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Inferences and influences on Groundwater Quality around Mining Environment as modeled through GIS

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Abstract: With an objective to understand the impact on groundwater quality, a Gondwana coal mining area of eastern India, known for its prime coking coal – Jharia Coal Field, has been modeled through GIS. Based on defined chemical parameters, four quality classes have been categorized and assessed against different thematic information's. Though only 3% area represents mining zone, the impact on groundwater quality in surrounding areas is sizeable. Geology of the area has a direct bearing on different quality classes and nearly 12% area is under threat due to mining activities in sandstone aquifers. Most of the high drainage density areas are under mining activities and thereby, good quality water zones are under threat. Nearly 29% area that falls under high lineament density class is associated with core and buffer activities indicate significant decreasing trend in recharge capacity with increasing damages on land. Nearly 20% of sandy loam soil area is indirectly associated with the adverse impacts due to mining. Evaluation on land capability indicates that the continuous mining activity not only records undesirable impact on groundwater but also leads to the generation of wastelands. Significantly, the study warrants an appropriate sustainable development program for the conservation of the water resources in the study mining area.
Keywords: Groundwater, Modeling, Impact, Mining area.

Introduction

During mining operation, impact on groundwater has been sizable[5, 7,14,15,16,19] both with respect to quality degradation[6, 8,10] and quantity depletion[9,12]. Damages in aquifers[4], recharge capacity, quality degradation mass wastage[13] is to be assessed properly to devise best management strategies to minimize the consequences. To substantiate the development proper understanding on the influences and response of various and planning, thematic parameters to mining damages are more useful. Such scenario could conveniently be modeled using GIS, which helps to understand the situation in a better way[11,17,18]. In this paper, an attempt was made to understand the relationship between groundwater quality with other parameters using GIS application in and around mining area.

Study area

Dhanbad District (Fig. 1) of Jharkhand State of India has been chosen for the present study, which is one of the resourceful districts of India with high quality coal. It covers about 2057.26 sq km areas. Basically, Dhanbad district is known for its long history of coal mining activities and the Jharia coalfield remains as the host of prime coking coal source of India. A synoptic view from Indian Satellite IRS1B is presented in Fig 2. Though the active mining areas spread only around 60 sq km, the associated activities and real impacts environment has been of a major concern. Owing to the century old coal mining operations

, its profound impact on the ground water has been significant.

