil; rainfed cultivation present.	Obliterated by mining activities Yield - < 25 m^3/hr. In Abandoned water log pits or shafts yield may be as high as 100 m^3/hr. Depth to water table is highly erratic and are influenced by active mining activity. Fluctuation of water table is high varying from 1-13 m.
Dissected Lateritic Upland (Upper)	Elevated land with or without duricrust, gently slopping or flat 'Table land', moderately dissected with rill/gully erosion, dusky red to red to red skeletal soil, mainly forestland.	Moderate Yield 25 - 50 m^3/hr Pre-monsoon water table varies between 6-8 m. Fluctuation 2-4 m.
Valley Fill	Accumulation zone of colluvial/alluvial materials with moderate to deep soil profile; mainly single crop area; double crop present at places.	Good Yield 50-100 m^3/hr.
Alluvial Plain (Lower)	Younger fluvial terrace with monotonous flat terrain, older meander scars, point bar deposit, greyish while to grey loamy soil-fine sand, silt and clay with high moisture content; mainly double crop area.	Good Yield 50-100 m^3/hr. Pre-monsoon water table varies between 7-9 m. Fluctuation 1-3 m.

Table 2 Classification of slope

No.	Class	Symbol	Description
1.	0 to 5^o	A	Very gentle
2.	5^o to 10^o	B	Gentle
3.	10^o to 15^o	C	Moderate
4.	15^o to 25^o	D	Moderately steep
5.	25^o to 35^o	E	Steep
6.	$>35^o$	F	Very steep

Groundwater condition

The geology and geomorphology of the area control the occurrence and movement of groundwater. The area suffers from chronic water shortage. In the shallow zone groundwater occurs in an unconfined condition and is generally abstracted by dugwell. The depth to water table generally varies between 6 m to 8 m below the ground surface in the pre-monsoon period and 4 m to 6 m in the post-monsoon period. Near the coalfield area the depth to water level is usually deep and declines considerably during the pre-monsoon period. The dugwell even dry up totally. Depth to water level varies between 15 m to 40 m below ground level in and around the coal mining areas. The depth of dugwell varies from 15 m to 25 m, which also indicates the thickness of the weathered residuum. The depth of tube wells fitted with hand pumps and lighted duty tube well fitted with submersible pump varies from 45 m to 60 m below ground level. Below this depth range the potentiality of the aquifer is poor because of the presence of massive rocks without fractures. The regional ground water flow is from west to east.

Percolation of water in mine faces down to a depth of 200 m from surface leads to filling up of the abandoned mine pits. Hydrological tests carried out in these pits have established that they constitute a potential source of water supply in the coalfield area (CGWB, 1998).

Apart from the shallow unconfined aquifer consisting of weather zone of hard consolidated or semi consolidated rocks the area has a number of deeper aquifers where groundwater occurs under confined condition. The deeper aquifer consists of deep-seated weak planes such as joints, faults, fissures, bedding planes, etc. Studies by the Central Ground Water Board in the area west of Raniganj indicates that the favorable weak planes generally 2 to 4 in number occur within the depth range of 30 m and 90 m below ground level. The yield of the exploratory in this area ranges between 0.6 and 38 m^3/hr (CGWB, 1998). Large yield were obtained from Raniganj and Panchet formations. The yield of boreholes in the vicinity of active coalmines will have smaller yield due to seepage of groundwater towards the mine. The transmissivity of the aquifer varies between 50m^2 /day and 60m^2/day.

Land Use

A land use map of 1972 has been prepared using the Survey of India Toposheet No. $73^{M}/_{2}$ (Fig. 9). A perusal of the map reveals that the land use practices are largely linked up with the extensive mining activities of this belt. However, the traditional agricultural practices are also in vogue in the fertile lands of the area. Pockets of remnant forest are also seen in some parts of the area. The land use classes, area occupied by each class and percentage of each class of the total area are given in Table 3. A second land use map (Fig. 10) was prepared from satellite imagery IRS ID LISS-III 1998. The various land use classes, areas and % of total areas are given in Table 4.

