Studies on Assessment of Ground Water Pollution Vulnerability Index for CUTM Campus Paralakhemundi, Odisha through Application of “DRASTIC” Model

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Abstract Nowadays, the prediction of pollution risk and the protection of groundwater is very important. The sub-surface hydro-geological environment influences the pollutant to migrate from surface to sub-surface water. So groundwater contamination can be minimized by delineating and monitoring vulnerable areas. The main objective of this paper is to find out the groundwater vulnerability index in CUTM campus, Paralakhemundi, Odisha using DRASTIC model. This model has seven hydro-geological parameters Depth of Groundwater (D), net Recharge (R), Aquifer media (A) Soil media (S) Topography (T) Impact of vadose zone (I) hydraulic Conductivity (C). Estimation of DRASTIC Index has done by multiplying each parameter weight by its rating corresponding to a particular location in the study area and summing the products of all seven parameters listed above. In order to assign the ratings, field and laboratory tests have been conducted. Based on DRASTIC index values it was observed that the vulnerability class in the study area falls between high vulnerability to very high vulnerability. The results provide important information for the local authorities and decision making personals for effective management of ground water resource. GIS software has been used for analysis and mapping the groundwater vulnerability index in the study area.

Keywords DRASTIC index, Groundwater vulnerability, GIS

1. Introduction

The quality of groundwater is as important as that of quantity. The water quality gets deteriorated due to the high growth of population, unplanned growth of cities, mixed land use patterns, improper sewage system, and poor disposal of the wastewater both from household as well as industrial activities. In contrast to surface water pollution, sub-surface pollution is difficult to detect and of more difficult to control. Groundwater vulnerability is a function of different hydro-geologic settings of an area. In any given area, the groundwater within an aquifer, or the groundwater produced by a well, has some vulnerability to contamination from human activities. Water pollution is a serious problem in India as almost 70% of its surface water resources and a great number of its GW reserves are already contaminated by biological, organic, and inorganic pollutants (Rao and Mamatha, 2004). Even today more than 90% of our rural population is primarily dependent on GW (Chandrashekhar, Adiga, Lakshminarayana, Jagdeesha and Nataraju, 1999). The DRASTIC model was developed in US Environment protection Agency (USEPA) to evaluate groundwater pollution potential for the entire United States by (Aller et al., 1987). “DRASTIC” aquifer vulnerability mapping technique or numerical rating scheme has been developed for evaluating the potential for groundwater pollution in a given...
area based on a set of hydro geological settings. This rating scheme is based on 7 factors chosen by over 35 groundwater scientists from throughout the United States by assigning relative importance weights and a point rating scale for each factor (Table 1). Lobo-Ferreira and Oliveira (2004) following “DRASTIC” model mapped the groundwater vulnerability of Portugal as a part of an investigation by a European commission's sponsored groundwater project. This was the first application in a European Union member state. The seven “DRASTIC” parameters and the final index were developed in GIS. Aller et al. (1987) developed a standardized system to evaluate groundwater pollution potential using hydro-geologic settings. Kimura (1997) worked on evaluating migration potential of contaminants through unsaturated subsurface in Texas Vulnerability Map. In this work the various vulnerability assessment methods were reviewed. Usha Madhuri and Srinivas (2004) worked on studies on assessment of Groundwater vulnerability index for the city of Visakhapatanam, Andhra Pradesh, India through application of “DRASTIC” model. GW vulnerability is a function of the geologic setting of an area, as this largely controls the amount of time, i.e. the residence time of the GW that has passed since the water fell as rain, infiltrated through the soil, reached the water table, and began flowing to its present location (Prior, Boekhoff, Howes, Libra, and VanDorpe, 2003). Rundquist et al. (1991) have produced state wide GW vulnerability assessment in Nabraska using DRASTIC/GIS model and identified the areas vulnerable to GW pollution and concluded that DRASTIC methodology can be executed successfully with minimal training and experience. Various parameters for GW quality like pH, EC, TDS, Cl, Na, K, total hardness(TH), etc. were tested and thereafter ILWIS GIS software was used for mapping the spatial variations of these parameters and also salt affected areas were demarcated (Durbude, Naradrajan and Purandara, 2003). A GW vulnerability mapping methodology that requires less extensive site-specific data, and at the same time, is robust when data are uncertain and incomplete will be a useful screening tool (A. Rahman / Applied Geography 28 (2008)).

