Journal of Spatial Hydrology
Vol.7, No.1, Spring 2007

# Assessing aquifer vulnerability to arsenic pollution using DRASTIC and GIS of North Bengal Plain: A case study of English Bazar Block, Malda District, West Bengal, India

*Surajit Ckakraborty [a], P. K. Paul [a] and P. K. Sikdar [b*]*

**Abstract**
Geographic Information System (GIS) was utilized to apply a modified DRASTIC method to assess the aquifer vulnerability to pollution of English Bazar Block of Malda District, West Bengal, India. In the western, central and southern parts of the study area the aquifer is prone to contamination. Therefore, in these regions pesticides, which may contain arsenic or arsenic rich groundwater, should not be used in irrigated land or mango orchards. In order to understand the reliability of the aquifer vulnerability, sensitivity analysis was carried out. This analysis indicates that in 62% of the area the vulnerability classes correspond to the present arsenic concentration in groundwater.

**Keywords:** DRASTIC, vulnerability, arsenic, groundwater, Malda, West Bengal

## Introduction
English Bazar Block of Malda district, West Bengal, is located on the western part of the alluvium-filled gap between Rajmahal hills on the west and the Garo hills on the east. The block is bounded by latitude 24°50'N to 25°05'N and longitude 88° 00'E to 88° 10'E with a total area of 265.5 sq. km. (Fig.1). The block can be divided into municipal area covering an area of about 13.6 sq. km in the east central part of the block and the non-municipal area covering about 251.9 sq. km. The municipal area is urbanized with a population density of 11,846 persons/sq km. The non-municipal area is rural in nature with a population density of 899 persons/sq. km and consists of 135 villages. The area is generally flat with topographic elevation ranging between 22.4 m and 25.3 m (Fig.1). The rainfall sets in by the middle of the June with the onset of monsoon.

The average annual rainfall in the area is 1,557 mm. On an average there are 67 rainy days in a year. The area is drained by the Ganga (known as Bhagirathi) River, the Mahananda River, and the Kalindri River. The Bhagirathi River demarcates the western and southwestern boundaries of the block and flows in a southeasterly direction. The Mahananda River, which flanks the northeastern boundary of the block, is next in importance. The other river, in the northern part of the block is Kalindri. (Fig.1). All the rivers in the area are mature and meander characteristically. Apart from the rivers there are number of typical ox-bow lakes along the abandoned channel courses.

The demand of potable water of the block is about 33.9 million litre per day (mld). Apart from this, groundwater is being extensively used for agricultural purpose. Sikdar and Chakraborty (in press) indicated that arsenicals used as fertilizer, pesticides in mango orchards and multicropped agricultural land, wood preservative and arsenic pumped out along with groundwater for irrigation may be the possible sources of arsenic in groundwater. High abstraction of groundwater could lead to downward infiltration of arsenic rich water used for agricultural purpose from the surface, and then horizontal movement of arsenious water within the aquifer towards the fresh water zones. These conditions would lead to pollution of uncontaminated zones of aquifer. The groundwater of

[a]Department of Mining and Geology, Bengal Engineering and Science University, Howrah-711103, West Bengal, India.
[b]Department of Environment Management, Indian Institute of Social Welfare and Business Management, College Street, Kolkata-700073,West Bengal, India. *Communicating author.: E-mail: p_sikdar@hotmail.com

western part of the municipal area has arsenic concentration above 0.05 mg/l. On the other hand the entire municipal area has arsenic concentration below the detection level.

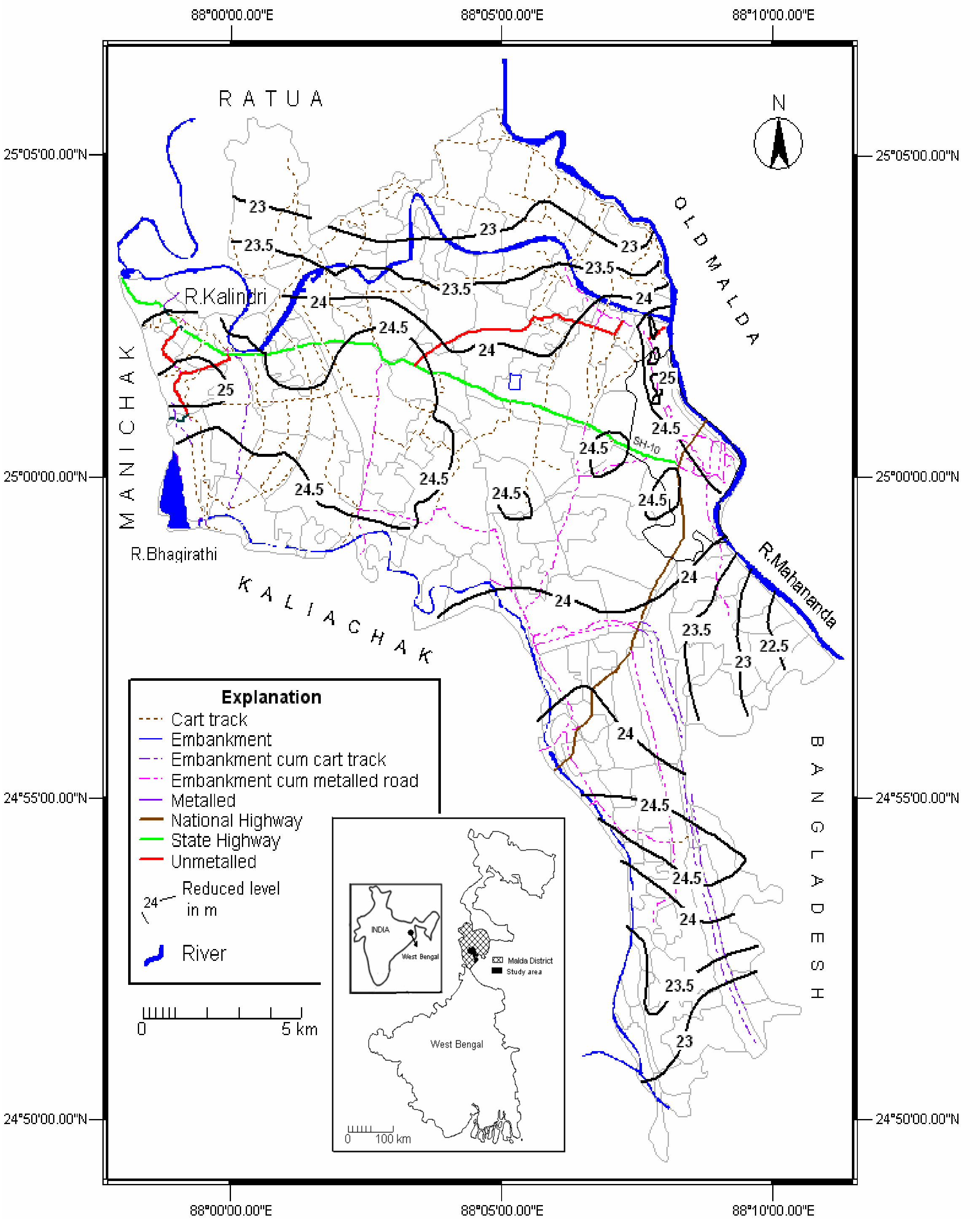


Fig. 1 Location map showing topographic contours

The demand of potable water of the block is about 33.9 million litre per day (mld). Apart from this, groundwater is being extensively used for agricultural purpose. Sikdar and Chakraborty (in press) indicated that arsenicals used as fertilizer, pesticides in mango orchards and multicropped agricultural land, wood preservative and arsenic pumped out along with groundwater for irrigation may be the possible sources of arsenic in groundwater. High abstraction of groundwater could lead to downward infiltration of arsenic rich water used for agricultural purpose from the surface, and then horizontal movement of arsenious water within the aquifer towards the fresh water zones. These conditions would lead to pollution of uncontaminated zones of aquifer. The groundwater of western part of the municipal area has arsenic concentration above 0.05 mg/l. On the other hand the entire municipal area has arsenic concentration below the detection level.

