

Assessment of Groundwater Vulnerability in Walawe River Basin, Sri Lanka

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Abstract— *In the present study, DRASTIC model has been used as a feasible methodology to assess the groundwater vulnerability in the Walawe river basin, Sri Lanka. The main objective of the study is to assess the potential level of groundwater vulnerability for pollution and to compare the areas with land use activities representing the degree of usage of fertilizers in agriculture. The Geographical Information Systems (GIS) has been used to develop vulnerability maps, showing the relative vulnerability of the area. The results concluded that the upper part of the basin shows very low vulnerability and the lower part shows higher vulnerability for groundwater pollution. The ground water vulnerability maps are compared with the agricultural land use pattern of the area and it is noticed that the areas with intense agricultural activities, overlapped with the areas with high DRASTIC index values. In the area with higher DRASTIC index and with intense agricultural activities including the extensive usage of fertilizers and pesticides, more attention should be focussed to establish a monitoring network for adequate groundwater quality control and to reduce the anthropogenic stress on groundwater resources.*

Keywords: Groundwater Vulnerability, Walawe River Basin, DRASTIC, GIS, Land Use

1. Introduction

There is a tremendous increase in the demand of groundwater utilization for agriculture, industry and domestic use. At the same time, the adverse effects like depletion of resources and degradation of groundwater quality will also enhance. The increasing trend of anthropogenic stresses on groundwater resource has made it vulnerable. Therefore, it is necessary to improve the planning, development, and management of groundwater resources in order to use groundwater safely without threats of depletion and pollution. Because of the known adverse health and economic impacts associated with groundwater contamination, especially in developing countries, the benefits of tools, used to identify and prevent the contamination are becoming more apparent.

The term 'vulnerability of groundwater to contamination' was introduced in the 1960s in France [1]. To evaluate the groundwater vulnerability, a methodology has been developed [2]. This method is called DRASTIC, with seven factors which influence the pollution potential level: depth to groundwater, recharge, aquifer media, soil media, topography, impact of the vadose zone and hydraulic conductivity. Groundwater vulnerability is usually expressed on maps. The main purpose of DRASTIC methodology is to create vulnerability maps that will permit to assess the groundwater pollution potential of any hydrogeologic setting systematically with existing information. The ultimate goal of the vulnerability map is a subdivision of an area into several units showing the differential potential for a specified purpose and use. Many authors provided detail reviews of groundwater vulnerability mapping with respect to groundwater contamination using DRASTIC technique; applied and validated

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the methodology [3-8]. In this present study the result of vulnerability assessment in the Walawe river basin has been portrayed on a map showing various homogeneous areas, which have different levels of vulnerability. The difference between the areas is however arbitrary, because vulnerability maps show only relative vulnerability of certain areas to others, and do not represent absolute values.

2. Methodology

Seven DRASTIC parameters are divided into either ranges or media types. The depth to groundwater table, recharge, topography and hydraulic conductivity have been divided into numerical ranges while the aquifer media, soil media and impact of vadose zone have been divided into media types. Each range or media type has been assigned with a rating, used to assess the groundwater pollution potential of each parameter. The typical ratings range from 1 to 10. The value of 10 would indicate an area of highest groundwater vulnerability whereas the value of 1 would indicate the lowest groundwater vulnerability. Since the ranges and the ratings of the parameters in the study area are deviated from the values assigned by EPA's committee of experts, the typical ranges and rating schemes given in DRASTIC guide manual [2] were modified according to the local hydro-geological conditions. Local modifications are based upon the specific regional data in Walawe basin and the

modified ranges and ratings have been accommodated to determine the local DRASTIC index.

The overall grade of vulnerability can be written as a numerical value (DRASTIC index). The DRASTIC Index (DI) for each hydro-geologic setting is obtained by summing up the multiple of rating and the relevant weight factor of each parameter as follows:

$$DI = D_w D_R + R_w R_R + A_w A_R + S_w S_R + T_w T_R + I_w I_R + C_w C_R \quad (1)$$

Where subscripts R is the rating for each factor and W is the weighting factor

3. Study Area

The Walawe River basin is located in the southern part of Sri Lanka, between North latitudes 6° 00' and 6° 40' and East longitudes 80° 40' and 81° 10' (Fig. 1). The catchment area of the basin is 2442 km² and it is the major irrigation area in the dry tropics of southern Sri Lanka. The whole basin is subdivided into sub basins and three major sub-basins in the downstream of Udawalwe reservoir have been selected for the analysis depending on the availability of hydro-geological data (Fig. 1). The selected part of the basin is located in the dry zone, which has an annual rainfall less than 1500 mm and groundwater is extensively used for agriculture and domestic use.