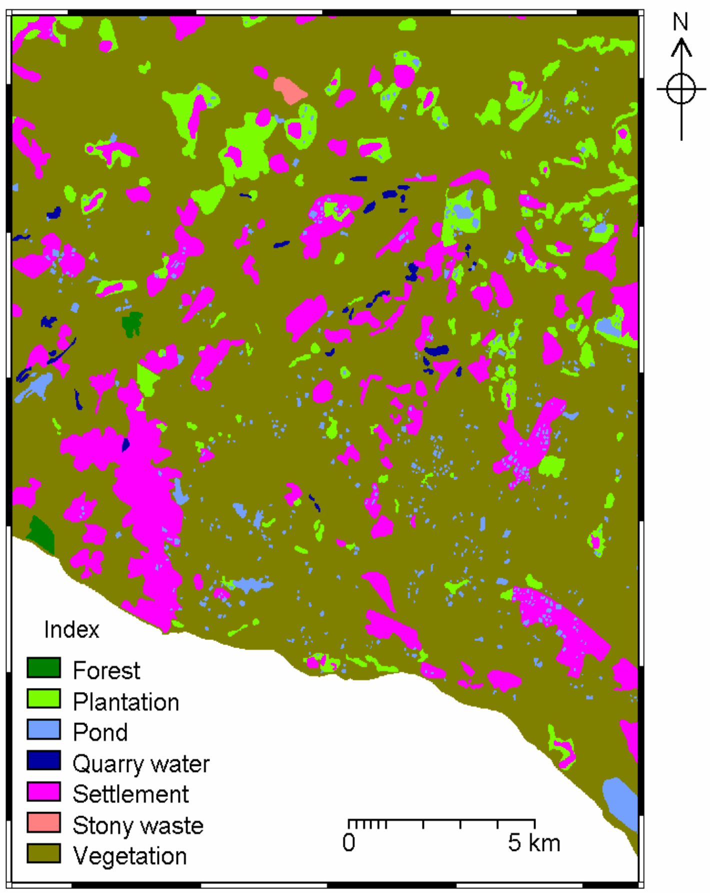

Fig. 9 Landuse/landcover map of Raniganj area (1972)

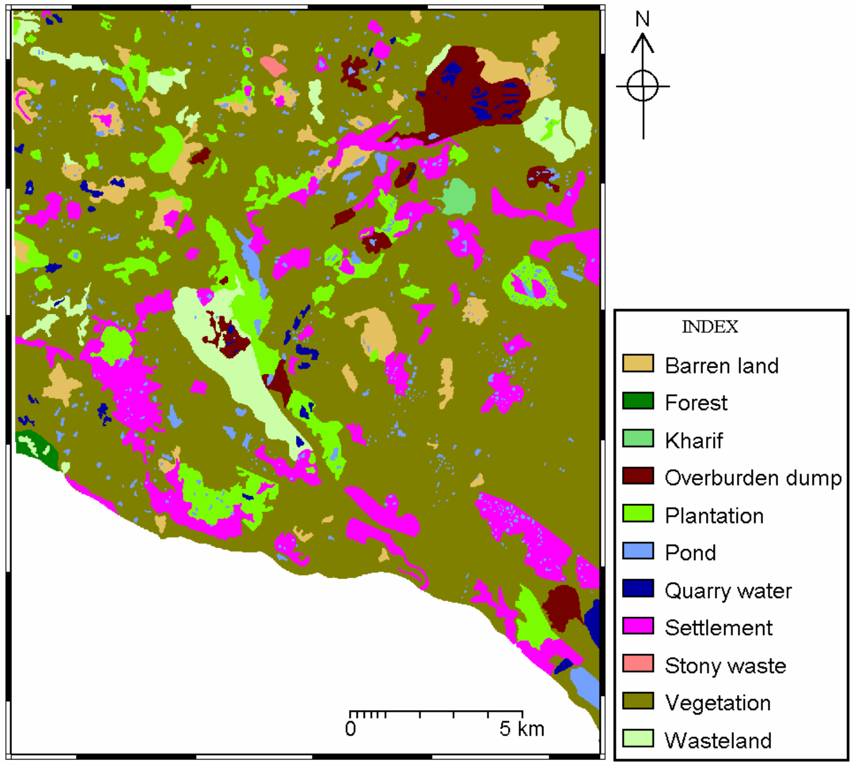

Fig. 10 Land use/Land cover map of Raniganj area (1998)

