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GROUNDWATER POLLUTION VULNERABILITY USING THE DRASTIC MODEL IN A GIS ENVIRONMENT, DEVAK-RUI WATERSHEDS, INDIA

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Assessment of groundwater pollution vulnerability using the DRASTIC model in a GIS environment has become more widespread for effective groundwater planning and management. Groundwater vulnerability is based on the assumption that the physical environment may provide some degree of protection to groundwater against contamination entering the subsurface environment. Groundwater pollution vulnerability maps are useful for groundwater quality monitoring, and to identify areas that need more detailed analysis for land use planning. The DRASTIC standardized system for evaluating groundwater pollution potential is based on different parameters, such as depth to water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity. The thematic layers of each parameter have been prepared and integrated through the DRASTIC model within a GIS environment to demarcate vulnerable zones. DRASTIC indices for both normal and agricultural pollutants have been derived to prepare groundwater vulnerability maps.

INTRODUCTION

This study presents a standardized system, which incorporates physical characteristics of the area into a methodology which can been used to evaluate groundwater pollution vulnerability. Assessment of groundwater pollution vulnerability is becoming more critical because groundwater represents a main source of drinking water that is threatened by the high concentration of human activities and associated municipal, industrial, and agricultural wastes. The Office of Technology Assessment of the U.S. Congress listed more than 30 different potential sources of groundwater contamination. A strategy for the protection of groundwater must be aimed at protecting the aquifer from becoming contaminated, and preventive efforts should concentrate on land use. In the study area around the Devak-Rui Watershed, Jammu region, India, groundwater is the main source of drinking water and groundwater pollution vulnerability maps are useful both for land use planning and groundwater quality monitoring. The groundwater pollution vulnerability map can be used to identify areas being adversely affected by contamination loads. The vulnerability of groundwater must be considered for sustainable groundwater protection and management planning. Parameters such as depth to water, net recharge, aquifer media, soil media, and topography, impact of vadose zone and hydraulic conductivity of the aquifer have been used to evaluate the groundwater pollution vulnerability zone of the study area.

The DRASTIC method (Aller et al., 1987) developed by U.S. Environmental Protection Agency, has been widely used to identify the area where groundwater supplies are most susceptible to contamination. The DRASTIC method has been widely used by various researchers in the United State including Hearne et al. (1992), Atkinson and Thomlinson (1994) and Kalinski et al. (1994). GIS based groundwater pollution hazard assessment by the DRASTIC model has been conducted by Merchant (1994). The method has been used for assessment of aquifer vulnerability (Nagar, 2002 and Napolitano et al., 1996). The method has been applied to generate a small-scale map of uppermost groundwater vulnerability to contamination (Shahid, 2000).

DESCRIPTION OF THE STUDY AREA

The study area lies between latitude 32^0 30' N to 32^0 45' N and longitude 75^0 to 75^0 15' E and covers a total area of 650 sq km. It includes both urban and rural developing areas (Figure 1). The study area enjoys a subtropical to moist temperate climate. The temperature ranges from 40^0 F in December to 118^0 F in summer. The average annual rainfall is 1116 mm of which monsoon rainfall is 800 mm. Agriculture is the main occupation of the people of the area. The northern part of the study area is hilly, comprising sharp to round crested, low to moderately high linear ridges with moderate to steep slopes. The drainage on the whole is fine to medium textured reflecting the amount of precipitation, permeability, topography and structure in the area. The structure and lithology have played major role in the evolution of the topography and drainage pattern in the area.