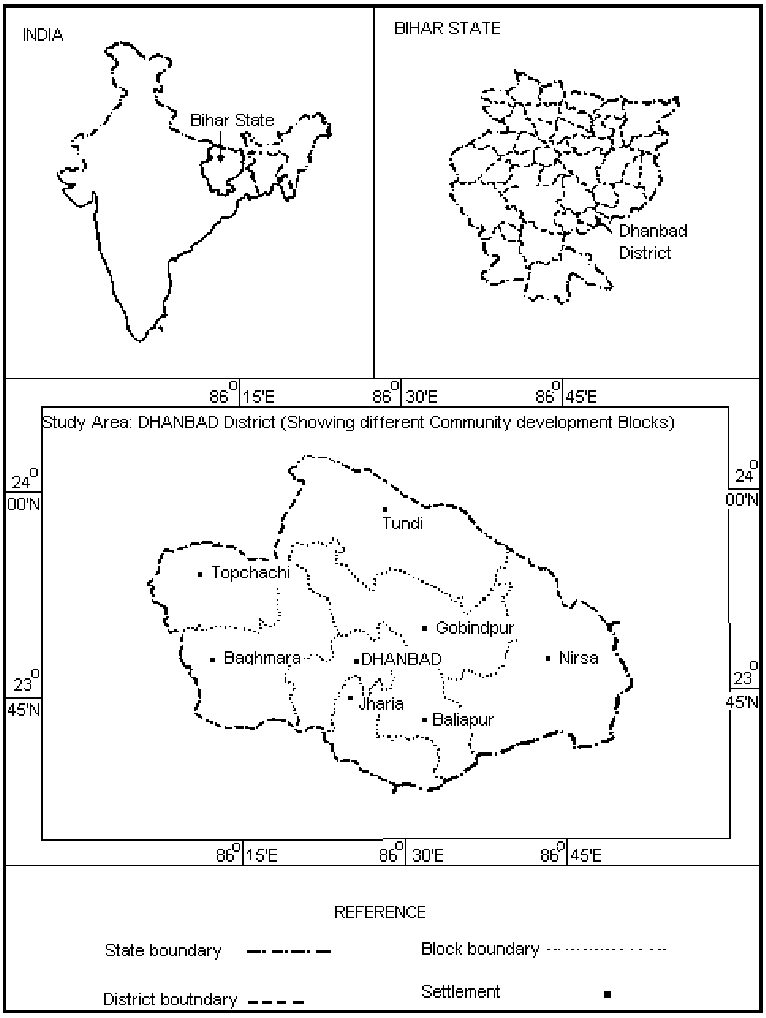
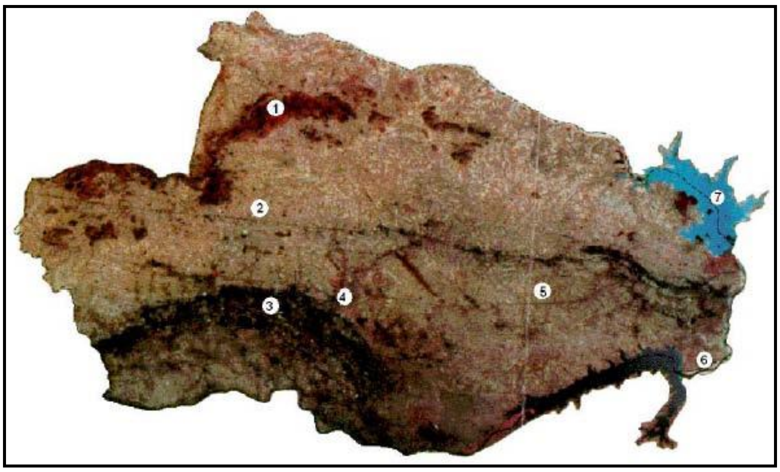


Figure 1 Location Map of Dhanbad district



Legend: 1.Tundi reserve forest 2.Grand Trunk Road 3.Jharia Coalfield 4. Dhanbad city 5. Railway line 6.Damodar River 7. Tenughat reservoir.

Figure 2. IRS-1B satellite imagery of Dhanbad district

Methodology

Water quality of the study area has been evaluated from the groundwater from 16 control wells spreading in and around Dhanbad District. Based on chemical data, various layers such as Total Hardness, Concentration of Fe, Ca, Mg, Mg, NO3 ions, Fluoride, Total Alkalinity and Sulphate have been generated using Geomatica GIS software and cutoff limit has been considered as per IS: 10,500 norms for tolerable limits for domestic use. Based on the assigned weightage on above layers and subsequently to each legend of the layer as well, the multi-criteria analysis has been attempted to derive groundwater quality map (for drinking water) with four quality classes. These quality classes were analyzed and assessed against selected thematic information for their associations and influences.

Results and Discussion

Drinking water quality assessment:

Four classes viz., excellent, good, moderate and poor have been categorized in the study area (table 1). The aerial distribution of the various integrated water quality classes is presented in Fig 3. The southern part of the study area falls under the excellent class of water quality and spreads about 21%. About 53% of the study area comes under good class of quality whereas nearly 24% area in the western side of the district is found under the class of moderate quality. Less than 1% of the area is represented by poor quality where the concentration of fluoride and iron are found to be on the higher side of the tolerance on limit.

