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# Geographic Information System for the Evaluation of Groundwater Pollution Vulnerability of the Northwestern Barind Tract of Bangladesh

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**Abstract:** Groundwater is the main source of drinking in the northwestern Barind region of Bangladesh. Therefore, prevention of this resource to pollution is crucial to avoid probable health and environmental hazards. An attempt has been taken in this study to map the vulnerability of the groundwater resource to contamination based on a multi-criteria approach known as DRASTIC within a geographic information system. Seven thematic maps of DRASTIC parameters are developed from available soil, borehole litholog, groundwater fluctuations and elevation model data of the region. The maps are integrated within geographic information system to generate the maps of groundwater vulnerability to both agricultural pollutants and general pollutants. The pollution vulnerability maps are validated with existing groundwater quality data. The result shows that almost 38.1% of the area is highly vulnerable to agricultural pollutants and 29.8% to general pollutants. Some management strategies are proposed for the protection of groundwater resource from pollution.

**Key words:** Geographic information system, barind tract, DRASTIC, groundwater pollution vulnerability

## INTRODUCTION

Groundwater contamination due to increased use of fertilizers and pesticides and other man-made activities is an emerging problem in Bangladesh. Therefore, more attention is required to pay on the possible impacts of irrigated agriculture and other anthropogenic activity on groundwater quality. The northwestern Barind region is one of the most important agricultural areas in Bangladesh. Since early 1960s the irrigated area has increased markedly, especially with the introduction of high yielding variety of rice. Cultivation of this high yielding variety rice requires increased use of fertilizers to achieve economically viable yields. This crop is less resistant to pests and requires relatively heavy application of pesticides. Consequently, use of chemical fertilizers and pesticides also increased significantly during the last two decades (Bari and Anwar, 2000). One of the major effects of this agricultural practice is the increase susceptibility of groundwater to pollution. As most of the people of the area meet their demands of water by tapping shallow aquifers, contamination of groundwater resources may cause sever health hazard in the region. Furthermore, groundwater in the region is free from Arsenic unlike many other parts of the country. It could be good resource for managing drought in the region, which becomes a recurrent natural phenomenon in recent decades. Therefore, measure should be taken before the groundwater of the area becomes contaminated. An attempt has been made in this study to identifying vulnerable aquifer areas to non-point source of contamination due to both agricultural pollutants and general municipal and industrial pollutants. The proposed ground water pollution potential map will help planners, managers, and local officials to take necessary planning and management steps to protect the ground water resources of the area from various sources of pollution.

Many methods have been proposed so far to assess vulnerability of a site. These include Soil-waste Interaction Matrix method (Phillips *et al*., 1977), Surface Impoundment Assessment (SIA) method (Silka and Swearingen, 1978), System for Early Evaluation of the Pollution Potential of Agricultural Groundwater Environments (SEEPAGE) (Richert *et al*., 1992), DRASTIC (Aller *et al*., 1985), SINTACS (Civita and De Maio, 2000), EPIK (Doerfliger and Zwahlen, 1995), etc. All the methods are used to quantify the vulnerability degree to contamination for the waters stored in an aquifer. However, among these methods the DRASTIC is the most widely used approach to groundwater vulnerability