Table 3 Land use pattern of the study area during 1972

Sl. No	Land use /land cover classes	Area (sq. km)	% of total area
1	Forest	0.7	0.24
2	Plantation	17.0	5.96
3	Pond	6.4	2.24
4	Quarry water	1.3	0.46
5	Settlement	36.1	12.66
6	Stony waste	0.4	0.15
7	Vegetation	223.2	78.29
	Total	285.1	100.00

Source: Toposheet No.73 M/2

Table 4 Land use pattern of the study area during 1998

Sl. No	Land use /land cover classes	Area (sq. km)	% of total area
1	Forest	0.7	0.24
2	Plantation	18.5	6.49
3	Pond	6.6	2.31

4	Quarry water	2.6	0.92
5	Settlement	27.5	9.64
6	Stony waste	0.5	0.18
7	Vegetation	197.4	69.23
8	Kharif	0.8	0.29
9	Barren land	10.9	3.83
10	Overburden dump	8.9	3.12
11	Waste land	10.7	3.75
	Total	285.1	100.00

Source: Satellite imagery IRS-ID LISS III 1998

Land use/land cover change

Land use/land cover maps of 1972 and 1998 were overlaid using the 'cross operation'. The 'cross operation' performs a overlay of two raster maps i.e. land use map of 1972 and land use map of 1998 by comparing pixels at the same locations in both the maps and keeping tract of all the combinations that occur between the values of classes in both the maps. During the 'cross operation', combinations of class names, identifiers or values of pixels in both maps is listed, the number of pixels occurring as this combination is counted, and the areas of the combinations are calculated. The results are stored in an output cross map and a cross table.

Figure 11 and Table 5 shows the change in areal extent of different land use/land cover classes during 1972-1998. The land use/land cover pattern of the study area shows marked difference in the areal extent from 1972 to 1998. Land covered by vegetation and settlement have decreased at the expense of mining activity which is reflected in the increase in area of overburden dump, barren land, waste land and quarry water. An important aspect of the land use/land cover change is the increase in forest area from 0.65 sq. km. in 1972 to 0.70 sq. km. in 1998. An attempt has been made to model the major land use/land cover conversion trend of the study area. The change in the areal extent of a particular class is linked to the change in areal extent of one or more classes of the study area. If different land use/land cover classes are considered as different parts of a single system, then each of these units are linked with each other through conversions. The model prepared for the study area is given in Fig. 12. The model shows that land covered by vegetation has been converted to plantation due to social forestry and to overburden dump, quarry and barren and waste land due to mining activity. Land use/land cover conversion has taken place in about 99.6 sq km, which account for 34.9 % of the total area, over 26-year period.