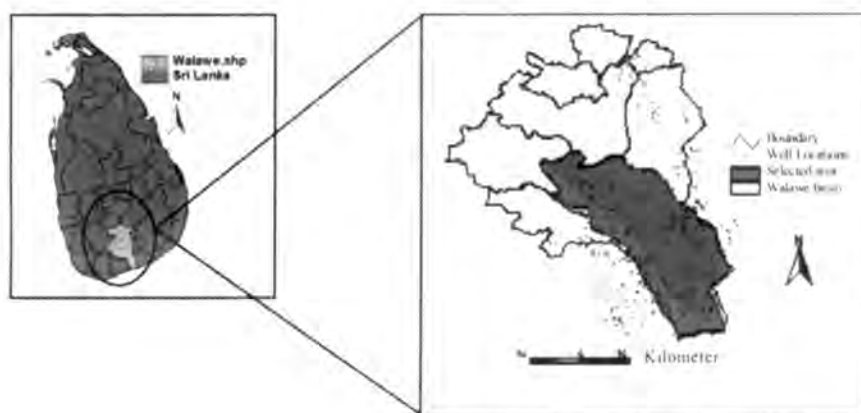


Fig. 1. Study Area

4. Results and Discussions

4.1 Application of DRASTIC model to Walawe River Basin

The seven DRASTIC parameters have been evaluated for groundwater vulnerability, using the available hydro-geological data. The ranges in depth to water have been determined based on depths where the potential for groundwater pollution significantly changes. Annual average groundwater depth has been taken into account to define the ranges and ratings for 'depth to groundwater'. Net recharge includes the average annual amount of infiltration and does not take into consideration the distribution, intensity or duration of recharge events. The average annual groundwater recharge has been estimated using a simple water balance approach.

The data related to the aquifer media was obtained from the collected data of the geology exploration reports and bore-hole logs. The aquifer types available in the Walawe basin

were classified into seven groups. The soil types were classified into groups with reference to the soil maps of the area (Geological Survey and Mines Bureau, Sri Lanka). According to the DRASTIC rating scheme with reference to US Soil Conservation Service, suitable values were assigned to each soil group. A Digital Elevation Map (DEM) of the area has been used to represent the topography of the study area. The steepness of the topography is very low when compared to the ranges given in DRASTIC scheme. Hence, high pollution potential can be suspected and higher ratings were assigned. The vadose zone was classified according to the data obtained from bore-hole log records. To calculate the hydraulic conductivity, several pumping test results, which were carried out in the study area, were used. Even though the number of test data was less, the available hydraulic conductivity values were grouped into ranges and ratings where high conductivity is associated with high pollution potential (see Table 1 and Table 2).

Table 1. Ranges and ratings for depth to groundwater table, net recharge, topography and hydraulic conductivity.

Depth to water table		Net Recharge		Topography (Slope)		Hydraulic Conductivity	
Range (m)	Rating	Range (mm)	Rating	Range (% slope)	Rating	Range (m/day)	Rating
0-1.5	10	0-25	1	0.002-0.2	10	0-5	1
1.5-4.5	9	25-50	3	0.2-1.0	9	5-10	2
4.5-9.0	7	50-75	6	1.0-2.5	7	10-15	4
9.0-15.0	5	75-100	8	2.5-3.5	5	15-20	6
15.0-22.0	3	>100	9	3.5-4.5	4	20-25	8
22.0-30.0	2			>4.5	3	>25	10
30.0+	1						

Table 2. Ranges and ratings for aquifer Media, soil type and vadose zone media

Aquifer Media		Soil type		Vadose Zone Media	
Range	Rating	Range	Rating	Range	Rating
Quartzites and Pegmatite	2	Clay	1	Fresh rock	1
Regolith	3	Sandy Clay	2	Sand, silt and clay	3
Crystalline limestone	6	Organic/decomposed materials	3	Biotite (Metamorphic rock)	4
Littoral sands	6	Clayey sand	6	Sand and Gravel	6
Alluvium	8	Clay with quartz and gravel	7	Limestone	6
Sand and Gravel	8	Gravelly sand	9	Boulders / Rubbles	9
Major faults, joints	10				