1.1. Study Area

The study area JITM campus of Centurion University for Technology and Management (Figure 1) is located at Parakhemundi, Gajapati district, Odisha covering an area of about 70 acres of land (Latitude - 18°48'32.5", Longitude - 84°8' 11.9"). The current population of the campus is 2500. The main source of water is ground water. For the study area the principal sources of contamination are a) Kitchen
waste from the hostels and quarters, b) Waste water from toilets and bathrooms, c) Waste material from workshop and laboratories.

Figure 2: Flow diagram of “DRASTIC APPROACH”
Table 1: Weights assigned to various hydro geological parameters of “DRASTIC” model

| Factors                          | Importance weight |
|----------------------------------|-------------------|
| Depth to Ground water (D)        | 5                 |
| Net recharge (R)                 | 4                 |
| Aquifer Media (A)                | 3                 |
| Soil Media (S)                   | 2                 |
| Topography (T)                   | 1                 |
| Impact of Vadose zone media (I)  | 5                 |
| Hydraulic Conductivity of the aquifer (c) | 3         |

Source: EPA document # 6002-85/018-1985, Linda Aller et al., 1987

2. Methodology

Determination of the “DRASTIC” index for a given area involves multiplying each factor weight indicated in Table 1 by its rating and summing the total. The total higher sum values represent greater potential for groundwater pollution, or greater aquifer vulnerability. For a given area each factor is rated from 1 to 10, indicating the relative pollution potential for that area. After assigned rating to each factor, each rating is multiplied by assigned weight, and the resultant numbers are summed as follows:

\[ D_{w}D + R_{w}R + A_{w}A + S_{w}S + T_{w}T + I_{w}I + C_{w}C = \text{Groundwater Vulnerability Index (GWVI)} \]  \( \cdots \) (1)

Where, \( r \) = rating for area being evaluated; \( W \) = importance weight for factor.

Table 2: Groundwater vulnerability index

| S. No | Drastic Index | Degree of vulnerability       |
|-------|---------------|-------------------------------|
| 1     | \(V<80\)      | Low vulnerability             |
| 2     | \(80 \leq V<120\) | Medium vulnerability         |
| 3     | \(120 \leq V<160\) | High vulnerability           |
| 4     | \(160 \leq V<185\) | Very High vulnerability      |
| 5     | \(\geq185\)   | Extremely vulnerability       |

Source: Added A and Hamza M. H, 1999

The weight of each factors assigned according to its pollution potential and it varies from 1 to 5. The ratings assigned each parameter (1 to 10) depends on the magnitude of the parametric property influencing the contaminates transport. 35 groundwater scientists from throughout the United States have identified the degrees or vulnerability based on the magnitude of ground water vulnerability index as given in Table 2. Higher value of groundwater vulnerability index indicates the high pollution potential.

3. Results and Discussion

3.1. Depth to Groundwater (D)

The depth to groundwater has been measured from the open wells distributed within the study area. The depth to ground water ranges from 2 feet to 5 feet. According to this data the rating has been assigned and the rating map is shown in Figure 3.
Table 3: Rating scale for the depth to groundwater

| Ranges (feet) | Ratings |
|--------------|---------|
| 0-5          | 10      |
| 5-15         | 9       |
| 15-30        | 7       |
| 30-50        | 5       |
| 50-75        | 3       |
| 75-100       | 2       |
| >100         | 1       |
| Weight       | 5       |

Source: EPA document # 600/2-85/018-1985, Linda Aller et al., 1987

Figure 3: GW depth rating map of CUTM campus

Table 4: Rating scale for the net recharge

| Annual recharge range (mm) | Ratings |
|---------------------------|---------|
| 0 – 50.8                  | 1       |
| 50.8 – 101.6              | 3       |
| 101.6 – 177.8             | 6       |
| 177.8 – 254.0             | 8       |
| >254.0                    | 9       |
| Weight                    | 4       |