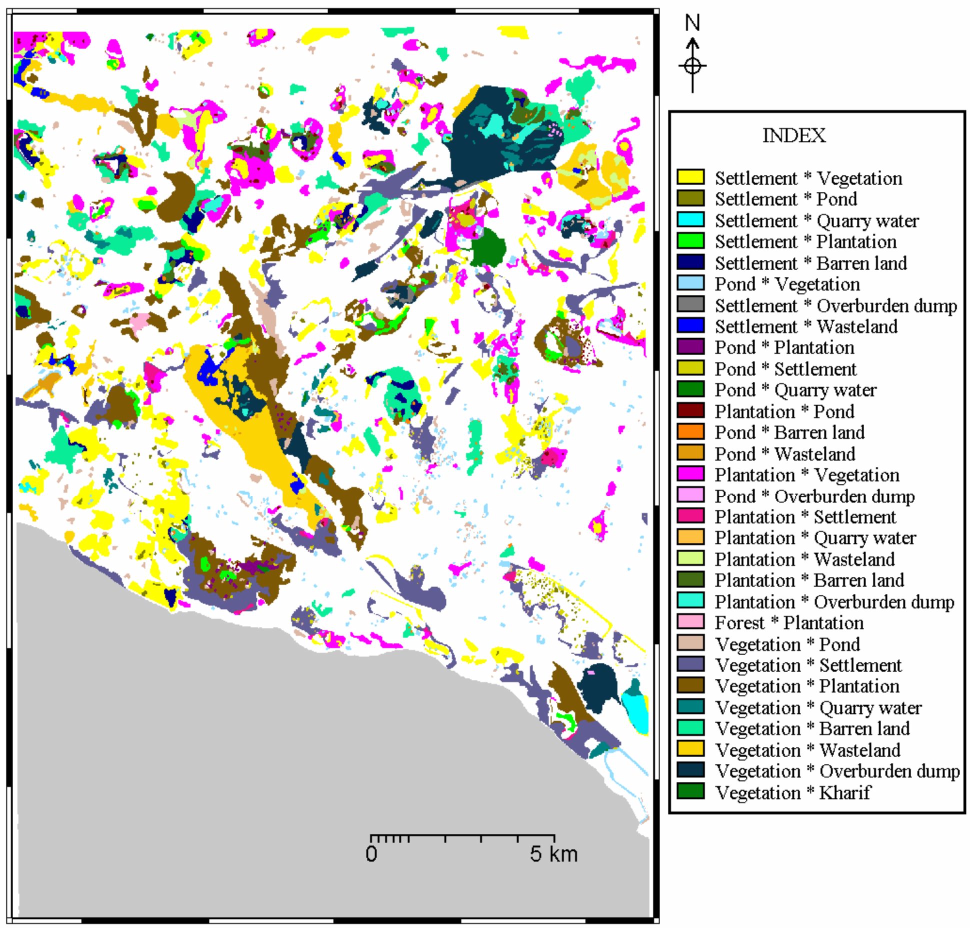

Fig.11 Land use/Land cover change map of Raniganj area (1972-1998)