Therefore, a study was undertaken to delineate the areas where the aquifer is vulnerable to pollution due to anthropogenic activities such as irrigation return flow and application of pesticides and wood preservatives. Thereafter, the reliability of vulnerability of the aquifer to contamination was verified using the spatial distribution of arsenic as an indicator. In the next step it was also examined whether arsenic rich groundwater could flow into the aquifer below the municipal area.

The geological setting of the area is a result of the tectonic history and subsequent sedimentation in the Garo-Rajmahal Gap, which divides the Bengal Basin into a northern foredeep in front of the Himalayas and a southern delta (Dasgupta, 1997). The formation of Garo-Rajmahal Gap in the Pleistocene resulted in new avenues of sediments from the Himalayan rivers. The area is thus covered by Quaternary alluvia of two different ages: the Older (Barind) Alluvium and the Newer (Rarh) Alluvium (Pal and Das, 1992; Deshmukh, 1973) (Table1). The Older Alluvium of Pleistocene age form the higher grounds. It is made up of reddish brown argillaceous bed and interspread with ‘kankar’ and laterite debris. The Newer Alluvium is flanked to the west of the Older Alluvium, is dark, loosely compacted and has a high moisture content. The recent alluvium also occurs in some of the restricted areas of the Barind tract within the proximity of the present day drainage. About 95% of the area constitutes the “Rarh” land where as ‘Barind’ has a limited outcrop in the eastern part, that too covered by a thin blanket of cultural soil and/or flash flood deposits.

Table 1 Morphostratigraphic and Geologic Units of English Bazar Block

| **Morphostratigraphic unit** | **Geologic unit** | **Geologic Age** |
|---|---|---|
| Diara Surface | Diara deposits | Recent |
| Kaliachak Surface | Older Flood Plain deposits | Upper Holocene- Mid Holocene |
| Maldah Surface | Purnea Formation | Mid Holocene-Lower Holocene |
| Barind Surface | Barind Formation | Pleistocene |

3-dimensionally the area consists of a continuous clayey silt bed varying in thickness from a thin veneer to about 20m at the top followed by sand of various grades mixed with gravels and carbonate nodules. The thickness of the clayey silt bed is thin in the western side and attains its maximum thickness in the eastern side. There are several clay lenses splitting the sand body into a multilayered sequence at various depths. The sand shows coarsening downward sequence. The sand is highly micaceous and often tends to be silty. The continuity in the sequence of sand, which forms the aquifer material, is broken by the occasional occurrence of clay lenses of limited lateral extent. These clay beds are dark grey to black in color, sticky and are plastic to semi-plastic in character. The clay beds are often found to contain stringers of silt and fine sand. They are less plastic wherever they are admixed with fine sand or silt. A conspicuous feature is the occurrence of fine to coarse sand horizon mixed occasionally with gravels and sandwiched between clay beds.

The top 10 m of the sedimentary column of the area is represented by the lithofacies distribution (Fig.2). A perusal of the map reveals that throughout the southern side of the block as well as in the municipal area, clay and silt is the predominant lithofacies. The grain size ratio (GSR) of the sediment is between 0 and 0.25 respectively. In the central part of the block there are two dominant lithotypes-sandy clay and clayey sand. The sandy clay occurs as a band on the western part of the municipality, which swings northeast, having a GSR between 0.25 and 1. Adjacent to it there is roughly NE-SW trending clayey sand (GSR between 1 and 8). A small pocket of clay and silt occurs on the western part of the block. An area of sandy clay surrounds it. A small pocket of sandy clay also occurs by the side of the Bhagirathi River in extreme west. Small pockets of sandy clay occur in the municipal region. Sand occurs as the dominant lithotype in the far north-west on either sides of the Kalindri River and also as a small round pocket in the western part of the block, where the GSR is greater than 8. The grain size of the lithotypes shows a progressive increase from southeast to the northwest. Accordingly the change in the lithofacies along this direction is:

**Clayey silt → Sandy clay → Clayey sand → Sand**

***Soil***

There are four types of soil viz. clay loam, silty loam, loam, sandy loam (Fig. 3). In the eastern part of the block along the Mahananda River the soil is clay loam containing iron nodules. The pH content of this soil varies from 4.2 to 5.5. Silty loam is found as pockets mostly in the central part of the block. These soils are soft with iron nodules overlain by a dark grey to dirty yellow organic material. In the major part of the block the soil is loamy in nature. This soil is very fertile and neutral in reaction. On the eastern side, the proportion of clay is greater. Further west the proportion of sand increases and ends at Bhagirathi River. Along the river bank the soil is highly fertile and is sandy loam in nature. The pH of this soil varies from 6.8 to 7.8.

***Groundwater Condition***

Groundwater occurs under unconfined condition in a thick (108 –117 m) zone of saturation within the alluvial sediments. At the upper part of the sedimentary column (within a depth of 10 m) there is a mixture of silt, clay and fine sand (Fig. 2). Below this there is a thick sandy horizon comprising fine to coarse material. Generally tube wells with drilling depths between 70 m and 104 m below ground level (bgl) have been constructed. However, the maximum depth is 121 m in the municipal area. Potential aquifers occur in the depth range of 44 m - 69 m and 73 m - 89 m where coarse sand and gravel is encountered. From the 93 network stations established in the study area it is observed that the water table during post-monsoon 2004 varies from 2.20 m to 12.65 m bgl (Fig. 4) and during pre-monsoon 2005 from 3.32 m to 16.50 m bgl. The groundwater contour map indicates that the dominant groundwater flow directions are E'ly, NE'ly and N'ly. Other less dominant flow directions are towards S and W (Fig. 5). The Mahananda river all along its western bank receives groundwater and therefore is a gaining or effluent river. The Kalindri River receives water from north and southeast and behaves also as an effluent one. The Bhagirathi is perhaps a loosing or an influent river as the flow lines are either parallel to it, or move away from it.