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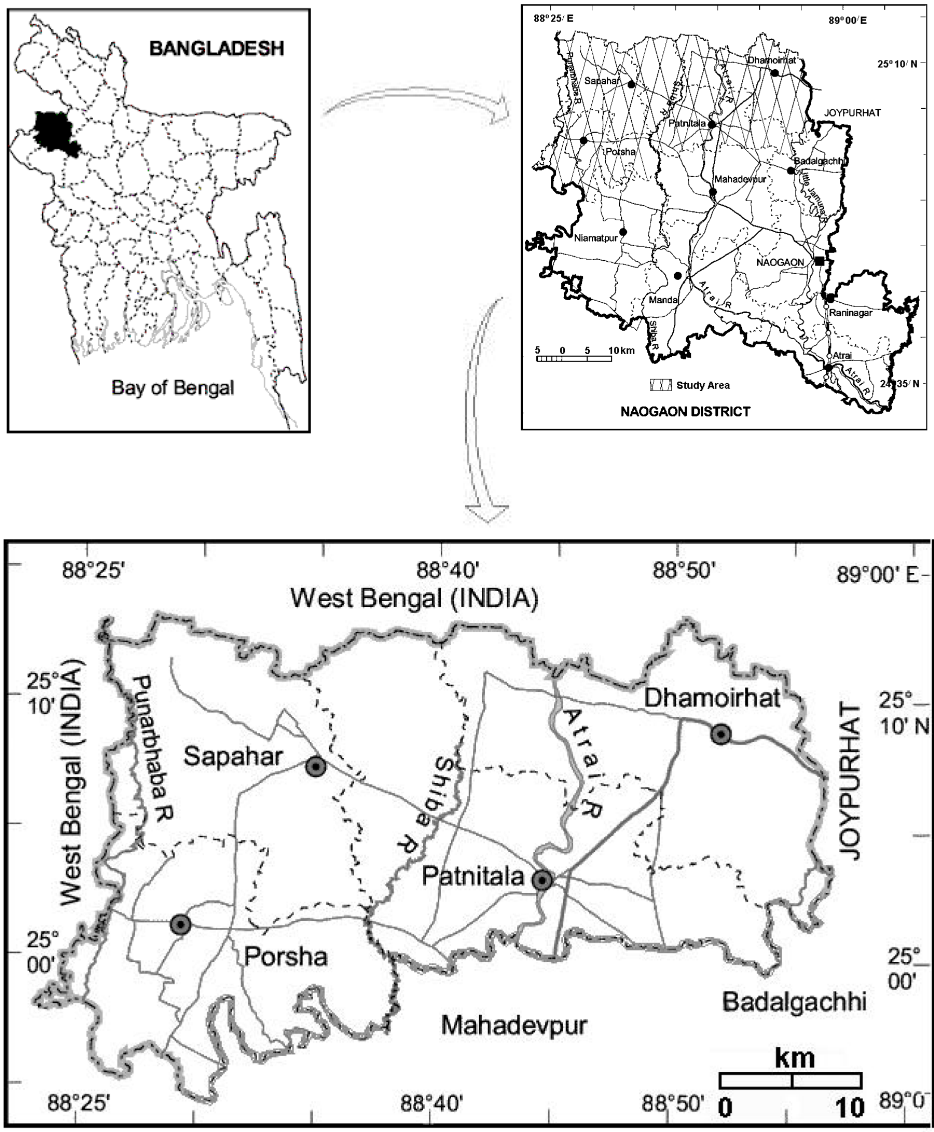



Fig. 1: Location of the study area in Bangladesh

assessments as it is relatively inexpensive, straightforward, and uses data that are commonly available or estimated, and produces an end product that is easily interpreted and incorporated into the decision-making process. Furthermore, it is possible to use this method for fast evaluation of groundwater vulnerability to contamination of a large area reliably (Hearne *et al*., 1992; Kalinski *et al*., 1994).

The DRASTIC method assigns numerical ratings to each of several hydrogeologic characteristics in a scale between one and ten. These ratings are then multiplied by a set of weighting factors and added to obtain an index that is used as the measure of vulnerability at the site. However, for vulnerability assessment over a large area, it often requires to assimilate information from many sites, each with a unique geographic location. The precise integration of multiple datasets, with various indications of ground water vulnerability, can decrease the uncertainty in the estimated model (Shahid *et al*., 2000). Geographic Information Systems (GIS) are ideal for efficiently capturing, storing, updating, manipulating, displaying and analyzing various factors indicating ground water vulnerability. Therefore, GIS is used in this study to integrate hydrogeological information following

DRASTIC methods to demarcate the ground water vulnerability map of the northwestern Barind region of Bangladesh.

**Description of the study area:** The study area (88°24′ E, 24°54′ S to 88°57′ E, 25°14′ S), location map shown in Fig. 1, is situated in the northwestern region of Bangladesh. The area is a part of Barind Tract which is the largest Pleistocene Terrace of the country. It is made up of the Pleistocene alluvium, also known as older alluvium. Physiographically, this region is divided into three units. These are Recent Alluvial Fan, Barind Pleistocene, and Recent Floodplain. These morphologic units are separated by long, narrow bands of Recent Alluvium. The soil in the region is mainly silty loom type. Topographically the area is situated on an average elevation of 75 feet with a gentle regional slope towards east. Climatically, the area lies in the monsoon region of the summer dominant hemisphere. The nature of the climate is characterized by high temperature, relatively low rainfall, often excessive humidity and fairly marked seasonal variations (Rashid 1991). A composite shallow potential aquifer at a depth varying between 5 and 20 m is found to exist in the region. The aquifer materials vary from fine sand to coarse sand with gravel (Salem *et al*., 2005).