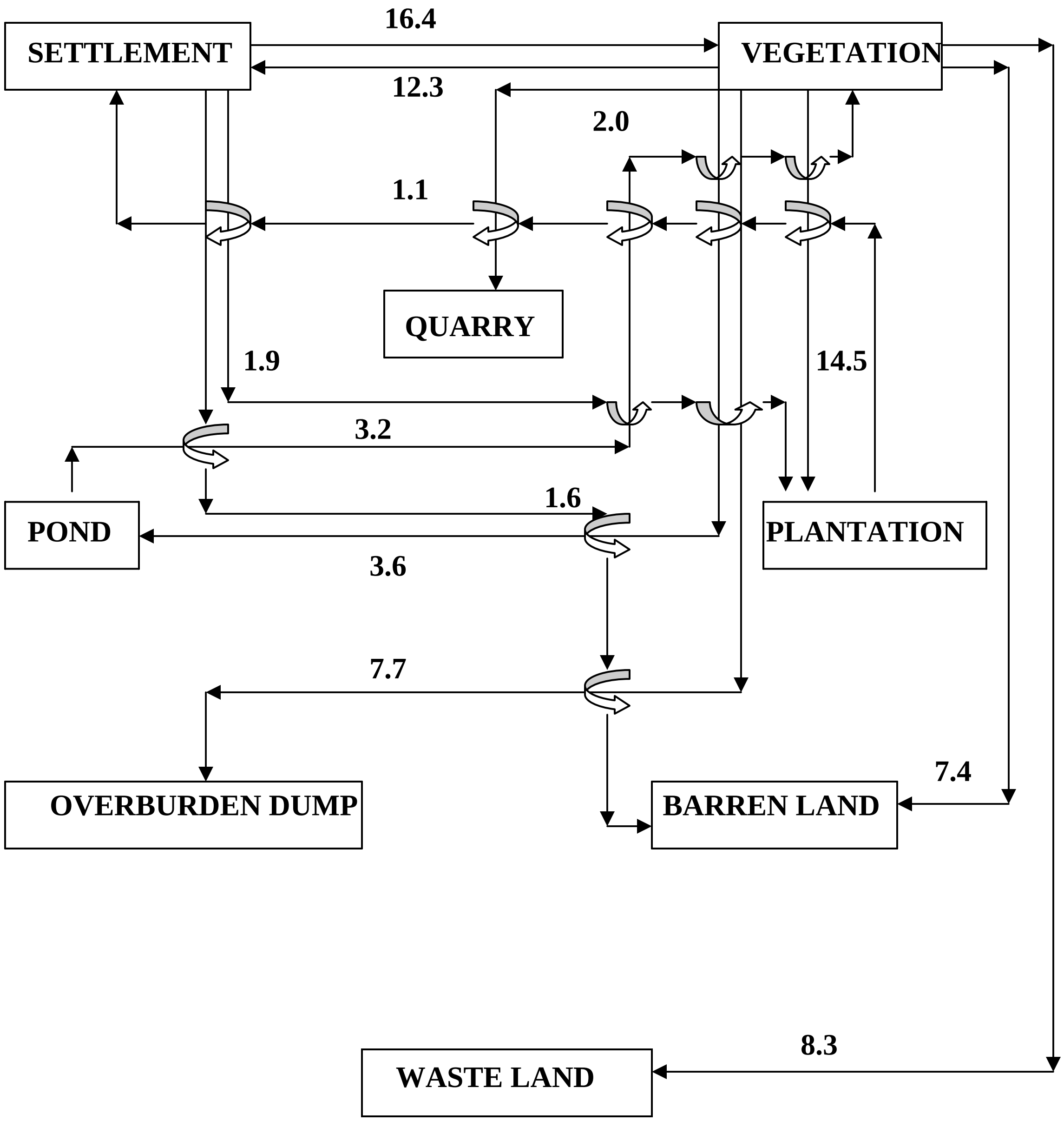

Fig. 12 Major land use/land cover conversion model of Raniganj Area. (Figures indicate areas converted in sq km.)

Table 5 Land use/Land cover change in Raniganj area (1972-1998)

Land use/Land cover change		Area change (sq. km)
From (1972)	To (1998)	
Settlement	Vegetation	16.4
Settlement	Pond	1.0
Settlement	Quarry water	0.6
Settlement	Plantation	1.9
Settlement	Barren land	1.6
Settlement	Overburden dump	0.2
Settlement	Waste land	1.0
Pond	Vegetation	3.2
Pond	Plantation	0.6
Pond	Settlement	0.7
Pond	Quarry water	0.1
Pond	Barren land	0.2
Pond	Waste land	0.3
Pond	Overburden dump	0.1
Plantation	Pond	0.6
Plantation	Vegetation	10.7
Plantation	Settlement	1.1
Plantation	Quarry water	0.1
Plantation	Wasteland	1.0
Plantation	Barren land	1.6
Plantation	Overburden dump	0.9
Forest	Plantation	0.2
Vegetation	Pond	3.6
Vegetation	Settlement	12.3
Vegetation	Plantation	14.5
Vegetation	Quarry water	2.0
Vegetation	Barren land	7.4
Vegetation	Waste land	8.3
Vegetation	Overburden dump	7.7
Vegetation	Kharif	0.7
	Total change	99.6

Groundwater Potential Zoning

The choice among a set of zones for future development of groundwater is based on multiple criteria such as drainage texture, geomorphology, lithology, present land use, and steepness of slope and frequency of lineaments. This process is most commonly known as Multi-Criteria Evaluation (MCE) (Voogd, 1983). Of several methods available for determining interclass/intermap dependency, a probability-weighted approach has been adopted that allows a linear combination of probability weights of each thematic map (W) with the individual impact value (IV) (Sarkar and Deota, 2000). The thematic maps have been ranked in a scale of 0 to 5 depending upon their suitability to hold groundwater. The rank of each has been converted to a probability weight using Bayesian statistics. These scores are again converted to impact values using Bayesian statistics. Similarly different categories of derived thematic maps have been assigned scores in a numeric scale 0 to 5 depending on their capability to store and transmit water. These scores are again converted to impact values using Bayesian statistics. These capability values (CV_i) are then multiplied with the respective probability weight of each thematic map (Table 6) to arrive at the final weight map (Fig. 13). The procedure of weighted linear combination dominates in raster based GIS software systems (Eastman et al., 1995 and Eastman, 1996).