Table 1 Distribution of various classes of Integrated Drinking Water Quality

Category	Area (Sq.Km.)	Area (%)
Excellent	434.94	21.14
Good	1103.48	53.64
Moderate	502.07	24.4
Poor	16.77	0.82
Total	2057.26	100

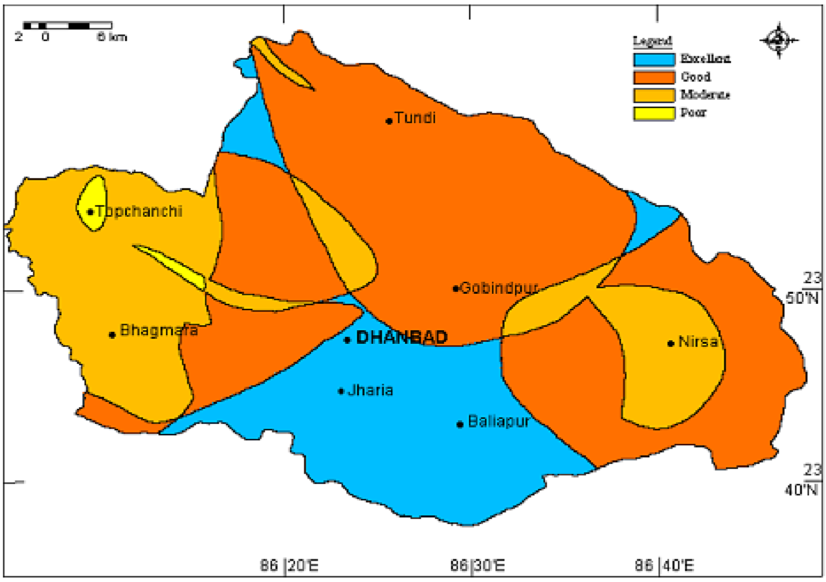


Figure 3 Groundwater Quality Classes in Dhanbad district

Influence of geology with groundwater quality:

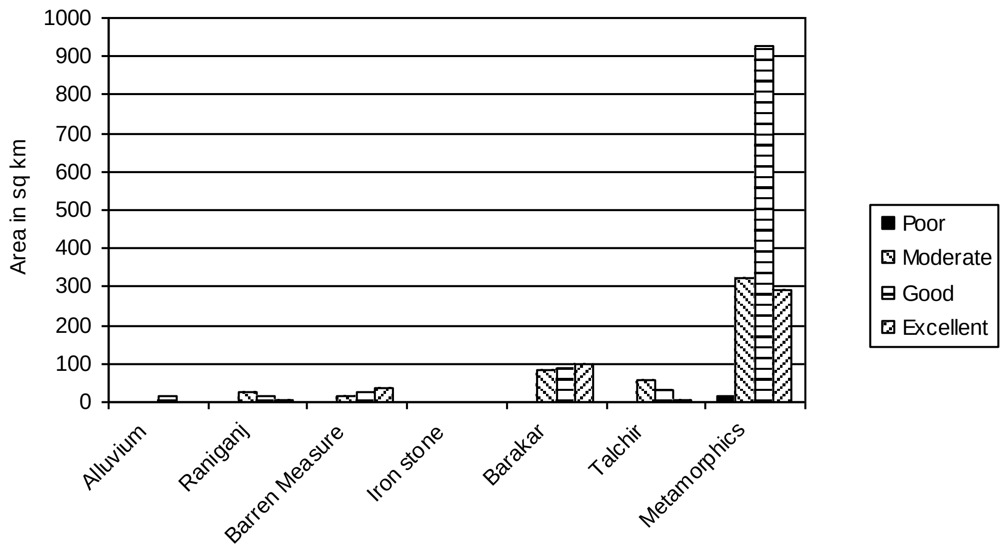
Aquifers associated with the mineralized zones are commonly prone to a critical threat during mining operations. Kuma[9] has reported that some 40% of the groundwater resources in Tarkwa gold mining area, Ghana associated with Banket rocks have been destroyed by mining operations. Metamorphic rocks occupies around 75% of the study area which are mainly consists of granite and gneisses of Achaean age. Sedimentary rocks covering portions of southern and eastern part of the study area are associated with Gondwana litho-facies which are represented by Talchir formation (4.56%), ironstone shale (0.12%) of Upper Carboniferous, Barakar of Lower Permian (13.06%), Barren measures (3.55%) of Middle Permian and Raniganj formation (2.15%) of Upper Permian age. Barakar formation has economically exploitable coal seams, interbedded with felspathic sandstone, grits, shale and carbonaceous shale. Jharia and part of Ranigank coalfields have the presence of Barakar formation with multi seam coal deposits.