The study area, covers almost 1080 km$^2$, consists of four towns and 1023 villages. The land of the area is mainly used for the cultivation of paddy. Total population in the region is 562,638. The people of area meet their drinking and domestic needs by tapping shallow aquifers.

## MATERIALS AND METHODS

The DRASTIC hydrogeologic vulnerability ranking method (Aller *et al*., 1985) uses a set of seven hydrogeologic parameters to classify the vulnerability or pollution potential of aquifer. The parameters are:

- Depth of groundwater (D);
- Recharge rate (R);
- The Aquifer media (A);
- The Soil media (S);
- Topography (T);
- The Impact of the vadose zone (I);
- The hydraulic Conductivity (C) of the aquifer.

For the mapping of pollution vulnerable zones, the thematic maps of the above DRASTIC parameters are developed by using a geographic information system. The features of each map are rated according to their relative susceptibility to pollution following DRASTIC ratings on a scale of 1-10. This rating is then scaled by a weighting factor and the weighted ratings are summed using aggregation methods of GIS. The DRASTIC index (DI) of each mapping unit of the integrated layer is calculated by using the following equation,

$$DI = D_W D_R + R_W R_R + A_W A_R + S_W S_R + T_W T_R + I_W I_R + C_W C_R \quad (1)$$

Where, $_W$ = weight and $_R$ = rating.

For each parameter there are 2 weights, one for application of DRASTIC to general municipal and industrial pollutants, while the other is for agricultural pollutants. The site having a high DI value is considered the most likely to become contaminated and the site having a low DI value is considered the least likely to become contaminated (Aller *et al*., 1985).

**Mapping of DRASTIC parameters:** The seven DRASTIC parameters are derived from soil and elevation maps, and the groundwater table fluctuation and available borehole litholog data of the area. All the thematic maps are prepared in vector format. Preparation of thematic maps of seven DRASTIC parameters isgiven in this study.

**Depth of groundwater table:** Average depth of the groundwater table is estimated from the water table fluctuation data collected from 27 sites of the study area. The groundwater table in the region is found to fluctuate seasonally between 2 and 15m. Average depth of groundwater table is used to prepare the depth of groundwater table map of the study area. A stochastic interpolation method, kriging (Journel and Huijbregts, 1981), that is widely recognized as standard approach for surface interpolation, based on scalar measurements at different points in space is used to estimate spatial variation of groundwater depth from point data. The most important task during kriging is the estimation of the variogram because it has greatest influence on kriging results. A cubic variogram, shown in Fig. 2(a), is used for the kriging of point data of groundwater depth. Thematic map of groundwater table of the study area is shown in Fig. 3(a). Average depth of groundwater in most part of the area lies between 3 and 5 m.

**Recharge:** The net recharge of groundwater is also calculated from groundwater table fluctuation data collected from 27 sites of the study area. The variogram used for the krigging of point recharge data is shown in Fig. 2(b). The recharge map of groundwater of the study area is shown in Fig. 3(b). A minimum fluctuation of groundwater level is found to be 0.9 meter in the study area. This means a high recharge of groundwater in the