Geologically, the study area forms a part of the Outer Himalayan foothill belt and represents the southern limb of the Surin-Mastgarh anticline. A detailed geological map of the area was first prepared by Bhandari et al. (1961) and subsequently Karunakaran and Rango Rao (1976). On the basis of lithology, the study area has been divided into the Upper Murree, Lower, Middle, and Upper Siwalik Subgroup, and alluvium of the Jammu formation by Rango Rao et al. (1988). The Mandli-Kishanpur thrust lies between the Upper Murree and Siwalik formation where boulder conglomerate, silt and clay occur as valley fill deposits (Figure 2). The Siwalik strata in the area have been folded into a major NW-SE trending anticline designated the Suruin-Mastgargh anticline, the core of which

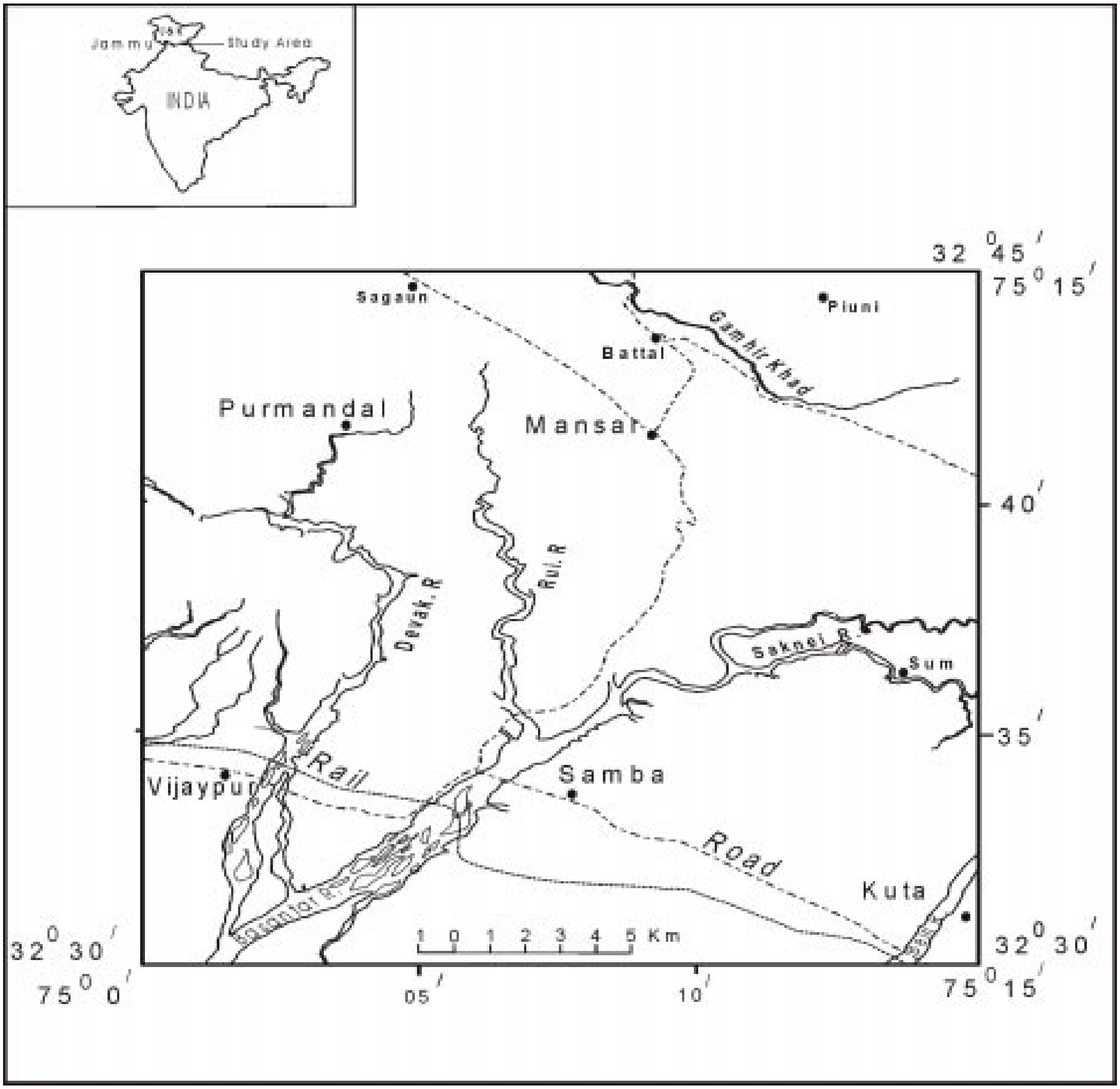

Figure 1. Location map of the study area.