Groundwater classes are correlated with various geological formations and details are presented in Table 2. The characteristics of various geological formations in terms of their association with quality classes are shown graphically in Fig 4 in percentage.

Table 2 Influence of Geology on Groundwater quality classes (in sq km)

Classes	Excellent	Good	Moderate	Poor	Total
Alluvium	0	14.63	0	0	14.63
Ranigani	4.22	14.48	25.42	0	44.12
Barren measures	34.21	25.36	13.56	0	73.13
Iron stone shale	0	2.19	0	0	2.19
Barakarr	101.11	86.84	80.76	0	268.71
Talchir	4.56	30.47	58.74	0	93.77
Metamorphics	290.8	929.63	323.51	16.77	1560.71
Total	434.9	1103.6	501.99	16.77	2057.26

Figure 4 Geological formation and Groundwater quality classes



All formations in the study area are characteristic of holding good quality water irrespective of either sedimentary or metamorphic rocks. While sedimentary formations hold water-retaining capacity in sandstone rocks, the metamorphic rocks that are widely crisscrossed by fractures also retain good water quality.

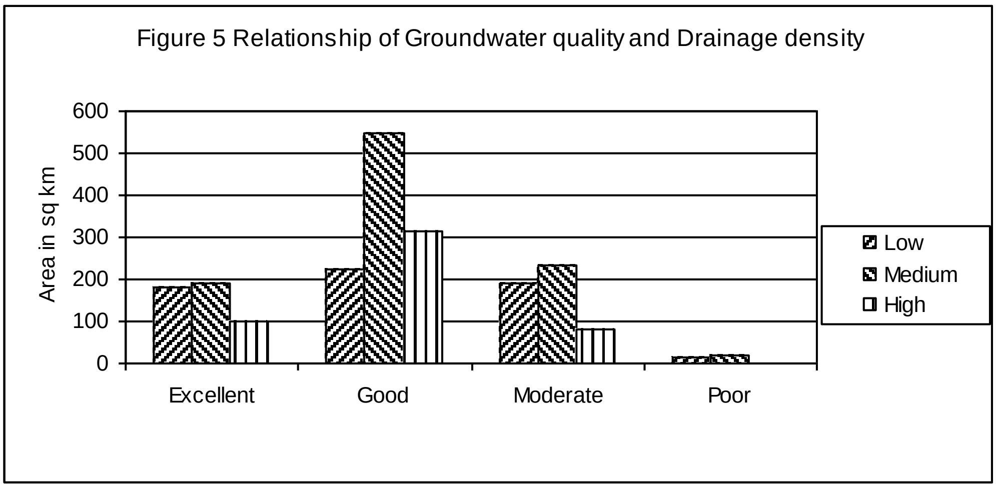
Though the Alluvium and Ironstone formations spread over only limited area, they host good class category. Excellent water category is seen associated with Barakar and Barren measure formations. Moderate water quality class is seen more in Raniganj and Talchir formation, which is mainly due to composition of the rock types. Poor class is noticed only in the metamorphic terrain, which is significantly less in extent.