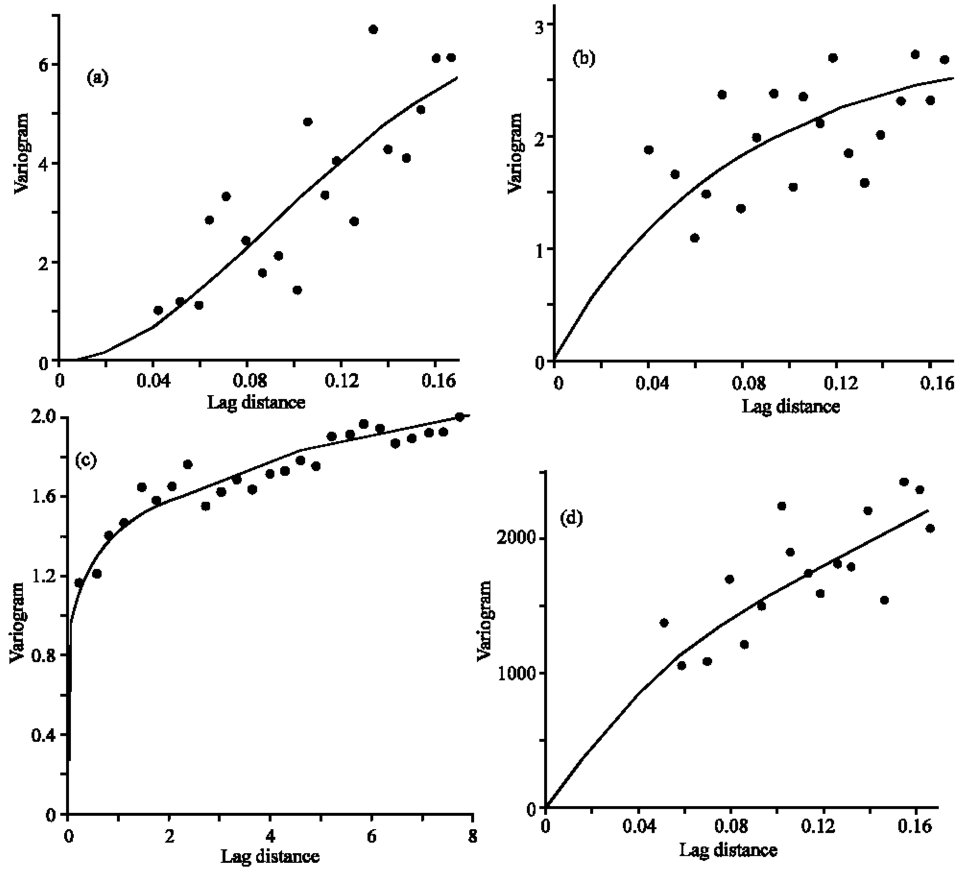



Fig. 2: Variograms used for the krigging of (a) groundwater depth, (b) recharge, (c) borehole litholog, and (d) hydraulic conductivity data

region. Therefore, following the DRASTIC recommendation the whole area is rated with a value of 10.

**Aquifer media:** Aquifer media is identified from the borehole litholog data. Litholog data available at 512 borehole points are contoured using krigging method to prepare the map of aquifer media of the study area. The variogram using for the krigging is shown in Fig. 2(c) and the thematic map of the aquifer media of the study area is shown in Fig. 3(c). The aquifer material in the region is found to vary from fine sand to coarse sand with gravel. However, medium sand is predominant in most of the area.

**Soil:** The soil map of the study area is shown in Fig. 3(d). Three types of soil cover is found in the study area viz., deep gray terrace soil which is silty loom type, acid basin clays which is mostly dominated by clay, and non-calcareous alluvium which is clayey loom type in nature.

**Topography:** The slope map is generated in ArcView (ESRI, 2001) from the DEM data provided in Bangladesh Country Almanac (BCA, 2004). The slope map of the study area (Fig. 3e) shows a flat geography in the eastern side and a mild slope in the west of the area.

**Impact of the vadose zone:** The vadose zone map is prepared from borehole ligholog and average depth of groundwater table data. The vadose zone is defined as the unsaturated zone lying between the earth's surface and the top of the groundwater table. In the present study, the media just above the average depth of groundwater level is considered as the vadose zone. The thematic map of vadose zone of the study area is shown in Fig. 3f.

**Hydraulic conductivity:** Hydraulic conductivity map of the study area is prepared from pumping test data available at 27 sites of the study area. The pumping test data are interpreted by using genetic algorithm technique based on Cooper-Jacob method (Mondal and Shahid, 2004). A spherical variogram as shown in Fig. 2dis used for the krigging of point data of hydraulic conductivity and preparation of corresponding