Mathematically, this can be defined as

$$Gw = f\,(Dr, Geom, Lin, Lith, Sl. Lu)$$

where, Gw = Groundwater

Dr = Drainage

Geom = Geomorphology

Lin = Lineament

Lith = Lithology

Sl = Slope

Lu = Landuse

Now groundwater potential map values can be expressed as

$$GWP = \Sigma\, W_i * CV_i$$

where, GWP = Groundwater Potential

W_i = Map weight

CV_i = Capability value

The resultant final weight map indicates the potentiality of groundwater occurrence in Raniganj area. This map is then classified into four categories, namely High, Medium, Low and Very low (Fig.13). The area in sq km, the percentage of the total area covered by each category, yield range, depth/thickness of aquifer and groundwater structures feasible is given in Table 7.

Table 6 Thematic map weights and capability values

Thematic Layer	Rank	Map Weight (W_i)	Category	Rank	Capability Value (CV_i)
Drainage Texture	4	4/23 = 0.175	Very coarse	5	0.33
			Coarse	4	0.27
			Moderate	3	0.20
			Fine	2	0.13
			Very fine	1	0.07
			Extremely fine	0	0.00
Geomorphology	5	5/23 = 0.217	Alluvium Plain lower	5	0.33
			Valley fill	4	0.27
			Dissected Lateritic Upland	3	0.20
			Lateritic Mound	2	0.13
			Dissected Gondwanaland	1	0.07
Lineament density	5	5/23 = 0.217	Very high	5	0.33
			High	4	0.27
			Moderate	3	0.20
			Low	2	0.13
			Very Low	1	0.07
			Nil	0	0.00
Lithology	2	2/23 = 0.087	Panchet Formation	5	0.417
			Raniganj Formation	4	0.333
			Barren Measure Formation	3	0.250
Slope	5	5/23 = 0.217	0 to 5^o	3	0.50
			5^o to 10^o	2	0.33
			10^o to 15^o	1	0.17
			15^o to 25^o	0	0.00
			25^o to 35^o	0	0.00
			$>35^o$	0	0.00
Land Use	2	2/23 = 0.087	Water body	5	0.33
			Forest	4	0.27
			Vegetation + Kharif	3	0.20
			Plantation	2	0.13
			Wasteland + Barren land + Overburden Dump	1	0.07
			Settlement	0	0.00

Table 7 Area covered by different groundwater potential zone

Category	Area Covered (Km^2)	Percentage of the total area	Yield range (m^3/hr)	Depth/thickness of aquifer	Groundwater structures feasible
High	14.70	5.2	50-100	Unconfined - 15-25 m.	Dug wells fitted with low power pumps and tubewell fitted with hand pump and submersible pump
Medium	184.83	64.8	25 - 50	Confined- 45-60	Dug well, dug-cum-bored well and tubewell fitted with hand pump
Low	85.38	29.9	<25	Unconfined - <15 m	Dug well, dug–cum-bored well
Very low	0.19	0.1	<25	Unconfined - <15 m	Generally groundwater structures will not be successful. Dugwell, dug-cum-bored well may be constructed. Surface water should be harnessed and rooftop rainwater harvesting schemes may be adopted
Total	285.10	100.0			