Source: EPA document # 600/2-85/018-1985, Linda Aller et al., 1987

3.2. Net Recharge (R)

The rainfall data for 10 years are considered and average rainfall is considered 1449.45mm for determining the net recharge based on soil type. The net recharge values as a % of annual rainfall for different soil type has been taken from the thesis by T. Usha Madhuri (2004). The rainfall data is obtained from the records of, Irrigation Department, Paralakhemundi. Soil type is obtained from the various laboratory tests. The net recharge for the study area ranges 173.934mm to 246.4065mm from Figure 4 shows the net recharge rating map of CUTM Campus, Paralakhemundi.
Figure 4: Net recharge rating map of CUTM campus

Figure 5: Aquifer media rating map of CUTM campus

Table 5: Rating scale for the aquifer media

| Types of Aquifer media                                       | Rating |
|-------------------------------------------------------------|--------|
| Massive shale                                               | 2      |
| Metamorphic/Igneous                                         | 3      |
| Weathered Metamorphic Igneous                                | 4      |
| Thin bedded sandstone, Limestone, Shale sequences            | 6      |
| Massive sandstone                                           | 6      |
3.3. Aquifer Media (A)

The aquifer for the study area is obtained from geology map from early study. The type aquifers in the study area are mainly Metamorphic/Igneous type. Based on this information the rating map with respect aquifer media is generated as a part of "DRASTIC" index calculations followings the standard rating scale specified earlier in Table 5 and the same is shown here as Figure 5.

Table 6: Rating scale for the soil media

| Range                        | Rating |
|------------------------------|--------|
| Thin or absent               | 10     |
| Gravel                       | 10     |
| Sand                         | 9      |
| Shrinkage and or aggregate clay | 7     |
| Sandy loam                   | 6      |
| Loam                         | 5      |
| Silty loam                   | 4      |
| Clay loam                    | 3      |
| Non shrinkage and non-aggregated clay | 1     |
| Weight                       | 2      |

Source: EPA document # 6002-85/018-1985, Linda Aller et al., 1987
3.4. Soil Media (S)

Soil media in the study area defined from sieve analysis, liquid limit test and plastic limit test according to IS classification system. The study area is covered with SM, SC, and SP type of soil. Figure 6 shows the rating maps of soil media of the study area.

Table 7: Rating scale for the topography

| Range % slope | Rating |
|---------------|--------|
| 0-2           | 10     |
| 6-Feb         | 9      |
| 12-Jun        | 5      |
| 18-Dec        | 3      |
| >18           | 1      |

Source: EPA document # 600/2-85/018-1985, Linda Aller et al., 1987

3.5. Topography (T)

Topography refers to slope of an area. Areas with steep slopes, having large amounts of runoff and smaller amounts of infiltration are less vulnerable to GW contamination. Flat areas were assigned high rates because in flat areas the runoff rate is less, so more percolation of contaminants to the GW. The study area is nearly slope. So the rating is very high. The result and Figure 7 shows the topography rating map of CUTM Campus, Paralakhemundi.

3.6. Impact of Vadose Zone

The vadose zone’s influence on aquifer pollution potential is essentially similar to that of soil cover, depending on its permeability, and on the attenuation characteristics of the media. The vadose zone is
evaluated on the basis of soil type. Impact of vadose rating map of CUTM Campus, Paralakhemundi is shown in Figure 8.

**Figure 8:** Impact of vadose zone rating map of CUTM campus

![Image of impact of vadose zone rating map](image)

**Figure 9:** Hydraulic conductivity map of CUTM campus, Paralakhemundi

![Image of hydraulic conductivity map](image)

**Table 8:** Rating scale for the vadose zone

| Range                                      | Rating |
|--------------------------------------------|--------|
| Silt / Clay                                | 1      |
| Shale                                      | 3      |
| Limestone                                  | 6      |
| Sandstone                                  | 6      |
| Bedded limestone, sand stone, shale        | 6      |
| Sand and Gravel with significant silt and clay | 6    |
| Metamorphic / Igneous                      | 4      |
| Sand and Gravel                            | 8      |
| Basalt                                     | 9      |
| Karst lime stone                           | 10     |
| Weight                                     | 5      |