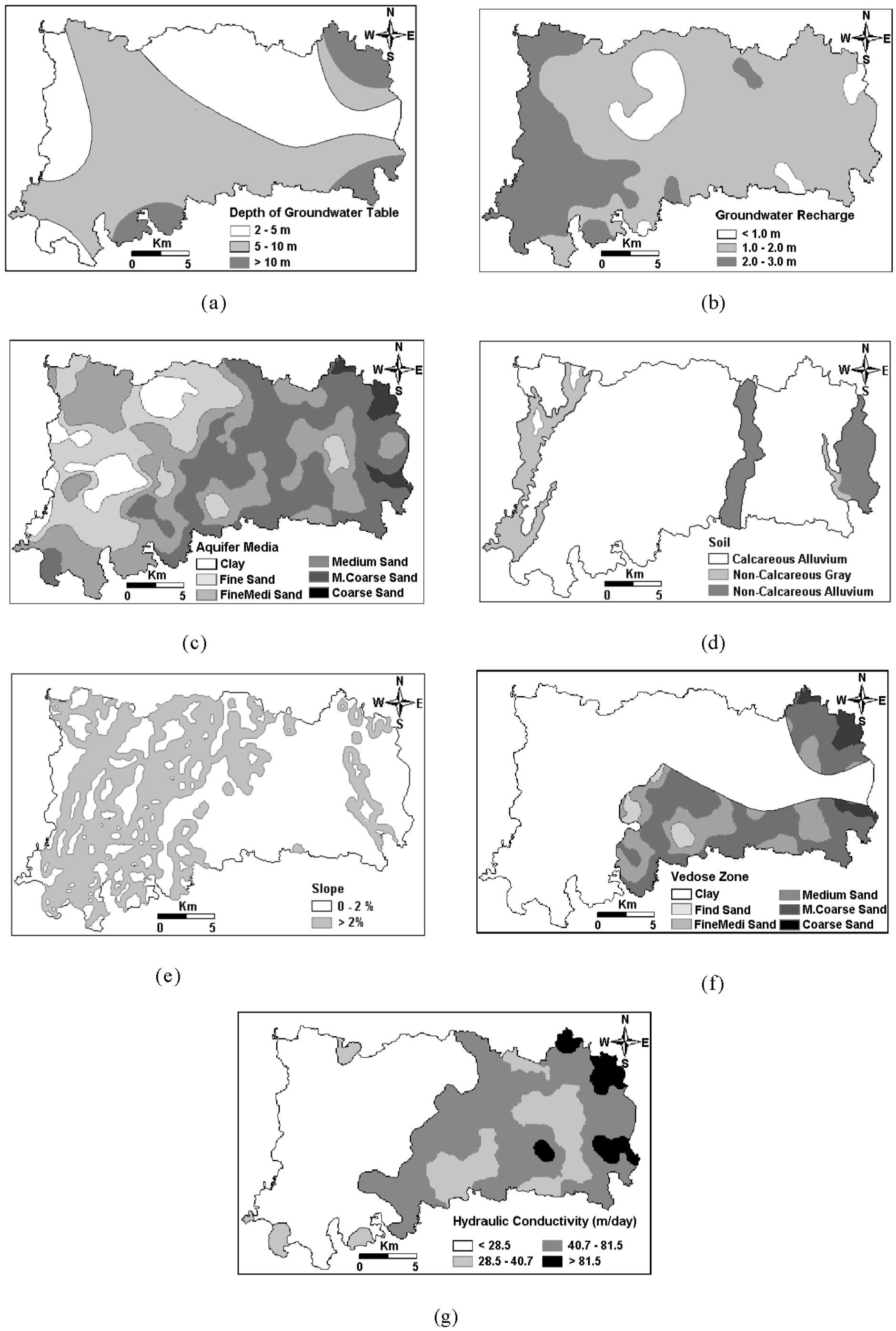
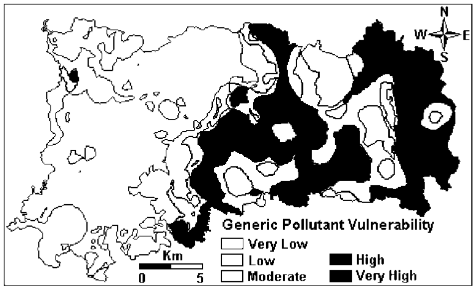


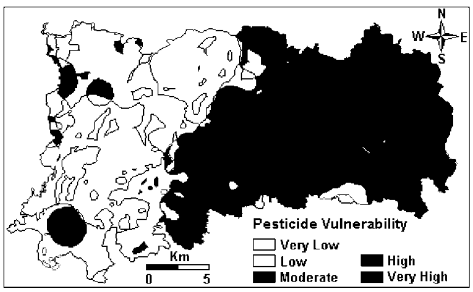

Fig. 3: Thematic maps of DRASTIC parameters of the study area: (a) depth of groundwater table; (b) groundwater recharge; (c) aquifer media; (d) soil; (e) topography; (f) vadose zone; and (g) hydraulic conductivity of aquifer

thematic map of hydraulic conductivity of the study area as shown in Fig. 3g.