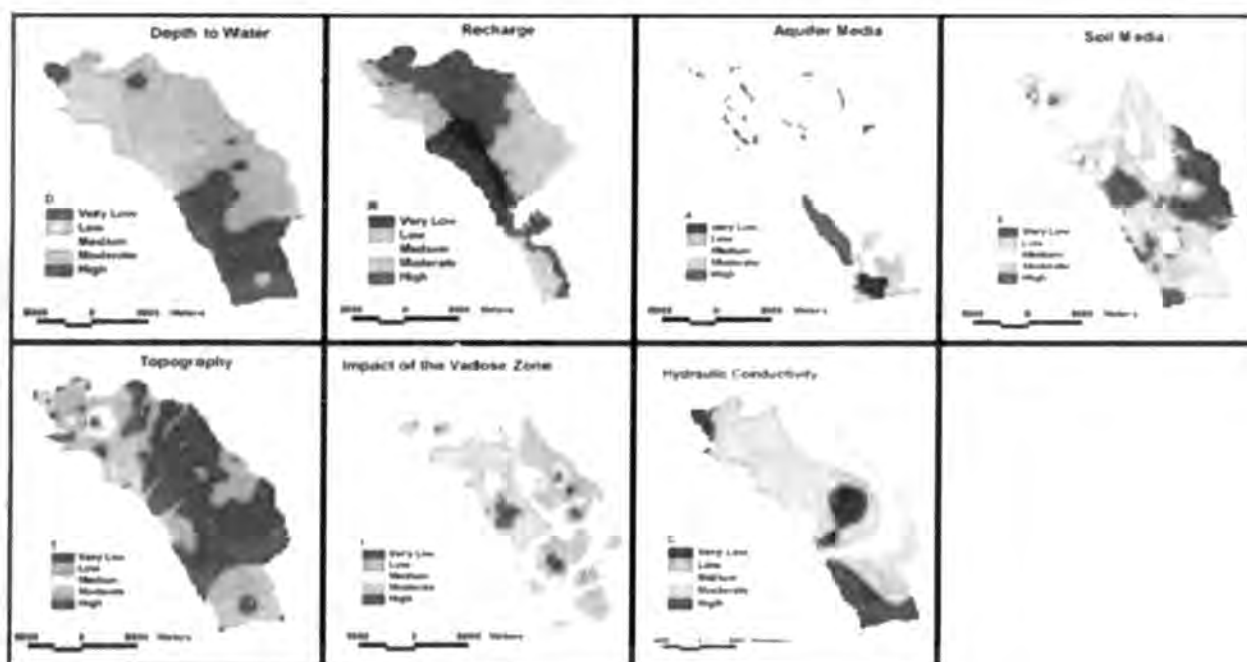


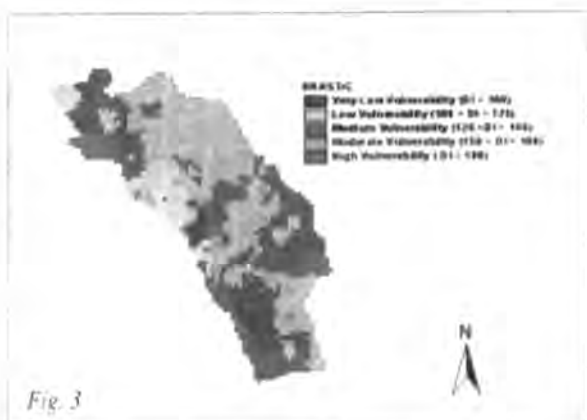
Fig. 2. The input map layers for each DRASTIC parameter

Table 3. The weighting factors for hydro-geological variables in DRASTIC method

Hydro-geological variable	Weighting Factor
Depth to Groundwater (D)	5
Net Recharge (R)	4
Aquifer media (A)	3
Soil media (S)	2
Topography (T)	1
Impact of the Vadoze zone (I)	5
Hydraulic Conductivity (C)	3

Each DRASTIC parameter has been evaluated with respect to the others in order to determine the relative importance of it. Thus, each parameter has a predetermined, fixed, relative weight that reflects its relative importance to vulnerability. The most significant factors have weight of 5; the least significant weight of 1 (Table 3). The DRASTIC Index is computed by summation of the products of rating and weights of each factor. To create the DRASTIC Index map, the study area was divided into 500m 500m grids. The resulting map of the DRASTIC index to represent the groundwater vulnerability has been calculated by the

operation of map overlays and classification performed in the GIS environment. After processing of the seven DRASTIC parameters into cell vector map layers using ARC/INFO, the layers were converted to ERDAS GIS raster format. Figure 2 shows the input map layers for each DRASTIC parameter and the respective vulnerability class. The ultimate result is a numerical value; the DRASTIC Index (DI) for each cell has been calculated using the additive equation.

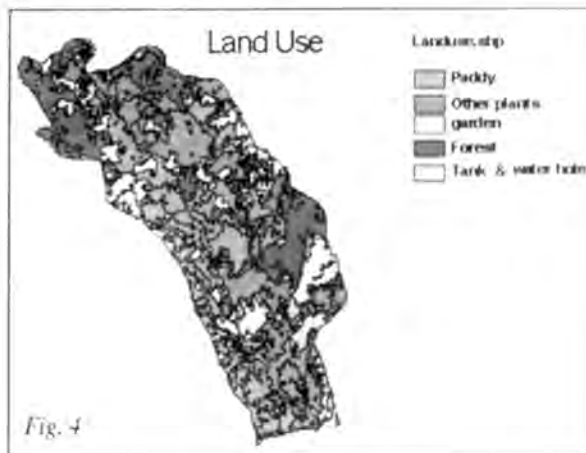


4.2 DRASTIC vulnerability index

The final DRASTIC coverage shows the distribution of DRASTIC vulnerability index over the study area (Fig. 3). The DRASTIC index ranges between 89 and 197 which are compatible with the range given by Aller et al [2] within the range 50 to 200. The DRASTIC index was further divided into five categories: very low, low, moderate, high, and very high. The higher DRASTIC index means the greater relative pollution potential. The classification is based in the DRASTIC Index as follows,