Sandstone rocks of Barakar and highly fractured nature of Barren formations indicate the higher degree of water holding capacity. But, during mining operations, aquifers (sandstone strata) inter-bedded with coal seams in the Barakar formation are being widely disturbed, resulting in significant damages. In many occasions, water has been pumped out depending upon the nature and method of mining methods from these formations. In this context, nearly 12% of the study area, which holds good groundwater resource, is under critical threat.

Relationship of groundwater quality with drainage density:

Damodar and Barakar Rivers flow at south and north of the study area respectively. Many tributaries drain the area. Most of the Damodar River tributaries are, one time or other, have been diverted from their main course due to mining activities in the Jharia coalfield.

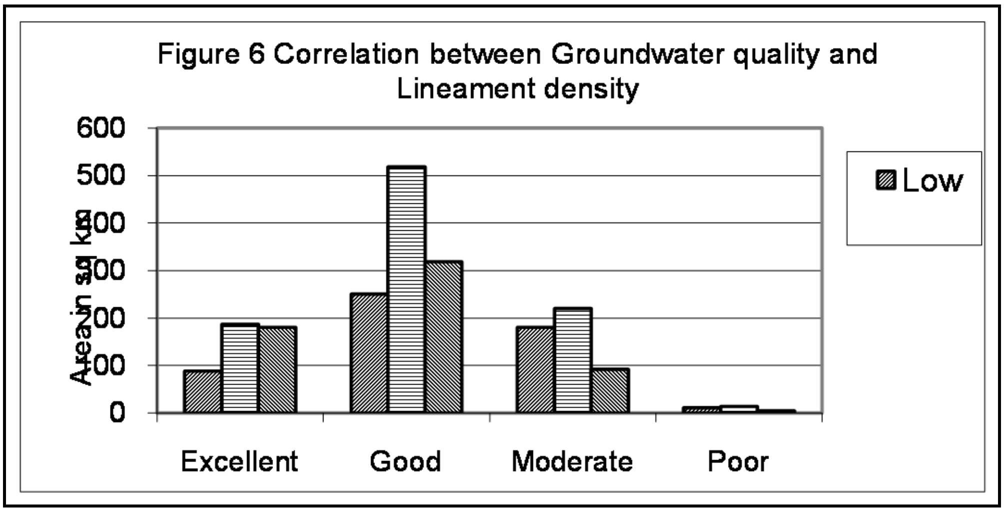
Medium drainage density class spreads around a half of the study area, low and high-density class covers each nearly a quarter of the total area. While analyzing the correlation of drainage density on groundwater quality based on spatial aspect, all quality classes are prominent in Medium density areas with declining towards low and high-density classes (Fig 5).



But, based on the characteristic of each density classes, the excellent water quality is seen more associated in low-density class. This trend substantiates the influence of geological nature of the area and the assimilative infiltration capacity of subsurface characteristics of the area. Since most of the high-density drainage areas are associated with mining areas, good quality water is at threat, which necessitates the systematic regional planning to conserve the water potential.

Correlation of groundwater quality with lineament density:

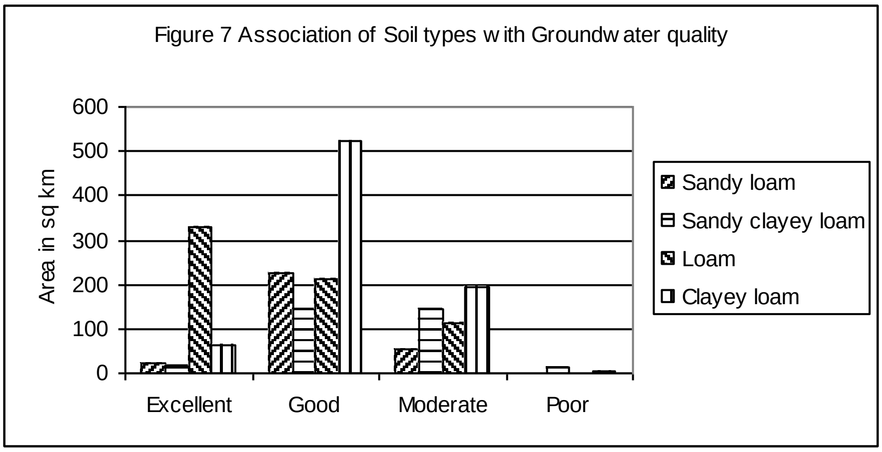
Lineament details of the study area have been obtained from satellite images and aerial photographs. According to intensity of lineament occurrences, three zones have been categorized. High-density zones mainly associated with mining areas occupy nearly 28.60% of the total area. Medium and low-density classes occupy 46.38% and 25.03% respectively. Figure 6 presents spread of each class against various quality classes.