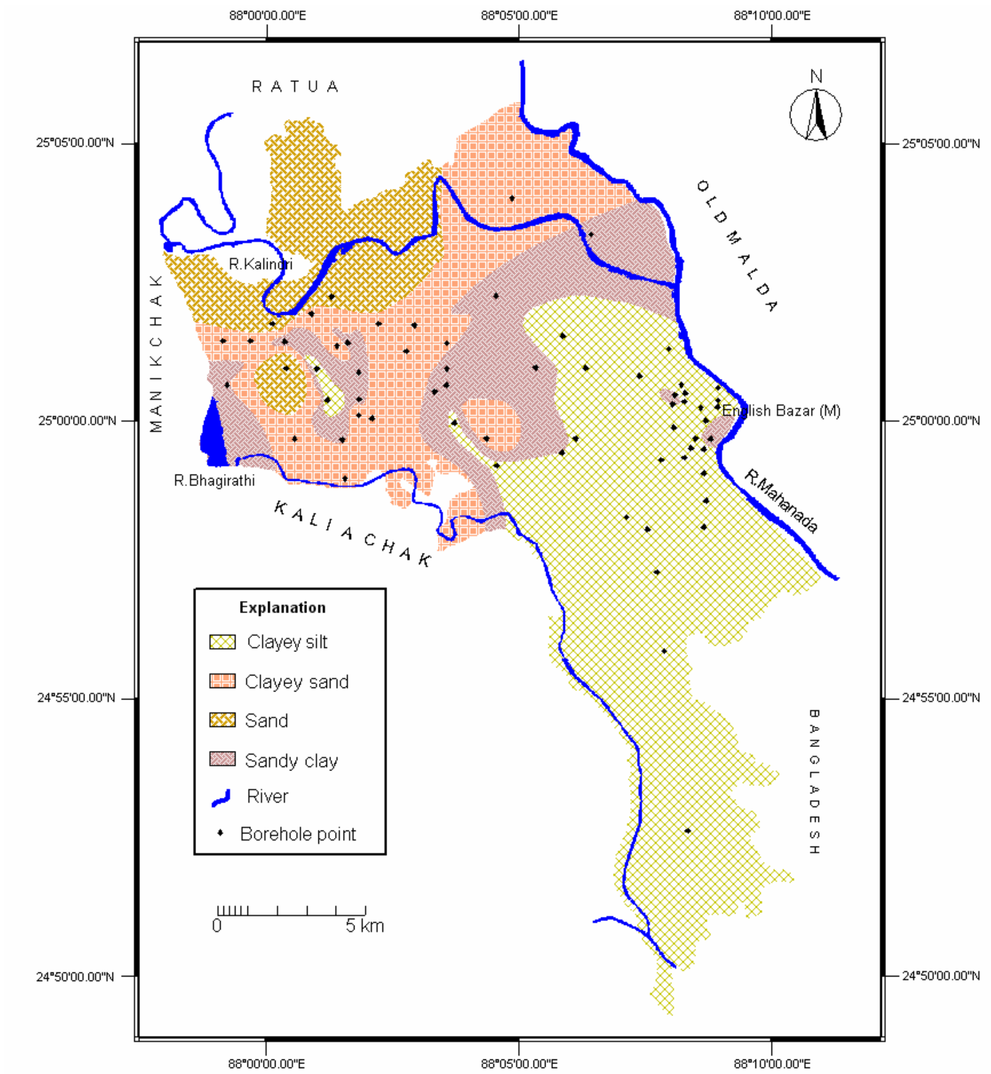


Fig. 2 Lithofacies map for the depth span of 10 m from ground level

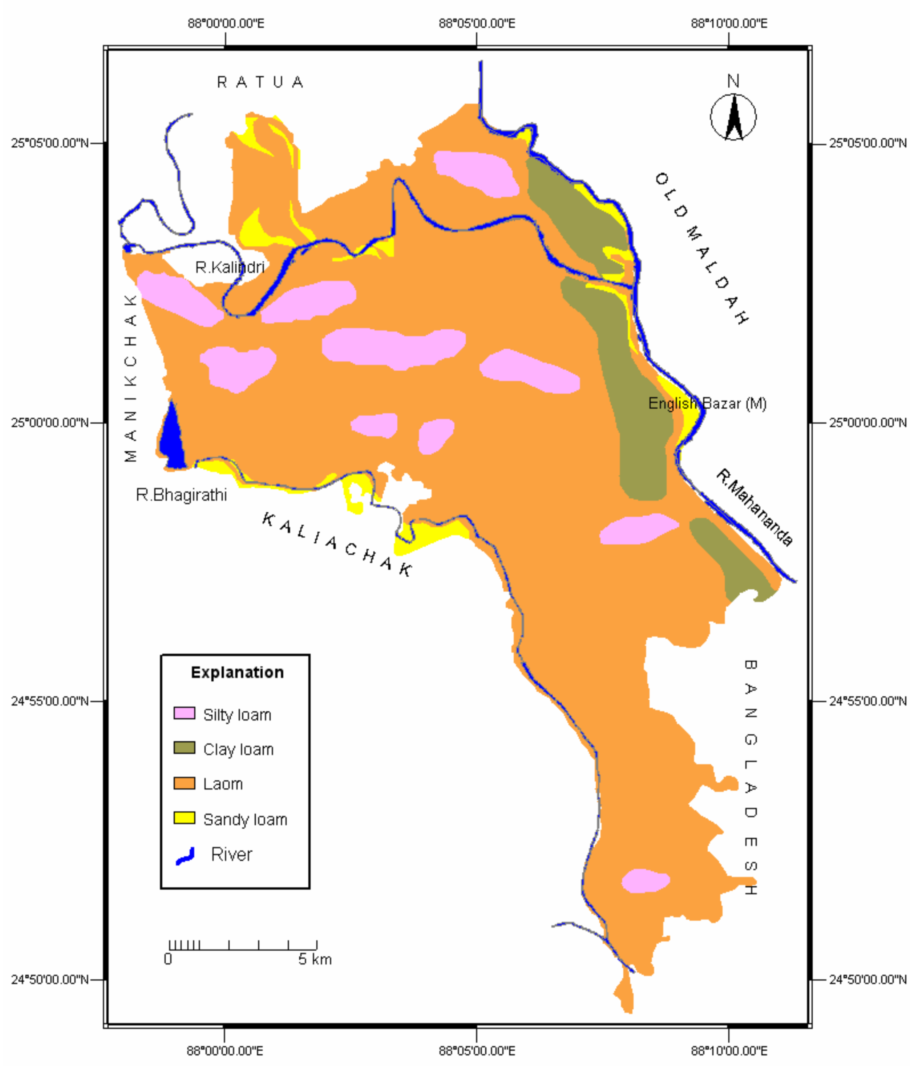


Fig. 3 Soil map of the study area

Arsenic in groundwater with concentration beyond the permissible limit of 0.05 mg/l (as per IS: 10500-1991) is found to occur within the depth span of 16 m to 57 m. The spatial distribution of arsenic in groundwater within the study area shows that the concentration broadly decreases from west to east (Fig. 5).