is formedin the lower Siwalik. The structure and lithology have played a major role in the evolution of geomorphology in the hilly area. The strike of bedding has controlled the trend of the hill range to a large extent. The strike and dip of the rock formation, joints and major tectonic elements have played significant roles in the development of drainage patterns. The Middle and Upper Siwalik subgroup in the Jammu region is best exposed in the southern limb. The Devak-Rui watershed is part of this limb. Bhandari et al. (1961) named the Upper Siwalik of the area the Kutwalta formation and subdivided the same into three members i.e. Parmandal sandstone members, Nargota silt member and Tawi conglomerate member. The Upper Siwalik sequence lies conformably over the Middle Siwalik subgroup. The Jammu formation consists of the sub-montane deposits laid down in the form of piedmont alluvial plains in the front of the Upper Siwalik hill slope delimiting the northern margin of the plain. These deposits are reworked materials derived from the upper Siwalik boulder conglomerate beds and comprise clast-supported deposits in the upper fan area, sheet like gravel and

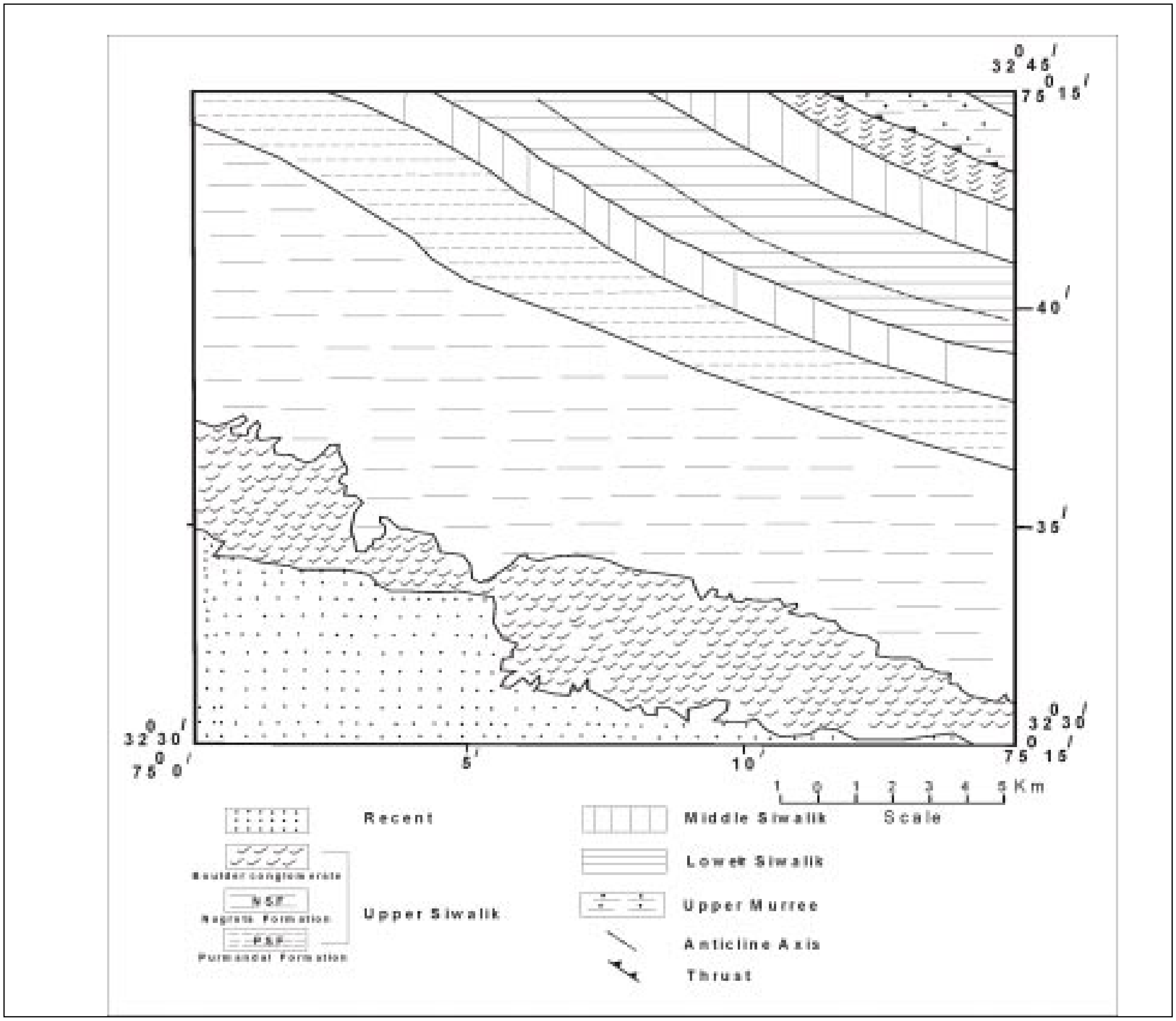

Figure 2. Geological map of the study area.

sandy deposits in the mid-fan area, sand and clay deposits with thin gravel bands in the distal fan. These deposits finally intermingle with the alluvial silts down the slope of piedmont area.

METHODOLOGY

Groundwater may contain dissolved minerals such as iron, calcium, magnesium, bicarbonate, chloride, and sulfate as well as dissolved gases and organic compounds. Normally, the concentration of these compounds is beneficial, giving water its taste and health benefits. On the other hand pollutants from landfills, overuse of fertilizers and pesticides and septic systems, which enter the aquifer, can become a serious problem and can result in groundwater contamination.