**Generation of pollution vulnerability maps:** Different polygons of the DRASTIC thematic maps are coded with DRASTIC ratings and then scaled with the weights. DRASTIC weights for both general pollutants and pesticide pollutants are used for scaling separately. The scaled maps are then integrated using the INTERSECT method in ArcMap (ESRI, 2004) to generate




(a)

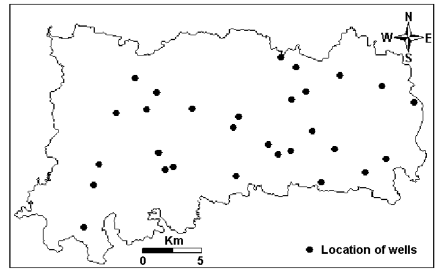



(b)

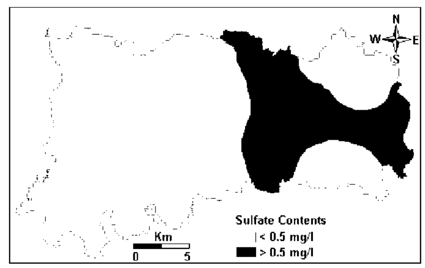
Fig. 4: Groundwater pollution vulnerability maps of the study area due to (a) general pollutants; and (b) agricultural pollutants

the vulnerability maps of both general and agricultural pollutants. During integration an overlay accuracy of 0.05 $km^2$ is used. Therefore, areas less than 0.05 $km^2$ are not shown on the maps. The polygons of the integrated layers contain the composite details of all the thematic layers together numerically, and the DI score of each polygon indicates the groundwater vulnerability of that area. For general pollution vulnerability lowest DI value of 130 and highest DI value of 195 are found in the area. For agricultural pollution vulnerability the obtained rage of DI values is 145-210. Finally, the DRASTIC Index (DI) values of the integrated maps are classified into five equal classes to generate the pollution susceptibility maps for both the general pollutants and agricultural pollutants of the area. The generated maps are shown in Fig. 4a and b, respectively.

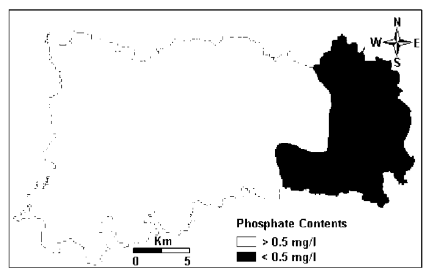
**Validation of pollution potential map:** Three types of fertilizers such as Urea, Triple Supper Phosphate (TSP) and Marinate of Potash (MP) are commonly used in agricultural of Bangladesh. The use of fertilizers raises the quantity of sulfate, nitrate, phosphate, potassium and ammonium in various amounts in groundwater. Besides this, potassium content in groundwater indicates



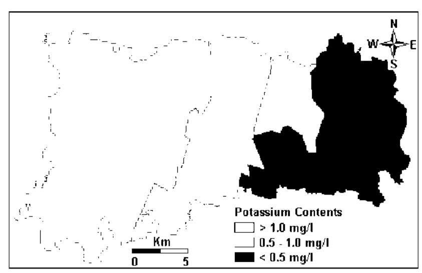

(a)




(b)




(c)




(d)

Fig. 5: (a) Location of wells used for monitoring groundwater quality of the study area; (b) contents of Sulfate; (c) contents of Phosphate; and (d) contents of Potassium in groundwater of the study area

contamination by sanitary landfills (Davison, 1969). Phosphorus contamination of groundwater comes from direct damping of wastes and from eroded suspended solids from urban and agricultural land. A higher value of sulfates in groundwater also indicates man-made pollution (Matthess and Harvey, 1982). Therefore, by measuring the contents of these chemicals in ground acquired from the aquifers of similar geologic setup, it is possible to identify groundwater contamination due to agricultural and other man made activities.