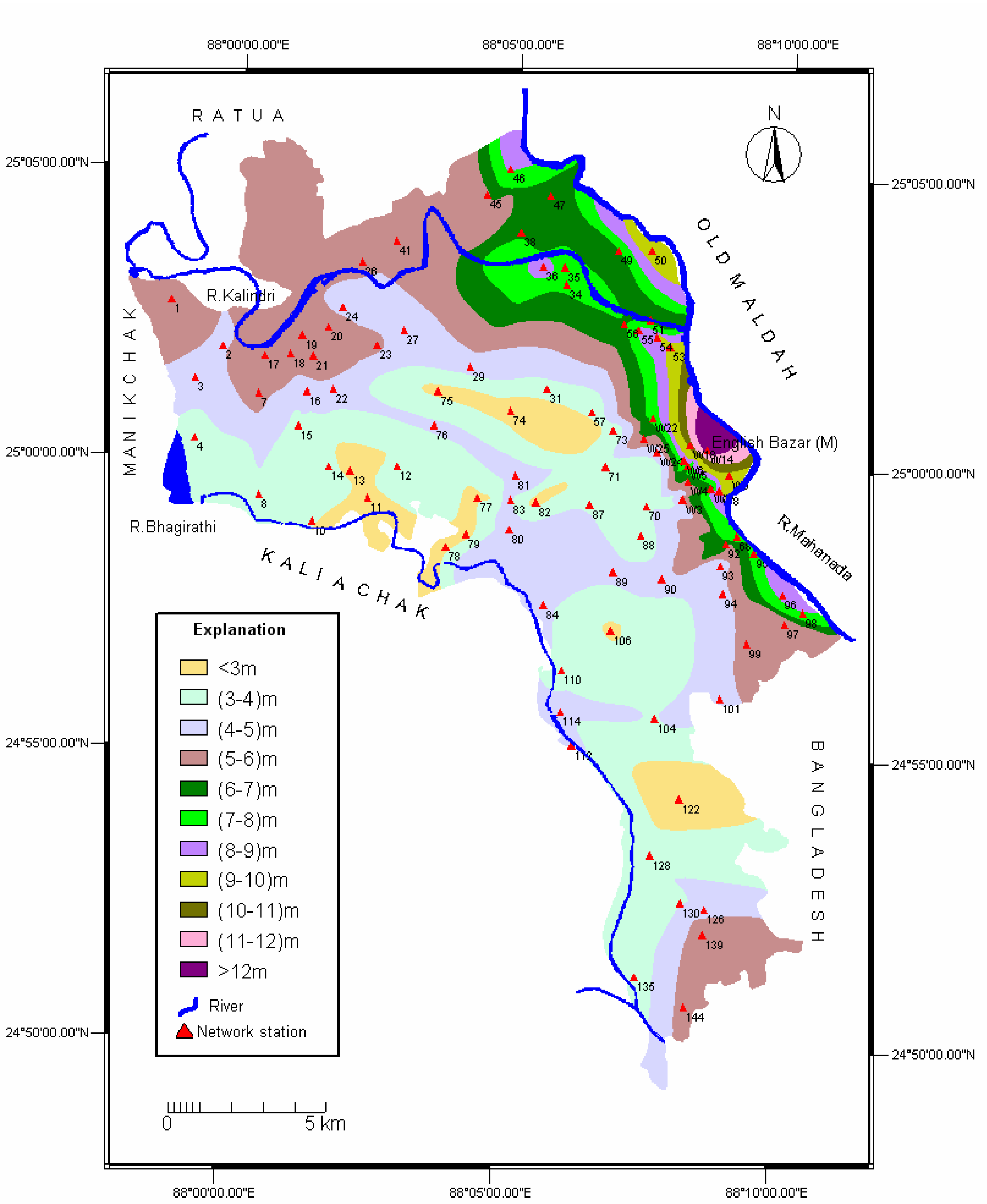


Fig. 4 Depth to water table map of post-monsoon 2004

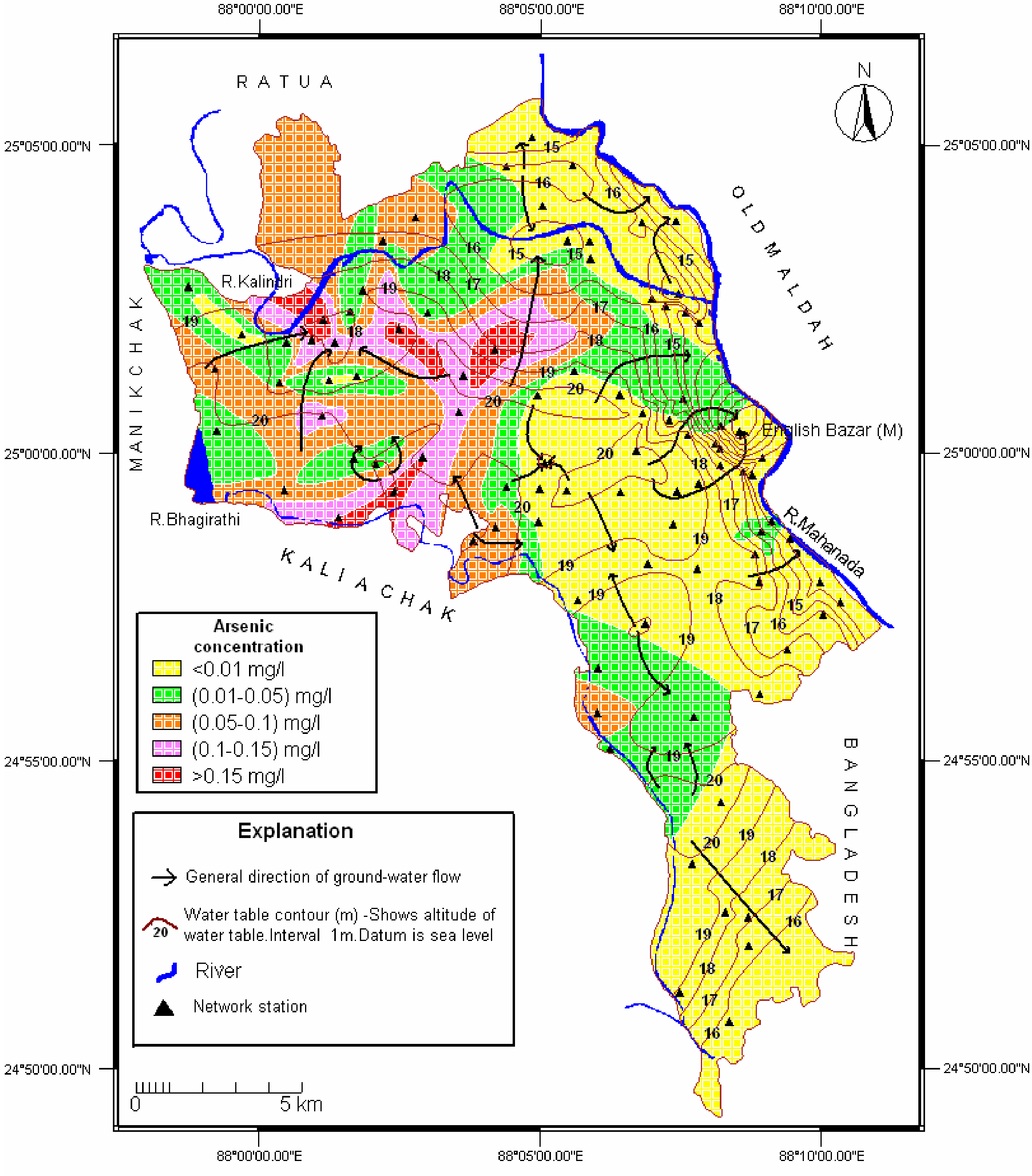


Fig. 5 Map showing pre-monsoon (2005) water table elevation contours and arsenic concentration

**Methodology**

Aquifer vulnerability overlay/index methods (Vrba and Zaporotec, 1994; USEPA, 1993; Zhang *et.al*., 1996) can be categorized into: (i) hydrogeologic setting classification and (ii) scoring method. The overlay/index procedure utilized for generating the vulnerability map present in the study is akin to the DRASTIC groundwater pollution hazard assessment method (Aller *et al*., 1987). The DRASTIC model functions on the basis of the following linear equation:

**Pollution potential** = $D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w$

where, **D** = Depth to water table (Fig. 4)
**R=** Recharge (Fig.6)
**A** = Aquifer media (geology)
**S** = Soil media (texture) (Fig.3)
**T** = Topography (slope) (Fig.1)
**I** = Impact of vadose zone (Fig. 2)
**C =** Hydraulic Conductivity of the aquifer,
and the subscripts **r** and **w** denote the rating and the weight, respectively.

Weights provide an indication of relative parameter influence within the equation in the scale of 1 to 5, where 1 represent the least significant factor and 5 represents the most significant factor. The DRASTIC method assumes that all the contaminants moves vertically downwards with the water and are introduced at the soil surface. A combination of variable weights have been evaluated and based on the results obtained a specific weight has been assigned to each DRASTIC parameter on the basis that each weight determines the relative significance with respect to pollution potential (Table 2).

Table 2 Assigned weights for DRASTIC parameters

| Parameters | Weights |
|---|---|
| Depth to water | 5 |
| Net Recharge | 4 |
| Aquifer Media | 3 |
| Soil Media | 2 |
| Topography | 1 |
| Impact of Vadose Zone | 5 |
| Hydraulic Conductivity | 3 |

Ratings reflect the relative significance of classes (1-10) within each of the seven parameters. All variables are dimensionless. Ratings for aquifer media, soil and hydraulic conductivity is taken from USPEA, 1993 (Tables 5, 6 and 9) since the ratings depend on physical character of the parameter which are more or less constant. New rates have been assigned to depth to water table, recharge, topography and vadose zone, which uniquely reflects English Bazar hydrogeologic environment and landscape characteristics influencing contaminant transport (Tables 3, 4, 7 and 8). The ratings of each layer are stored in an attribute table in the column ratings in GIS platform. DRASTIC index calculated indicates relative pollution potential. Higher the DRASTIC index greater the pollution potential. Based on DRASTIC values, aquifer vulnerability can be low, moderate, high and very high. The areas with high and very high index values are relatively more vulnerable to contamination and consequently need to be managed more carefully.

The aquifer vulnerability analysis was carried out under GIS environment using raster based GIS software ILWIS 3.3 (Integrated Land and Water Information System) Academic version. Though DRASTIC model was not originally designed as a GIS-based tool, but GIS can be utilized for such analysis (Merchant, et al., 1987; Griner, 1989; Regan, 1990; Evans and Myers, 1990; Rundquist *et al*., 1991; Riggle and Schmidt, 1991; Lusch *et al*., 1992; Trent, 1993; Merchant, 1994; Shahid, 2000; Menani, 2001; Piscopo, 2001; Chevrel, 2003; Tezcan and Ekmekci, 2004; Jha and Joseph, 2005; Panagopoulos, et al., 2006; Herlinger Jr., 2007). Initially all the seven DRASTIC maps were geo-referenced, digitized, and edited to generate polygon maps. These polygon maps were classified either into ranges or into significant media types, which have an impact on pollution potential. The range for each factor has been assigned a subjective rating, which varies between 1 and 10. The ratings are incorporated into the GIS attribute table of specific polygon maps. The polygon maps containing the rating values were then converted into specific raster maps. Weight multipliers are then used for each raster maps to balance and enhance its importance. Combining all the raster maps using the above equation a final vulnerability map was generated.