The DRASTIC methodology has two major portions; the designation of mappable unit, termed the hydrological setting and the application of a scheme for relative ranking of hydrological parameters. The DRASTIC hydrological vulnerability ranking order method uses a set of seven hydrological parameters to classify the vulnerability or pollution potential of an aquifer.

- Depth to Groundwater (D)

- Net recharge due to rainfall (R)
- Aquifer media (A)
- Soil Media (S)
- Topography (T)
- Impact of the vadose zone (I)
- Hydraulic Conductivity (C)

Based on the seven factors, seven base maps are produced as input modeling. The DRASTIC factors have been assigned a subjective rating, which can vary between 1 and 10. The parameter is weighted according to the relative susceptibility to pollutant potential of the aquifer. A DRASTIC index (DI) is computed as the weighted sum overlay of the seven layers as shown by 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 $_R$ refers to rating of the parameters ranges and $_W$ refers to the weighting of the parameters. The higher the DI values, the greater the groundwater pollution potential.

GENERATION OF THEMATIC LAYERS

Depth to Water Table

Depth to groundwater is an important primary parameter, which determines the depth of material through which a contaminant must travel before reaching the aquifer. The average depth of the water table is estimated from the water table data collected from the different points in the study area during the Pre-monsoon and post-monsoon periods. A map has been generated showing the average depth of the water table by interpolation of the point map. The rasterized point map is assigned a rating according to the DRASTIC method (Figure 3).