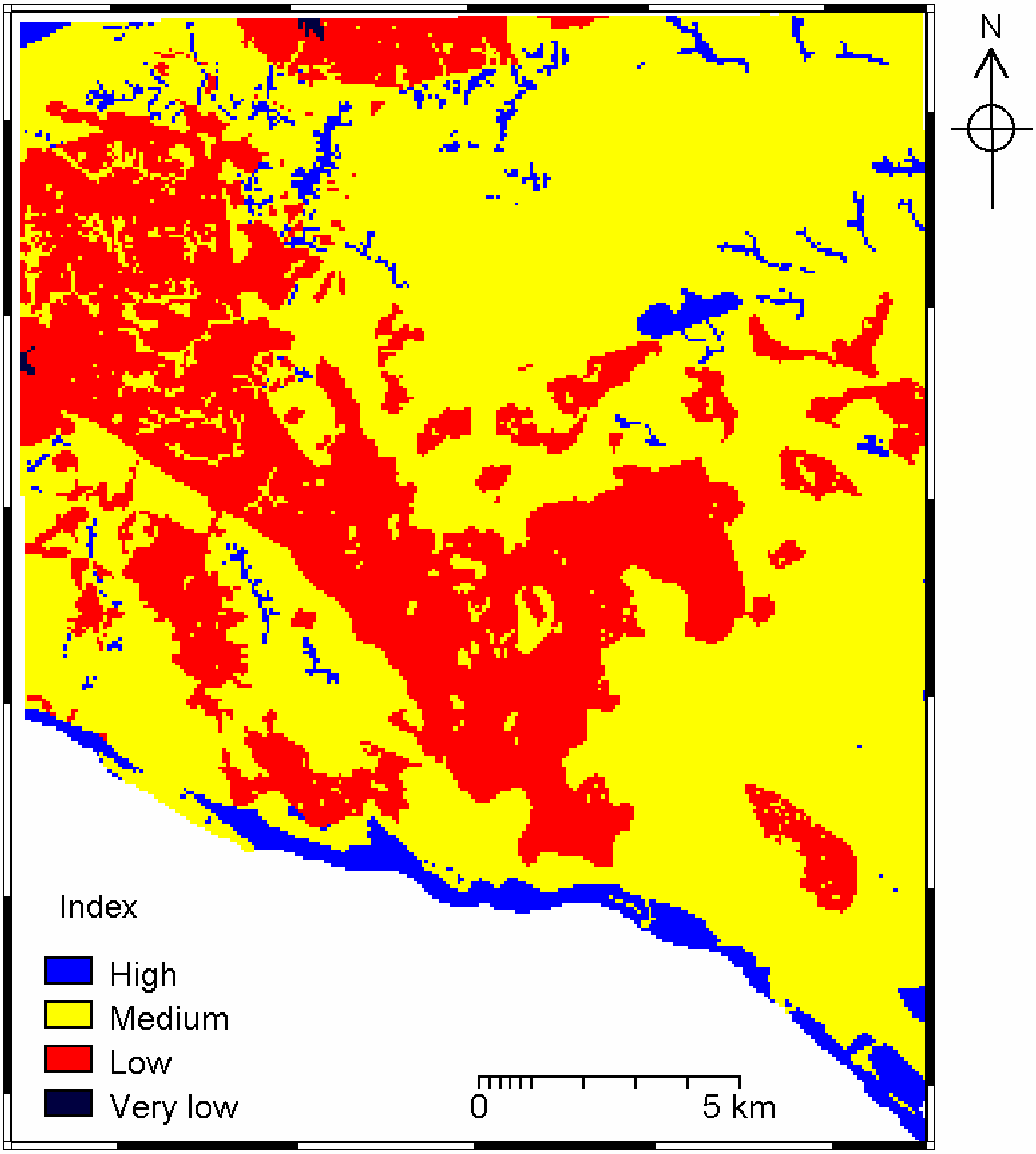

Fig. 13 Groundwater potential map of Raniganj area

Conclusion

In general the ground water potential for future development in Raniganj coal mining area is medium. There is a major northwest-southeast trending zone of low groundwater potential apart from small pockets scattered throughout the area. High ground water potential is observed along the Damodar River and in small pockets in northern part of the study area .The groundwater abstraction structures feasible in the high potential areas are dug wells fitted with low power pumps and tubewell fitted with hand pump and submersible pump, in the medium potential areas are dug well, dug-cum-bored well and tubewell fitted with hand pump and in the low potential areas are dug well, dug–cum-bored well. In the very low potential areas generally groundwater abstractions structures will not be successful. Dugwell, dug-cum-bored well may be constructed. Surface water should be harnessed and rooftop rainwater harvesting schemes may be adopted. The areas affected by mining have medium groundwater potential. Therefore, the pumped out water from active mining areas should be utilized for domestic and other purposes to tide over the water crisis in the pre-monsoon period.

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