*Source: EPA document # 6002-85/018-1985, Linda Aller et al., 1987*
Table 9: Rating scale for the hydraulic conductivity

| Hydraulic conductivity (m/day) | Rating |
|-------------------------------|--------|
| 0.005-0.5                    | 1      |
| 0.5-1.5                      | 2      |
| 1.5-3.5                      | 4      |
| 3.5-5                        | 6      |
| 10-May                       | 8      |
| >10                          | 10     |

Weight 3

Source: EPA document # 6002-85/018-1985, Linda Aller et al., 1987

Figure 10: GWVI map of CUTM campus, Paralakhemundi

Table 10: Ground water vulnerability index

| Area / Location         | Depth | Net recharge (mm) | Aquifer media | Soil media | Topography (% of slope) | Impact of vadose zone | Hydraulic conductivity (m/day) | DRASTIC index |
|-------------------------|-------|-------------------|---------------|------------|-------------------------|-----------------------|-------------------------------|--------------|
| Dhaba                   | 4’4”, R=10 | 188.4285, R=8 | Metamorphic/Igneous, R=3 | SM, R=6 | NL, R=10 | SM, R=6 | 1.0499, R=2 | 149 |
| Mahendra tanaya girls hostel | 3’, R=10 | 173.934, R=6 | Metamorphic/Igneous, R=3 | SC, R=6 | NL, R=10 | SC, R=6 | 1.430, R=2 | 141 |
| Diploma boys hostel     | 3’7”, R=10 | 173.934, R=6 | Metamorphic/Igneous, R=3 | SC, R=6 | NL, R=10 | SC, R=6 | 1.30, R=2 | 141 |
| MDC                     | 4’, R=10 | 173.934, R=6 | Metamorphic/Igneous, R=3 | SC, R=6 | NL, R=10 | SC, R=6 | 1.885, R=4 | 147 |
| MBA badminton court     | 4’, R=10 | 188.4285, R=8 | Metamorphic/Igneous, R=3 | SM, R=6 | NL, R=10 | SM, R=6 | 3.866, R=6 | 151 |
| Tribal village          | 3’, R=10 | 173.934, R=6 | Metamorphic/Igneous, R=3 | SC, R=6 | NL, R=10 | SC, R=6 | 3.973, R=6 | 153 |
| Old guest house         | 3’4”, R=10 | 173.934, R=6 | Metamorphic/Igneous, R=3 | SM-SC, R=6 | NL, R=10 | SM-SC, R=6 | 4.943, R=6 | 153 |
| B. Tech Boys hostel 2   | 2’7”, R=10 | 173.934, R=6 | Metamorphic/Igneous, R=3 | SC, R=6 | NL, R=10 | SC, R=6 | 2.334, R=4 | 147 |
3.7. Hydraulic Conductivity (C)

Hydraulic conductivity of the study area is obtained by falling head permeability test. Hydraulic conductivity of the study area ranges from 1.0499 m/day to 7.129 m/day. Considering the data obtained the rating assigned to each area. Figure 9 indicates the hydraulic conductivity rating map.

The final steps are the calculation of the GWVI using equation 1. Considering the ratings along with weightages listed in Table 1 the values or GWVI have been obtained and the final results are shown in Table 10 and Figure 10 shows the GWVI map for the study area which is obtained by superimposing the layer shown in Figure 2 to 8 after incorporating the weightages of the DRASTIC parameters.

4. Conclusion

Groundwater plays an important role in drinking and other household work in CUTM campus, Paralakhemundi, Odisha. In this study DRASTIC model is used to assess the groundwater vulnerability in the study area. Seven parameters included, which represents the hydro-geological setting of the study area, are Depth to water, Net recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, and hydraulic Conductivity. The results of groundwater vulnerability to pollution assessment shows index value which varies from 141 to 183. According to the results, the study area divided into two zones i.e. high vulnerable and very high vulnerable zone. The maximum area has been fallen under high vulnerable zone (Figure 10).

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