High-density class has been associated with the excellent and good water quality areas and vice versa with moderate quality class. However, all categories of density classes are seen associated with good quality water potential areas, substantiating the concept of groundwater recharge through lineaments. The main concern of the study area is that nearly 28.60 % of the total area is related to core and buffer mining areas. Such situation leads to minimize the recharge potential thereby reducing the groundwater level gradually as well as may induce pollution injection through opened up and uncared lineament zones.

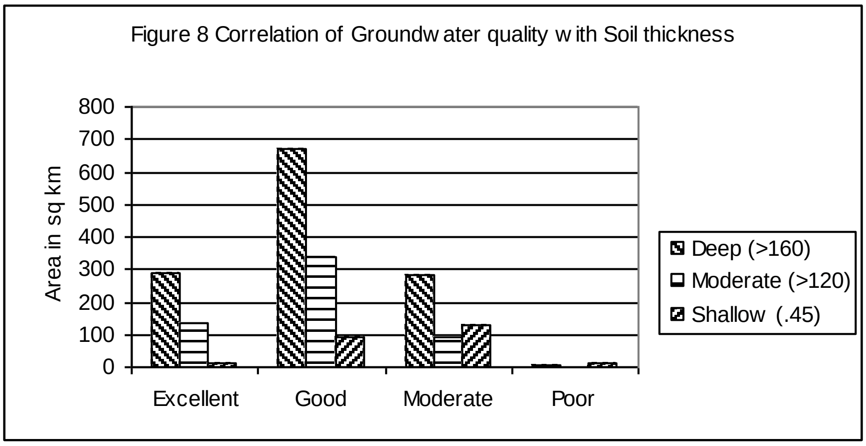
Association of soil types with groundwater quality:

There are four types of soil groups in the study area (Fig 7). Most of the agricultural activities are associated with loam and clayey loam soil types (nearly 70% to the total study area) wherein the groundwater quality is appreciable. Soil types such as sandy loam and sandy clayey loam are mainly representing recent and immature group of soil, which support limited cultivation. In this particular less productivity group, nearly 406.84 sq km area, which amounts to 20% of the total study area, is associated with excellent and good groundwater quality class. It is noticed that most of the active mining areas are located at these classes causing threat to good water quality potential.



Correlation of groundwater quality with soil thickness:

Soil thickness classes of the study area have been generalized into three major classes with reference to recent classification[3]. Soil thickness shows a positive correlation with soil types of the area wherein clayey loam and loam category of soil groups are associated with deep to moderate thickness classes (Fig 8). Shallow soil thickness class cover one tenth of the study area with immature soil types but generally associated appreciable measures of good and moderate water quality classes. One fourth of the study area is covered with moderate soil thickness class, which is significantly allied with good and moderate water quality classes. Most of the study area, more than half of it is enveloped with deep soil class and coupled with good and excellent water quality classes.