**Data layer preparation**

To carry out the aquifer vulnerability analysis using DRASTIC seven thematic maps were prepared. They are as follows:

***Depth to water table (D)***

Depth to water table (Fig. 4) is a significant factor controlling the ability of pollutants to reach the aquifer. It affects the time available for contamination to undergo chemical and biological reactions such as dispersion, oxidation, natural attenuation, sorption etc. A shallow depth to water table will lead to a higher vulnerability rating. Depth to water table map has been estimated based on post monsoon (2004) water table data collected from 93 network stations. Rating values for water depths was assigned based on the assumption that a shallower water table is more vulnerable to pollution (Table 3).

Table 3 Ranges and rating for depth to water table

| Range (m) | Rating |
|---|---|
| <3 | 10 |
| 3-4 | 9 |
| 4-5 | 8 |
| 5-6 | 7 |
| 6-7 | 6 |
| 7-8 | 5 |
| 8-9 | 4 |
| 9-10 | 3 |
| 10-11 | 2 |
| 11-12 | 1 |
| >12 | 1 |

***Recharge (R)***

Recharge (Fig. 6) describes the amount of water available at the surface that infiltrates into the soil and then continues to percolate through the vadose zone into the aquifer. Recharge represents the primary contaminant transport mechanism into the aquifer and depends on the soil characteristics. A sand or loamy sand soil will have the maximum infiltration capacity (2-6 inch/hr) where as compacted clay loam may allow very small amounts of infiltration (0.2-0.6 inch/hr). In urban areas where the soil is covered by an impermeable layer no recharge would occur. Ratings were assigned based on the fact that sandy soil with higher recharge rate is more vulnerable to pollution (Table 4).

Table 4 Ranges and rating for recharge

| Range (inch/hr) | Rating |
|---|---|
| <0.2 | 2 |
| 0.2 - 0.6 | 4 |
| 0.6 – 2.0 | 6 |
| 2.0 – 6.0 | 8 |
| > 6.0 | 10 |

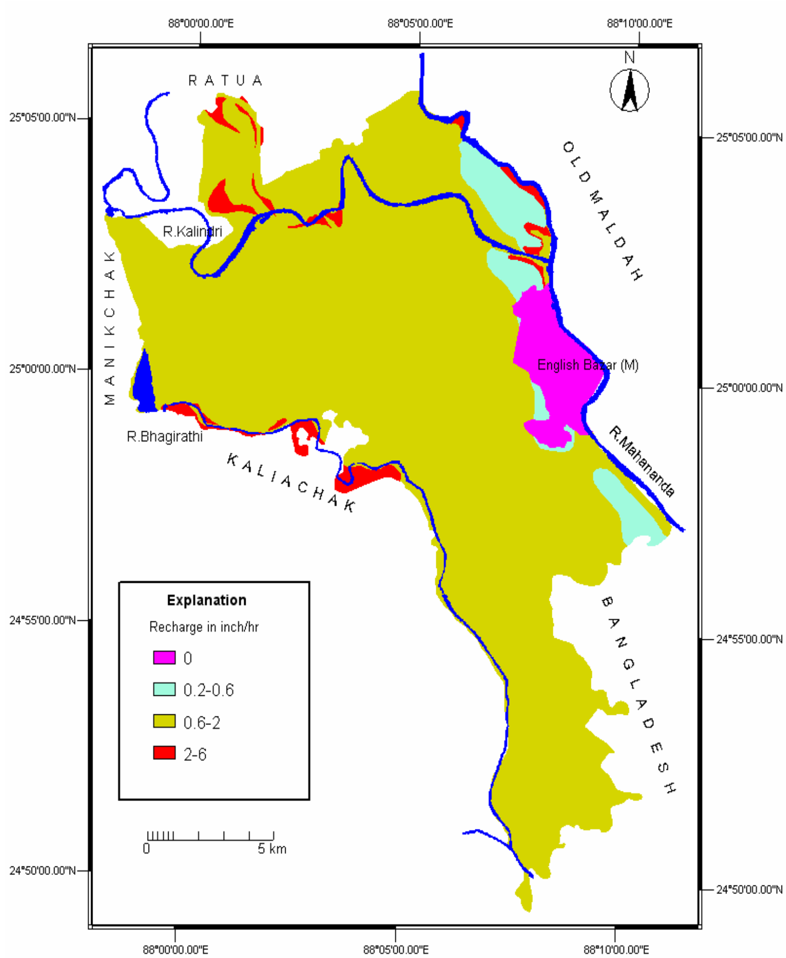


Fig. 6 Spatial distribution of recharge rate of the study area

***Aquifer media (A)***

Aquifer media has been identified from field mapping and borehole data. The aquifer in the study area consists of fine to medium sand with occasional gravel. Following the USEPA recommendation the aquifer has been assigned a value of 8 (Table 5).

Table 5 Ranges and rating for aquifer media

| Range | Typical Rating |
|---|---|
| Massive shale | 2 |
| Glacial Till | 5 |
| Bedded sandstone and shale sequence | 6 |
| Massive sandstone | 6 |
| Sand and Gravel | 8 |

***Soil media (S)***

Soil media (Fig. 3) is the portion of the unsaturated zone characterized by significant biological activity. The characteristics of the soil influence the amount of recharge infiltrating into the groundwater body, the amount of pollutant dispersion, the purifying process of contaminants etc. A number of soil characteristics control the capacity of contaminants to move into the groundwater. The thickness of soils determines the length of time contaminants reside within the media. The longer the contact time, the more opportunity for interaction with biological and physical elements that can potentially degrade pollutants or dissolve contaminants such as arsenic. Organic material, clays, and other minerals react with contaminants to degrade, absorb or volatilize the chemicals. The soil hydraulic conductivity, texture and structure influence the rate at which water percolates through the soil profile. Soil types are strongly controlled by the surface deposits and morphology. This relationship is sufficiently consistent so that boundaries of surface geological units can be considered the same as those of contrasting soil types. District soil survey reports and surface geological map were used to evaluate soil composition and landscape relationships. Ratings were assigned to define soil classes based primarily on the texture of the soils (Table 6). Texture is based primarily on the ratio of sand: silt: clay. More the finer particles present less is the vulnerability of the soil to pollution.

Table 6 Range and rating for soil media

| Range | Rating |
|---|---|
| Silty Loam | 4 |
| Sandy Loam | 6 |
| Loam | 5 |
| Clay Loam | 3 |

***Topography (T)***

Topography refers to the slope of land and is expressed as percent slope. Areas with low slope tend to retain water longer. This allows a greater infiltration of recharge water and a greater potential for contaminant migration. Areas with steep slopes, having large amount of run-off and smaller amount of infiltration, are less vulnerable to groundwater contamination. A contour map on the scale of 1.4 cm = 10 km was collected from the Geological Survey of India. Two maps on the scale of 1:50,000 and 1:25,000 were collected from the Survey of India. These maps have been overlaid on GIS platform. All the maps were then geo-referenced, digitized and edited to get a topographic contour map in the scale of 1:50,000 (Fig.1). The contour map was then rasterised using ILWIS 3.0 Academic version software to generate the Digital Elevation Model (DEM). On the generated DEM, DfDx and DfDy filters were applied to generate the slope percentage map using the function [100 * HYP (DX, DY)/ PIXSIZE (DEM)]. The GIS was then used to convert slope percent values to ratings by processing slope data through the defined functions (Table 7). The slope percent range from 9-10.