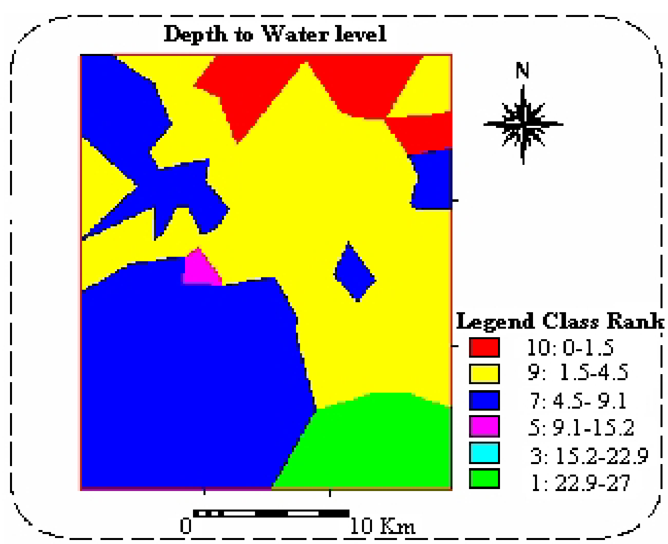

Figure 3. Depth to groundwater table.

Net recharge

Net recharge is the amount of water per unit area of land, which penetrates the ground surface and reaches the water table. Recharge is important because the infiltration water is a pollutant transport vector. Net recharge of an area has been calculated using a rainfall infiltration index method. The net recharge of the study area is assumed to be more than 254 mm per year and the entire study area is assigned a rating value 9 according to the DRASTIC method.

Aquifer media

The aquifer media exerts a major control over the flow path, hydraulic conductivity and gradient. Larger grain sizes and more fractures within the aquifer increase the permeability and lower the attenuation capacity, increasing the pollution potential. Aquifer media have been identified from the borehole data and lithological data of the different wells in the study area (Figure 4). Sand with gravel is the primary water bearing zone in the study area. According to the DRASTIC method, the aquifer media are assigned the rating value 8.

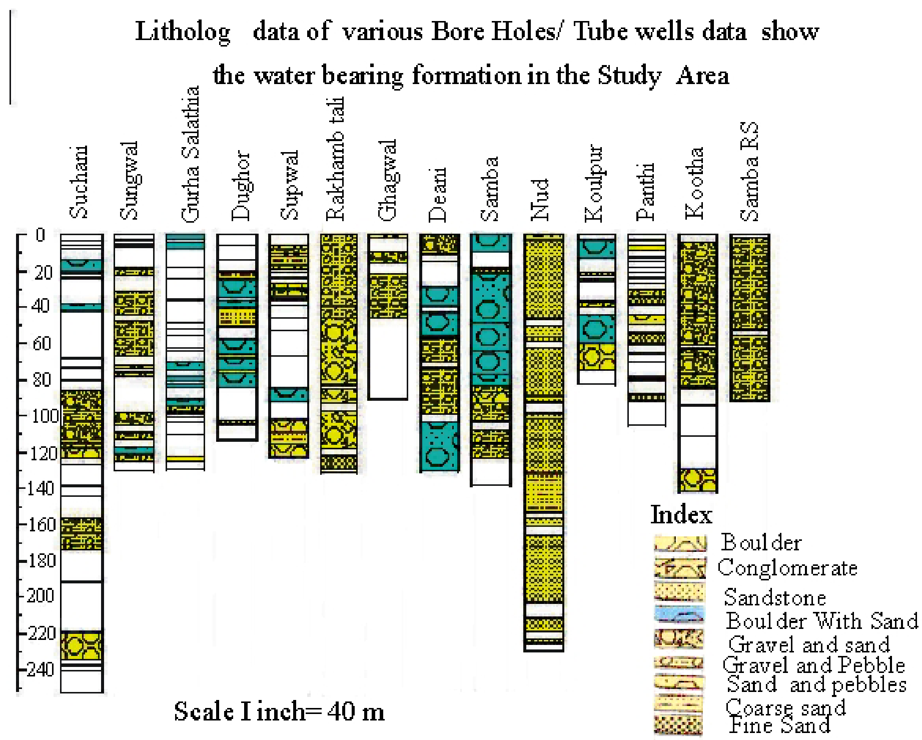

Figure 4. Litholog of various bore well/tube wells data shows the water bearing formation in the study area.