Most of the study area is seen associated with excellent and good water quality classes in sedimentary terrain. It is seen that sedimentary terrain is characteristic of deep soil class and shallow soil class is widely seen with metamorphic terrain. However, coal-mining activity is being practiced in sedimentary terrain of Gondwana basin, which indicates the endangering situation of excellent and good water quality class associations. Whether it is opencast or underground mining, impacts on water regime are considerable in sedimentary terrain, in turn, systematic conservation strategies are to be implemented with due care to minimize the significant transformations in the land and ecological regimes.

Inferences on soil erosion with groundwater quality:

Soil erosion in the study area is categorized into three groups depending upon the soil type and slope of the area. Since the study represents dominantly of rolling uplands and pediment terrain, the soil erosion has been a significant problem. Appreciable amount of area is under various magnitude of erosion (Fig 9). Generally, the land appreciably associated with the erosion behavior of the terrain.

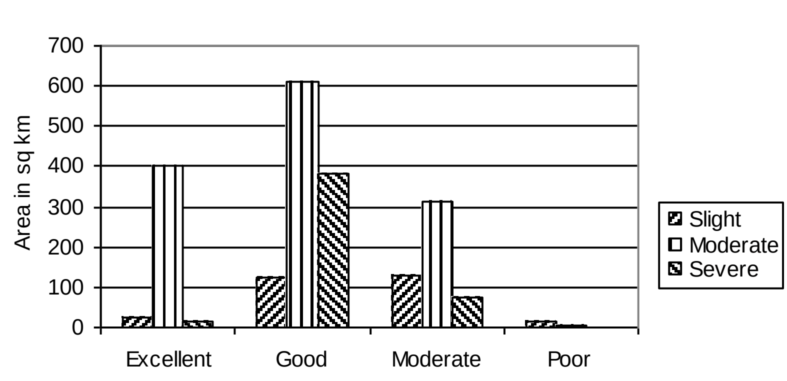


Figure 9 Soil erosion categories and Groundw ater quality types

The correlation indicates that the areas having good water quality faces moderate to severe erosion hazards. In such places, agricultural practices are at stack. Most of the excellent water quality areas are associated with moderate erosion class. It is observed that mining areas too substantiate erosion behavior of the area in terms of defacing the real terrain setup and subsequent generation of dumps. Due to above possible threats, even areas with good quality water could have missed the sustainable development. In spite of having good quality water resources, in many places around mining zones, one can witness either the nature of barren environment or underdevelopment in respect to ecological improvements.

Implications of groundwater quality on land use practice:

Land use map of the study has been prepared from images of IRS (Indian Remote Sensing Satellite) based on Classification on National Remote Sensing Agency[2] of India. For the purpose of the present study, land use map has been generalized into major groups and their relationship with groundwater quality zones are presented in Fig 10.