Table 7 Range and rating for topography

| Range (% Slope) | Rating |
|---|---|
| 0-2 | 10 |
| 2-4 | 9 |
| 4-6 | 8 |
| 6-8 | 7 |
| 8-10 | 6 |
| 10-12 | 5 |
| 12-14 | 4 |
| 14-16 | 3 |
| 16-18 | 2 |
| >18 | 1 |

***Impact of Vadose Zone (I)***

The vadose zone (Fig. 2) is the unsaturated horizon above the water table. If vadose zone is highly permeable, then this will lead to a high vulnerable rating (Corwin, *et al*., 1997). Vadose zone map has been generated from the lithofacies analysis of the top 10 m sediments and rating was assigned as per the lithofacies class (Table 8).

Table 8 Range and rating for impact of vadose zone media

| Range | Rating |
|---|---|
| Clay and silt | 3 |
| Sandy clay | 4 |
| Clayey sand | 6 |
| Sand and gravel | 8 |

***Hydraulic Conductivity (C)***

Geologic material composed of coarser particles, such as sand and gravels have high conductivity values. Aquifer vulnerability is related to hydraulic conductivity through the aquifer's capacity to transport pollutants away from the point at which they enter the aquifer. The greater the hydraulic conductivity the further contaminants will travel and potentially contaminate greater volume of groundwater (Table 9). Central Ground Water Board has carried out only three pumping tests in and around the area. Scanning the results it is observed that the hydraulic conductivity of the block ranges between 50 to 70 m/day (CGWB, 2001) and therefore the rating has been assigned as 8.

Table 9 Ranges and ratings for hydraulic conductivity

| Ranges (m/day) | Rating |
|---|---|
| 0-5 | 1 |
| 5-15 | 2 |
| 15-30 | 4 |
| 30-50 | 7 |
| 50-70 | 8 |
| 70-90 | 9 |
| >90 | 10 |

**Aquifer Vulnerability**

Aquifer vulnerability analysis was carried out as described in 'Methodology' section. The aquifer vulnerability values ranges from 95 to 186. The values were categorized into four classes. They are low (<120), medium (120-145), high (145-170), and very high (>170) groundwater vulnerability. Table 10 shows the total area covered by each of the class. Fig. 7 indicates that the eastern part, in and around the municipal area, the vulnerability to pollution is low to medium. In the western part the vulnerability ranges between high and very high. In the central and the southern parts of the block, vulnerability to pollution is high. In these regions pesticides which might have arsenic and other heavy metals or arsenic rich groundwater should not be used in the agricultural fields and mango orchards, since the pollutants may easily leach into the aquifer through the vadose zone.

Table 10 Total area of vulnerability class

| Aquifer Vulnerability Class | Area (sq. km) |
|---|---|
| Low Vulnerability | 8 |
| Medium Vulnerability | 18 |
| High Vulnerability | 228.5 |
| Very high Vulnerability | 11 |

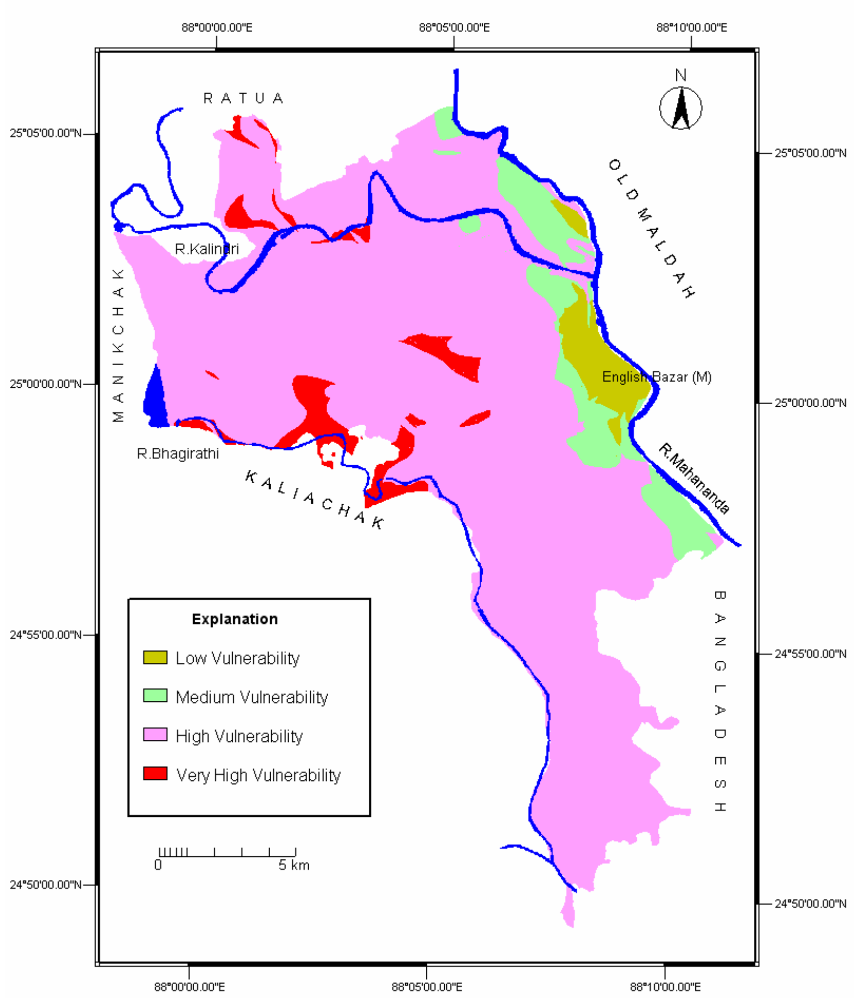


**Fig. 7 Aquifer vulnerability map of the study area**

**Sensitivity Analysis**

The vulnerability analysis is subjective in nature. Therefore, to avoid subjectivity sensitivity analysis was carried out. Sensitivity analysis characterizes the distribution of both individual variables and input parameter, on the resultant output of an analytical model. Many factors influence the result such as the type of overlay operation performed, the value of the weights, the number of data layers and map units in each layer, the error or uncertainty associated to each map unit, and so on. The sensitivity operation has been carried out by using the present arsenic concentration within the block by cross operation under GIS platform. Four classes have been attributed to the arsenic distribution. They are low (< 0.01 mg/l), medium (0.01 – 0.05 mg/l), high (0.05 – 0.1 mg/l) and very high (> 0.1 mg/l). In the next step, the vulnerability map and the arsenic zone map have been crossed to generate two maps. Fig.8 shows the areas where the various vulnerability classes have matched with the arsenic distribution. This covers 164.31 sq. km, which is 62% of the total block area (Table 11). In the rest of the area the present arsenic concentration and aquifer vulnerability do not match (Fig. 9, Table 12). Therefore, it can be said that the aquifer vulnerability analysis is more or less reliable.

**Table11 Cross operation table showing areas where vulnerability and arsenic concentration correspond to each other**

| Match Class | Area (sq. km) |
|---|---|
| Low Vulnerability * Low arsenic | 4 |
| Low Vulnerability * Medium arsenic | 3 |
| Medium Vulnerability * Low arsenic | 16 |
| Medium Vulnerability * Medium arsenic | 2 |
| High Vulnerability * Medium arsenic | 64 |
| High Vulnerability * High arsenic | 47 |
| High Vulnerability * Very high arsenic | 21 |
| Very High Vulnerability * High arsenic | 5.5 |
| Very High Vulnerability * Very high arsenic | 3 |
| Total area | 165.5 |
| Percentage of total area | 62% |

**Table 12 Cross operation table showing areas where aquifer vulnerability and arsenic concentration do not correspond**

| No-Match Class | Area (sq. km) |
|---|---|
| High Vulnerability * Low arsenic | 97 |
| Very High Vulnerability * Medium arsenic | 2 |
| Very High Vulnerability * Low arsenic | 1 |
| Total area | 100 |
| Percentage of total area | 38% |