- Very low vulnerability ($DI < 100$)
- Low vulnerability ($100 < DI < 125$)
- Medium vulnerability ($125 < DI < 150$)
- Moderately high vulnerability ($150 < DI < 180$)
- High vulnerability ($DI > 180$)

The DRASTIC indexes are relative values and, a site with a low index need not necessarily



mean that it is free from groundwater contamination, but it is relatively less susceptible to contamination compared to the sites with high or very high DRASTIC indexes. Fig. 3 shows that the values of the DRASTIC index clusters around moderate vulnerability with very few points in the low and high vulnerability ranges. It favourably shows that the lower part of the basin is exposed to higher vulnerability while the upper eastern part has very low and low vulnerability. The central region of the basin covers with medium to moderate vulnerability.

4.3 Groundwater Vulnerability and Land Use Pattern

To incorporate the impact of land use activities with extensive fertilizer usage over prolonged periods of time, the land use pattern of the area has been evaluated with DRASTIC maps. For this purpose, the land use data for the area were obtained from the maps of the Geological Survey and Mines Bureau, Sri Lanka. The land use coverage can be classified into five main groups based on the land use infiltration; paddy fields, impervious areas or gardens, forests, reservoirs or waterways and other agricultural areas. The other agricultures are sugar cane, chena (dry-land cultivation) and upland crops. The forests mainly consist of marshy lands, scrubs, grass lands and mild and thick forests (Fig. 4). Most of the paddy fields are located in the lower part of the basin. The

flat and gentle lands in the lower basin are suitable for paddy cultivation. There is an underlying alluvial deposit layer in almost all paddy field areas [9]. This alluvial layer leads to a higher infiltration of contaminant to deep groundwater. The other agricultural crop areas especially dry-land cultivations are also identified as active non-point sources of groundwater contamination. There is higher infiltration occurring in agricultural crop areas such as upland crop fields due to high permeable soil layers. Human activities in agricultural fields, mainly the overuse of fertilizers and pesticides, affects the groundwater contamination and those areas can be considered as areas where the levels of risk to groundwater from potential pollution are expected to be high. The forests with less anthropogenic activities have less pollution potential. The forests are mainly distributed in the upper part of the basin and the upper area has steep slope and higher depth for groundwater level. The values of the DRASTIC index also favorably show that the lower part of the basin is exposed to higher vulnerability while the upper and eastern areas are exposed to low and very low vulnerability. It is noticed that the paddy fields and other cultivation areas are overlapped with the higher DRASTIC index regions, which show the highest potential for the vulnerability (compare Fig.3. and Fig. 4). These are the areas where percolation of pollutants to groundwater is enhanced. The areas with both higher DRASTIC index and extensive agricultural usage have the maximum potential for groundwater pollution. Thus an effective use of composite DRASTIC and land use assessments can assist in assessing the groundwater vulnerability and planning guidelines which take into account the hydrological realities as well as human activities. The anthropogenic stress of highly vulnerable areas such as usage of fertilizers and pesticides must be managed and controlled to protect the contamination of groundwater resources. Attention must be focussed to the

areas with extensive land use activities and human activities, mainly the overuse of fertilizers and pesticides for the crops, sewerage facilities, landfills and waste disposal activities. While making the land use control policies, these ground water vulnerability maps are very useful to take appropriate decisions and subsequent measures for pollution prevention and mitigation.

5. Conclusions

Among the methods for measuring groundwater vulnerability, DRASTIC index is a feasible indicator to understand groundwater vulnerability, based on the physical setting of the groundwater system and it was successfully applied to Walawe river basin to develop groundwater vulnerability maps. Localized ranges and ratings have been used, where required, to implement and adopt data according to local conditions. The resultant DRASTIC indexes for the entire study area reflect mostly low to moderate vulnerability while the lower part of the basin is exposed to higher vulnerability and the upper eastern part of the area has low and very low vulnerability. The high and very high vulnerable areas are coincident with the paddy cultivated lowland areas with the terraces built from alluvial deposits and shallow groundwater table. In such areas, the density of monitoring points for adequate groundwater quality control must be enhanced and land use guidelines and limitations must be carefully drawn up to control the groundwater contamination and to protect the groundwater resources for sustainable groundwater usage strategies.

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Biographical Sketch

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