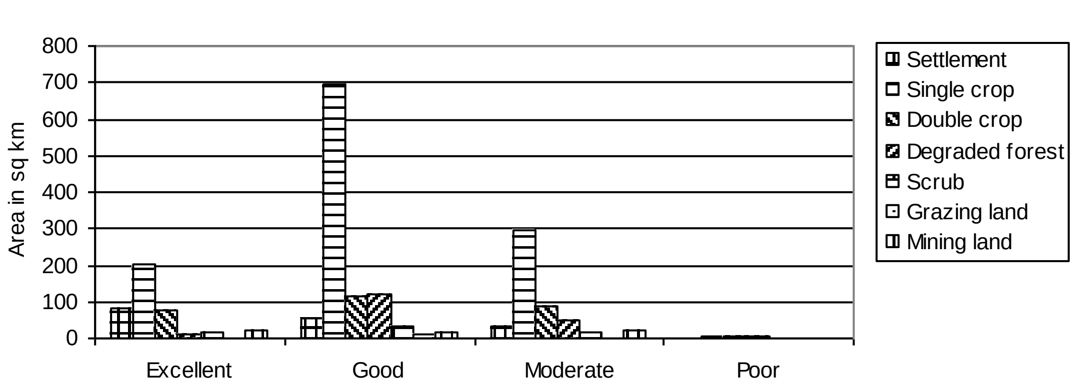


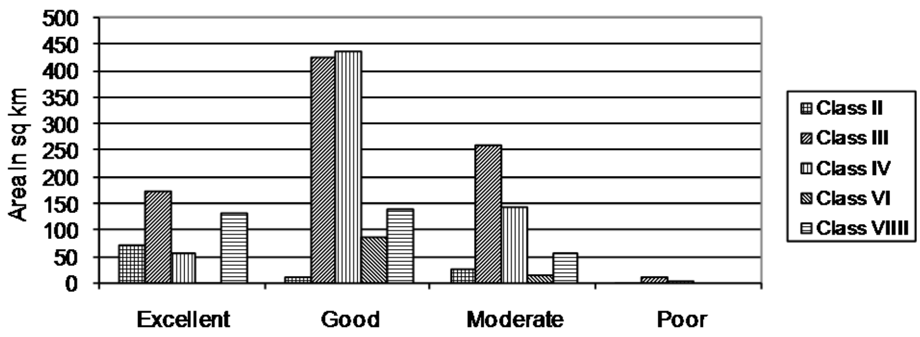
Figure 10 Implication of Groundw aterr quality on Landuse practice

While agricultural land is the dominant land use (70%) represented by the single and double crops, the mining is the significant activity in the study area (3%). Water bodies occupy nearly 4% of the total area. While analyzing the water quality occurrence against each land use category (Fig 10), it is seen that settlement areas have enough good quality water for domestic development. Agricultural lands of both single and double crop areas are provided with appreciable water resources of good quality. Also, forestlands including private forests are associated with favorable water potential areas. The aerial extent of grazing land in the study is limited. Most of the scrub areas are with wastelands, which have scope for transformation as with available water availability. Out of about 60 sq. km mining areas (about 3% to the total study area), more that 65 % of the total mining lands are associated with excellent and good ground water resources and are constantly under threat in the study area.

Association groundwater quality with various land capability zones:

Based on the guidelines of the Indian Council of Agricultural Research[1], Land capability classification has been carried for the study area. The capability classes are derived on the basis of the capability of land to produce common cultivable crops and pasture plants without detoriation over a long period. Eight classes are grouped into two major categories viz., suitable for cultivation and unsuitable for cultivation but suitable for other land use practices.

Figure 11 Association of Groundwater quality with Land capability classes



Generally, class II to IV holds good prospect for agricultural practices. More than 79% of land falls in this category (Fig 11). Nearly 300 sq km and 878 sq km of total study area come under excellent and good groundwater quality potential areas respectively. Nearly 21% of total study area is unsuitable for agriculture, which categorized into class VI and VIII. The area associated with class VIII is degraded land category, which has extremely poor scope for any type of improvement and development. This class amounts to about 16% of the total study area. The entire active mining zones (3% to the total study area) enveloped into this class VIII. In other words, the area under class VIII represents wasteland, which is associated with active mining areas, degraded areas due to mining and barren rocky lands. While assessing the relationship of groundwater quality to the class VIII, the excellent and good quality groundwater classes are associated with nearly 270 sq km area (i.e. 13% of the total area). With the continuous mining activity, not only the good groundwater quality would be appreciably disturbed but also the increasing degraded land would be evident.

Conclusion

In the present study, GIS has been used to understand the relationship between groundwater quality zones with other thematic parameters in and around one of the prime coal mining fields of eastern India. It is observed that the impact on groundwater quality has been appreciably influenced by geology, soil, drainage density and lineament density. However, the present mining activities are much associated with areas where good quality of groundwater is available. Though mining area occupies only about 3% of the study area, proportionally more areas under threat as for the groundwater is concerned. Such prolonged mining activities have signaled a gradual increasing trend in quality degradation and water wastages and decreasing in recharge capacity of the area. It is warranted to take appropriate steps to look into the issues more sternly in future.

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