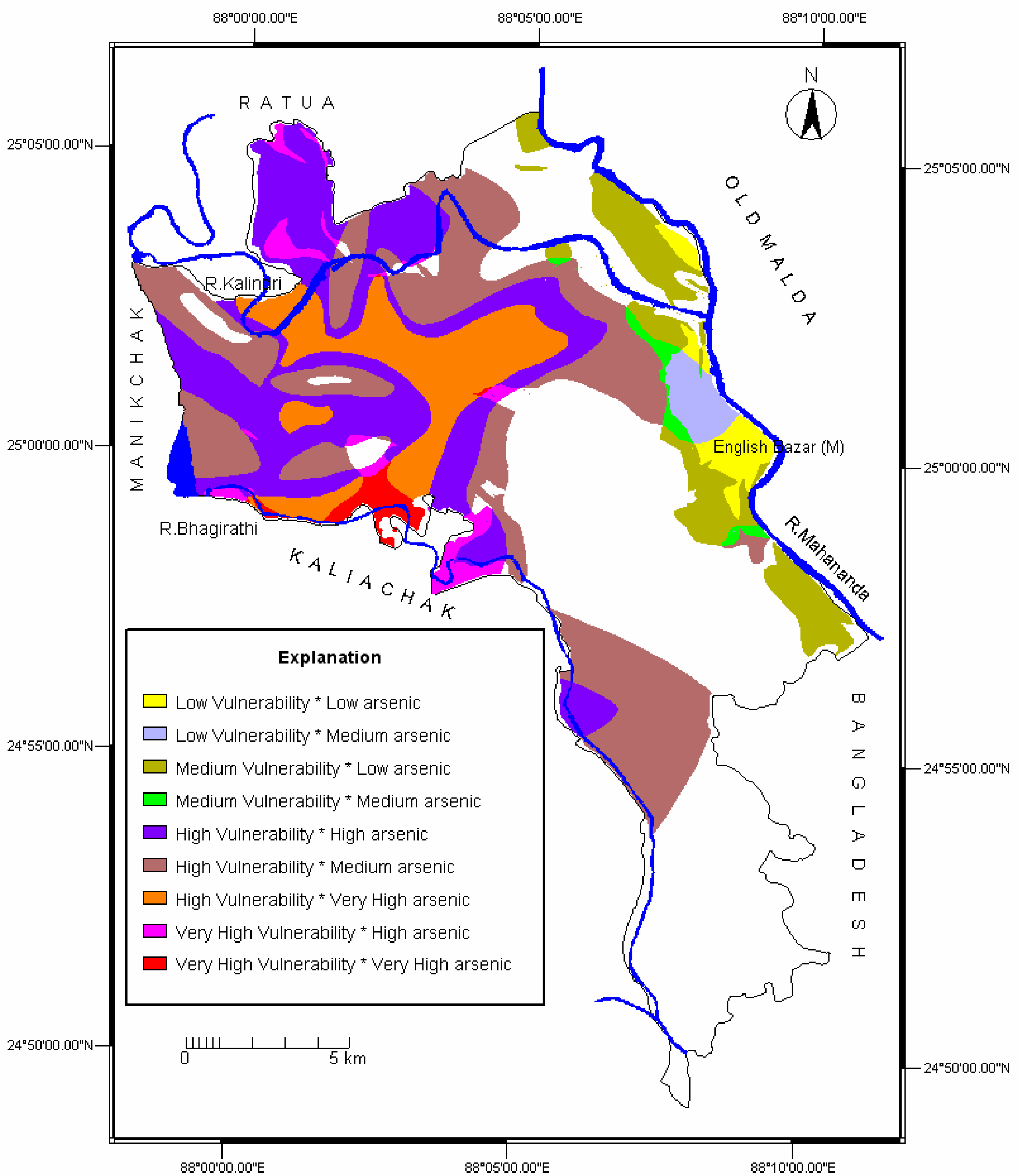


**Fig. 8 Map showing areas where aquifer vulnerability class and arsenic concentration correspond to each other**

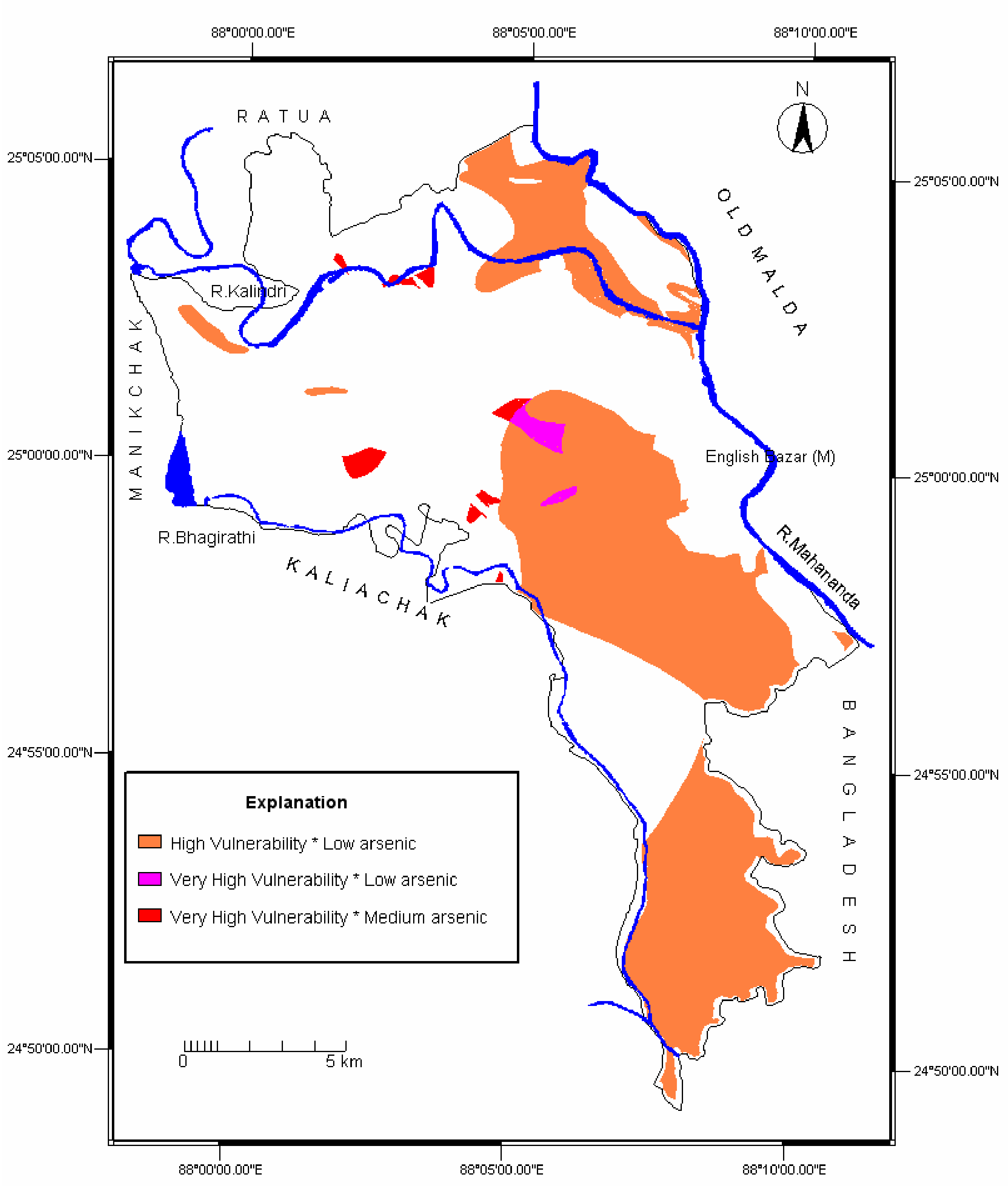


**Fig. 9 Map showing areas where aquifer vulnerability class and arsenic concentration do not correspond**

**Conclusion**

The study area is covered by Quaternary alluvia of two different ages. They are Older Alluvium and the Newer Alluvium. 3-dimensionally the area consists of a continuous clayey silt bed varying in thickness from a thin veneer to about 20m at the top followed by sand of various grades. The continuity in the sequence of sand, which forms the aquifer material, is broken by the occasional occurrence of clay lenses of limited lateral extent. The groundwater of English Bazar block occurs in an unconfined condition. The water table is shallow in the western part whereas it is very deep in eastern part in the municipal area. The dominant groundwater flow directions are easterly, northeasterly and northerly. In the western part the groundwater has high concentration of arsenic. This high concentration is found to occur mostly below the abandoned channels and meander scrolls where farming is extensively practiced and between the depth span of 16 m and 57 m bgl. In the eastern part, in and around the municipal area, the vulnerability to pollution is low to medium. In the western part the vulnerability ranges between high and very high. In the central and the southern parts of the block, vulnerability to pollution is high. In these regions pesticides which might have arsenic and other heavy metals or arsenic rich groundwater should not be used in the agricultural fields and mango orchards. Sensitivity analysis reveals that in 62% of the area vulnerability matches with the arsenic distribution.