National groundwater quality data in Bangladesh were acquired by the Department of Public Health Engineering, Bangladesh for the monitoring of arsenic in groundwater from 3534 wells over the country during the months of June and July in 1999. However, besides Arsenic content nineteen more constituents of groundwater including sulfate, phosphate and potassium were also measured in that program. The water quality data of 29 wells situated in the study area are used to assess the content of sulfate, phosphate and potassium in groundwater of the area. The locations of the wells in the study area are shown in Fig. 5a. All the wells are hand tube-wells. The data were collected from a depth varying between 10 and 20 m. The contours maps of sulfate, phosphate and potassium content in groundwater of the study area are shown in Fig. 5b-d, respectively. It can be observed from the figures that though the contents of these chemicals in groundwater are very less, there presence is more prominent in the eastern side of the study area which is more vulnerable to pollutant. This proves the effectiveness of DRASTIC method in assessing the vulnerability of groundwater pollution in the context of Bangladesh.

## RESULTS AND DISCUSSION

The area under different vulnerable zone in the study area is given in Table 1. It can be noted that 4.4% of the area of northwestern Barind Tract is extremely vulnerable, 25.0% is highly vulnerable, 14.7% is moderately vulnerable, 23% is less vulnerable and 32.9% area is extremely less vulnerable to general pollutants. On the other hand, 22.8% of the area is extremely vulnerable, 15.3% is highly vulnerable, 19.0% is moderately vulnerable, 22.8% is less vulnerable and 20.1% area is extremely less vulnerable to agricultural pollutants. From the pollution susceptibility maps of Fig. 4a and b, it can be observed that the eastern side of the study area is more susceptible to pollutants compared to western side. However, the eastern side of the area is most potential for groundwater resources (Salem, 2005). Therefore proper management approaches should be adopted to provide a long term pollution free groundwater supply in the area.

The northwestern part of the Barind region is mostly inhibited by rural people. Almost 98% land of the area is used for agriculture. Only a few agriculture based small industries, mainly for producing rice from paddy, can be found in the area. Therefore, groundwater is mainly susceptible to agricultural pollutants. Groundwater contamination to agricultural pollutants mainly happens due to excessive and improper use of agricultural chemicals. However, the farmers in the study area are mostly very poor and uneducated. Practices of excessive chemical application generally does not found in the area. Pollution might happens mainly due to improper use of chemical in the agriculture.

Table 1: Area under different classes of vulnerability in the northwestern barind tract

| Class of vulnerability | General pollution | | Agricultural pollution | |
|---|---|---|---|---|
| | Area ($km^2$) | Area (%) | Area ($km^2$) | Area(%) |
| Very less | 355.32 | 32.9 | 217.08 | 20.1 |
| Less | 248.4 | 23.0 | 246.24 | 22.8 |
| Moderate | 158.76 | 14.7 | 205.2 | 19.0 |
| High | 270.0 | 25.0 | 165.24 | 15.3 |
| Very high | 47.52 | 4.4 | 246.24 | 22.8 |

The timing of a chemical application is critical in determining whether it will leach to groundwater. The closer the time of application to a heavy rainfall or irrigation, the more likely some chemicals will leach to groundwater. Therefore, timing of chemical application should be chosen carefully to protect the groundwater resources in the region. It is important to remember that agricultural chemicals and groundwater relationships are site-specific, and even minor changes in the soil-crop-environment-chemical relationship can change the potential for groundwater contamination. However, some general principles of agricultural management can help to control the situation and should be considered in agricultural planning in the area. Best management practices should be chosen based upon consideration of the chemical and physical processes that occur from the agricultural chemicals. The agricultural practices that have less effect on infiltration of pollutant are to be encouraged in the high potential zone of groundwater pollution. The activities that may cause pollution to groundwater should be limited to low pollution potential zones only. Finally, it is required to give utmost important in capacity building, educating the public, particularly farmers, in conservation of the quality of groundwater and sustainable management of the resource.

## CONCLUSION

Groundwater pollution vulnerability map of the northwestern Barind region of Bangladesh has been developed in the study. It has been found that at least 29.8% of the area is highly vulnerable to both general and pesticide pollutants. Protection of groundwater from contamination costs less than remediation. Therefore, agricultural activities in the region should be directed properly to prevent the aquifer from non-point source of pollutants. The developed maps will be helpful for planner to guide the selection and implementation of best management practices in different areas for the long-term pollution free groundwater supply of the region.

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