Impact of the vadose zone

The unsaturated or vadose zone media determine the attenuation characteristics of the material between the soil and the water table. Sandstone, sand gravel and pebbles, and boulder pebbles and conglomerate are considered the vadose zone of the study area. According to the rating values a thematic map has been prepared (Figure 5).

Soil media

Soil media represent the portion of unsaturated zone characterized by significant biological activity. Soil has a significant impact on the amount of recharge which can infiltrate into the ground surface. Four types of soil texture have been digitized from the India Bureau of Soil Survey and Land use Planning, Nagpur. The soil map shows four types: 1) loamy skeletal, 2) coarse loamy, 3) fine loamy soil, and 4) fine silty soil. The soil map (Figure 6) is assigned the rating as recommended by DRASTIC method.

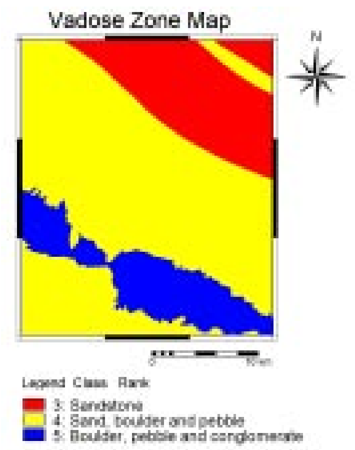

Figure 5. Map of impact of vadose zone.

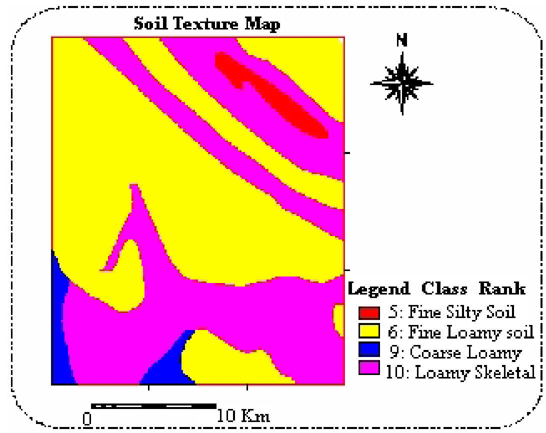

Figure 6. Soil media map.

Topography

The slope map is generated through the Digital Elevation Model (DEM). The digitized topographic contours are processed by the GIS to extract slope morphology. Contours were digitized from the topographic map from a survey of India (1:50 000 scale) at an interval of 20 meters and a DEM of the terrain was prepared. The area having low slope tends to retain water longer and has greater chance for infiltration and greater potential for contaminant migration. The slope percentage is assigned the rating value as recommended by DRASTIC model shown in (Figure 7).

Hydraulic Conductivity

The hydraulic conductivity values are calculated after calculating transmissivity from the pumping test data. The hydraulic conductivity values have been calculated from the pumping test data of the different wells of the study area and found to be greater than 10 m/day, and the entire study area has been assigned the rating value 10.

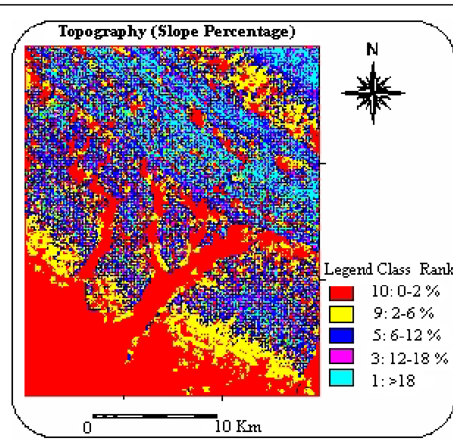

Figure 7. Slope map.