**Acknowledgement**

The authors are thankful to Prof. N.R.Banerjia, Vice Chancellor, B.E.S.U.S and Prof.Ashok K. Dutta, Director, IISWBM for providing infrastructural facilities. The work is carried out under project " Assessment and Management of Groundwater of English Bazar block, Malda District, West Bengal, India" sanctioned by the Department of Science and Technology, New Delhi. The authors are thankful to the sponsoring authority for financial support. The authors also thankful to the unknown reviewer for his valuable comments to make the paper stronger.

**References**

Acharrya, S.K. ( 2001) Arsenic pollution in groundwater from Lower Ganga Plain, Bengal Basin, Indian Journal of Geology,73(1), 1-19.

Aller, L., T. Bennett, Lehr, J.H., Petty, R., and Hackett, G. (1987) DRASTIC: A standardized system for evaluating groundwater pollution potential using hydrogeologic settings.USEPA 622p.USEPA, Cincinnati, OH.

Bandopadhyay, R.K. (2002) Hydrochemistry of arsenic in Nadia district, West Bengal, Journal Geological Society of India, 59(1), 33-46.

CGWB (Central Ground Water Board), (2001) Ground Water Resources and Development of Malda District, West Bengal, Technical Report: Series "D" Ministry of Water Resources, Govt of. India. 28p.

Chevrel, S. (2003) Assessing and monitoring the environmental impact of mining activities in Europe using advanced Earth Observation techniques. Project funded by the European Community under the "Information Society Technology" Programme (1998- 2002). 40p

Corwin, D.L., Vaughan, P.L., and Loague, K. (1997) Modelling nonpoint source pollutants in the vadose zone with GIS. Environmental Science and Technology, 31, 2157-2175.

Das, A., and Panja, S. (1999) Cultural History of Malda and South Dinajpur West Bengal: A Geoarcheological Perspective. Gondwana Geol.Magz., Spl.4, 347-359.

Dasgupta, A.B. (1997) Geology of Bengal Basin, Indian Journal of Geology, 69(2), 161-176.

Deshmukh, D.S. (1973) Geology and Groundwater Resources of the alluvial areas of West Bengal, Bull. Geol. Surv. Ind. Sr. B34.

Evans, B.M., and Myers, W.L. (1990) A GIS-based approach to evaluating regional groundwater pollution potential with DRASTIC. Journal of Soil Water Conservation, 45, 242-245.

Griner, A.J. (1989) The automation of DRASTIC: A regional model for mapping susceptibility of groundwater contamination. In Proc. of the GIS/LIS '89 Symp. Orland, FL.26-30 Nov.1989. Am. Soc. for Photogrammetry and Remote Sensing, Bethesda, MD, 679-684.

Herlinger Jr. R., and Pedro Viero, A. (2007) Groundwater vulnerability assessment in coastal plain of Rio Grande do Sul State, Brazil, using drastic and adsorption capacity of soils. Environmental Geology; 52(5), 819-829.

Jha, M.K., and Sebastian, J. (2005) Vulnerability Study of Pollution upon Shallow Groundwater Using Drastic/GIS Conf.7$^{th}$ -9$^{th}$ Feb. Map India, New Delhi.

Lusch, D.P., Rader, C.P., Barrett, L.R., and Rader, N.K. (1992) Aquifer vulnerability to surface contamination in Michigan. Map and Descriptive Information, Centre for Remote Sensing, Michigan State Univ., East Lansing, M I.

Menani, M. R. (2001) Evaluating and mapping the groundwater pollution susceptibility of the El Madher alluvial aquifer, Eastern Algeria, using the DRASTIC method. Science et changements planétaires / Sécheresse. 12(2), 95-101.

Merchant, J.W. (1994) GIS-Based Groundwater Pollution Hazard Assessment: A Critical Review of the DRASTIC Model. Photogrammetric Engineer & Remote Sensing, 60(9), 1117-1127.

Merchant, J.W., Whittemore, D.O., Whistler, J.L., McElwee, C.D, and Woods, J.J. (1987) Groundwater pollution hazard assessment: A GIS approach. In Proc.of the Int. Geographic Information System Symp., Arlington, VA..

Pal, S.K., and Das, A. (1992) Quaternary Geology and Geomorphology in parts of Malda District, W.B.Unpublished G.S.I. Report FS 1989-90.Rec.Geol.Surv.India, 123 (3), 64-65.

Panagopoulos, G. P., Antonakos, A. K., and Lambrakis, N. J. (2006) Optimization of the DRASTIC method for groundwater vulnerability assessment via the use of simple statistical methods and GIS. Hydrogeology Journal, 14(6), 894-911.

Regan, J.J. (1990) DRASTIC: Ground water pollution potential mapping in Arizona counties using a PC-based GIS.p.232-240.In Proc.of the Third Forest Service Remote Sensing Applications Conf., Tucson, AZ.9-13 Apr.1990.Am.Soc.for Photogrammetry and Remote Sensing, Bethesda, MD.

Riggle, M.A., Schmidt, R.R. (1991) The Wisconsin groundwater contamination susceptibility map. Journal of Urban Regional Inf. Syst.Assoc., 3, 85-88.

Rundquist, D.C., Rodekohr, D.A., Peters, A.J., Ehrman, L.Di., and Murray, G., (1991) Statewide groundwater-vulnerability assessment in Nebraska using the DRASTIC/GIS model. Geocarto Int.2, 51-58.

Shahid, S. (2000) A study of groundwater pollution vulnerability using DRASTIC/GIS, West Bengal, India. Journal of Environmental Hydrology, 8, paper 1.

Sikdar, P. K., and Chakraborty, S. (2007) Genesis of arsenic in groundwater of North Bengal Plain using PCA: A case study of English Bazar block, Malda District, West Bengal, India, Hydrological Processes, in press.

Sikdar, P.K., and Banerjee, S. (2003) Genesis of arsenic in groundwater of Ganga delta – an anthropogenic model, Journal of Human Settlement, April 10-22.

Tezcan, L., and Ekmekci, M. (2004) Surface cover infiltration index: a suggested method to assess infiltration capacity for intrinsic vulnerability in karstic areas in absence of quantitative data. International Journal of Speleology, 33(1/4), 35-48.

Trent, V.P. (1993) DRASTIC mapping to determine the vulnerability of groundwater to pollution. In Proc.of the Symp.on Geographic Inf.System and Water Resources, Mobile, AL.14-13 Mar.1993.Am.Water Resour.Assoc.Bethesda, MD.

USEPA (U.S. Environmental Protection Agency), (1993) A review of methods for assessing aquifer sensitivity and ground water vulnerability to pesticide contamination.USEPA, Office of Water Washington DC.

Vrba, J., and Zaporotec, A. (eds.). (1994) Guidebook on Mapping Ground Water Vulnerability. IAH Int.Contribution for Hydrogeology, 16(94), Heise, Hannover, 131.

Zhang, R., Hamerlinck, J.D., Gloss, S.P., and Munn, L. (1996) Determination of Nonpoint-Source Pollution Using GIS and Numerical Models, Journal of Environmental Quality, 25 (3), 411-418.