Table 1. DRASTIC Two Weight Classes

	Normal DRASTIC	Agricultural DRASTIC
D	5	5
R A	4 3	4 3
S	2	5
T	1	3
I	5	4
C	3	2

INTEGRATION OF THEMATIC LAYERS IN GIS

All the seven layers generated in the GIS combine to assign the relative weight value (1-5), which has been used to compute the vulnerability index. The relative weight 5 is most significant and 1 is least significant. The ratings of the each data layer are stored in the attribute table in the column rating. The weights have been assigned to each DRASTIC factor in order to determine the relative importance of each factor. DRASTIC uses two weight classifications, the "normal" and "agricultural" (Table 1). The layers of different thematic maps assign rating values as attribute information in the GIS environment. Each attribute map is then multiplied by both DRASTIC weights for normal (industrial-municipal) pollutants and pesticides pollutants and then summed to yield DRASTIC index values. The DRASTIC Index (DI) score in the final integrated map is classified and a pollution susceptibility map for both normal (industrial- municipal) pollution and pesticide pollution. The "normal pollution" (Figure 8) and "pesticide pollution" (Figure 9) maps have been prepared by using the slicing operation. The post classification filter has been applied to both to reduce the high frequency variation and finally both maps are prepared. In the normal pollutants map only 9% percent of area comes under the high and very high pollutants zone. The pesticide pollutants map shows 23% area comes under the high and very high pollutants zone.

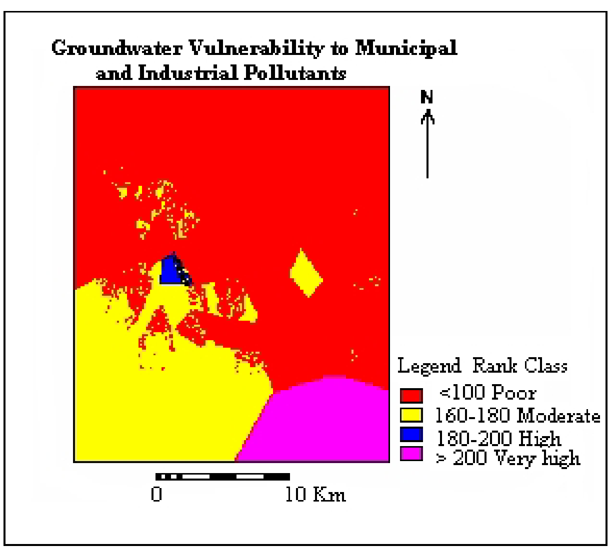

Figure 8. Groundwater vulnerability to municipal and industrial pollutants.

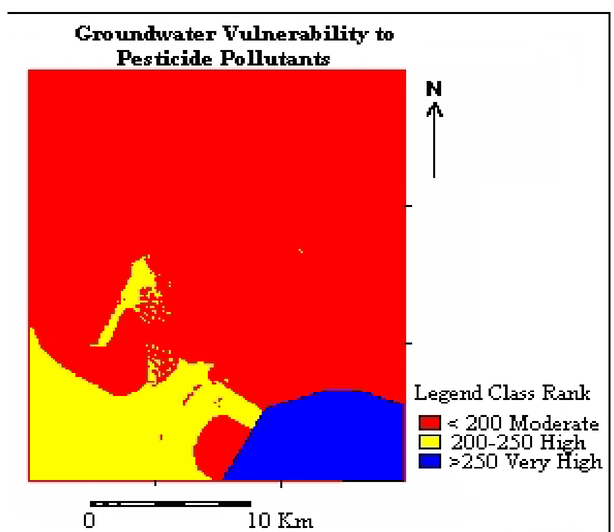

Figure 9. Groundwater vulnerability to pesticide pollutants.

CONCLUSION

The thematic layer of each parameter has been prepared; each polygon map is labeled with a DRASTIC rating and then scaled with the weights. The ratings are scaled for both the DRASTIC weights for normal (industrial-municipal) pollutants and pesticides pollutants separately to generate the pollution vulnerability map of the study area. The DRASTIC Index (DI) score in the final integrated maps have been used for pollution susceptibility maps for both normal (industrial-municipal) pollution and pesticide pollution. Based on the DRASTIC method study, proper management approaches for areas which are vulnerable to groundwater pollution should be adopted to provide a long term pollution free groundwater supply.

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