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Assessment of Aquifer-Land Use Composite Vulnerability in Walawe River Basin, Sri Lanka

Priyantha Ranjan*, Ashim Das Gupta[1], So Kazama and Masaki Sawamoto[2]

Graduate School of Environmental Studies, Tohoku University
Aoba yama 06, Sendai, 980-8579, Japan
[1]School of Civil Engineering, Asian Institute of Technology
P.O. Box 4, Klong Luang, Pathumthani, 12120, Thailand
[2]Department of Civil Engineering, Tohoku University
Aoba yama 06, Sendai, 980-8579, Japan
✉ ranjan@kaigan.civil.tohoku.ac.jp

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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. Geographical Information System (GIS) has been used to develop vulnerability maps, explaining the relative vulnerability of the area. The DRASTIC output concluded that the upper and western parts of the basin show very low vulnerability while the lower part shows higher vulnerability. The groundwater vulnerability maps are compared with the agricultural land-use pattern of the area and it is noticed that the intense agricultural areas and high DRASTIC index areas are overlapped. To emphasise the natural state of the aquifer media as well as the potential pollution of extensive land use, a new indicator has been introduced as Aquifer-Land use Composite Vulnerability Index. This indicator further concludes that the lower part of the Walawe River basin depicts a higher risk for future groundwater quality and hence more attention should be focused to establish monitoring network for adequate groundwater quality control in the area.

Key words: Groundwater pollution, vulnerability, DRASTIC index, land use, GIS.

Introduction

There is a tremendous increase in demand of ground water 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, specially impacts of extensive land use leads to increase in the groundwater pollution and contamination. Therefore, it is necessary to improve the tools and mechanisms which can be used to identify and to prevent the contamination of groundwater resources in order to use ground water safely without threats of depletion and pollution. Because of the known adverse health and economic impacts associated with groundwater pollution, the benefits of such tools used for the development and management of groundwater resources are becoming more apparent. Therefore, vulnerability assessment of groundwater resources should aim at providing preliminary information and criteria for decision-making in such areas as: designation of land use controls, delineation of monitoring networks and management of groundwater resources in the context of regional planning as related to protection of groundwater quality (Secunda et al., 1998).

To evaluate the groundwater vulnerability, a methodology has been developed by Aller et al. (1987). This method is called DRASTIC, with seven factors which influence the pollution potential: depth to groundwater, recharge, aquifer media, soil media, topography, impact

*Corresponding Author

of the vadose zone and hydraulic conductivity. In DRASTIC methodology, groundwater vulnerability is usually expressed on maps. The main purpose of DRASTIC vulnerability maps is to assess the groundwater pollution potential of any hydrogeologic setting systematically with existing hydrogeological information. DRASTIC vulnerability map subdivide the area into several units showing the differential potential for specified purposes and use. The difference between the areas is however arbitrary, because vulnerability maps show only relative vulnerability of certain areas to others.

Many authors provided detail reviews of groundwater vulnerability mapping with respect to groundwater contamination using DRASTIC technique and validated the methodology for different hydrogeologic settings (Canter, 1990; Kalinski et al., 1994; Rosen, 1994; Vrba and Zaporozec, 1994; Adams and MacDonald, 1995; Melloul and Collin, 1998; Wilchelm et al., 2000). The Geographic Information System (GIS) which is being widely used for vulnerability mapping applies DRASTIC technology in groundwater resources management. GIS offers the facilities to store and analyze data in different formats at different scales. Recently, the integration of DRASTIC models in GIS environment is becoming more interesting (Babiker et al., 2005; Dixon, 2005; Al-Adamat et al., 2003; Thirumalaivasan et al., 2003). The effectiveness of DRASTIC vulnerability maps can be improved by calibrating on the basis of the correlation among groundwater quality and hydrogeologic settings and anthropogenic activities such as land-use activities of the study areas (Evans et al., 1990; Rupert, 2001).

Present study is the first attempt to apply DRASTIC methodology to assess the groundwater vulnerability in Walawe river basin, Sri Lanka. We aim to portray the results of vulnerability assessment on a map showing various homogeneous areas, which have different levels of vulnerability. Finally we combine the DRASTIC index and land-use data to integrate aquifer vulnerability and extensive agricultural land use covering the Walawe river basin to incorporate both the natural state of the aquifer media as well as the potential danger posed by the long-term effect upon the media of existing extensive land usage to the region's groundwater.

Materials and Methodology

Study Area: Walawe River Basin

Walawe river basin is located in the southern part of Sri Lanka, between North latitudes 60° 00′ and 60° 40′ and East longitudes 80° 40′and 81° 10′ (Figure 1). The catchment area of the basin is 2442 km^2 and it is the major irrigation area in the dry tropics of southern Sri Lanka. Walawe river flows from north to south with the total river length of 105 km. The northern watershed boundary of the Walawe river basin lies along the crest of the high escarpment and marks the southern edge of the hill country of Sri Lanka. The western part of the basin includes the eastern ends of the Sabaragamuwa ridge systems. The eastern boundary of the basin is the watershed between the Walawe river and Kirindi Oya basin in the centre, and the course of Malala Oya in the south.

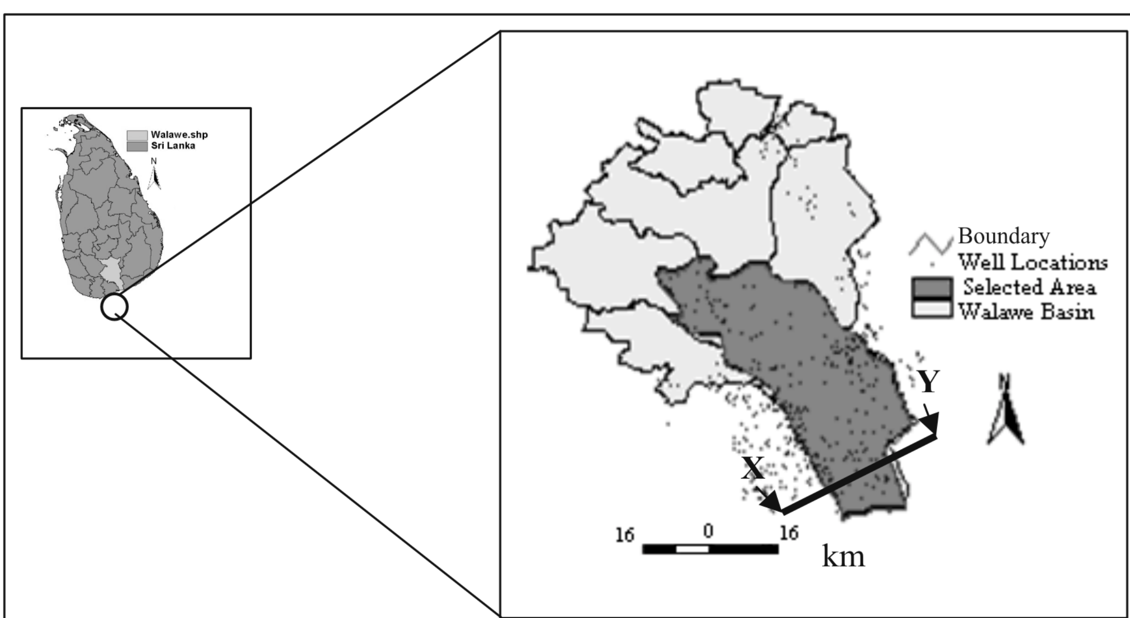

Figure 1: Study area: Walawe river basin.

Walawe river basin can be divided into three well defined areas based on relief and geomorphology viz. the coastal plains in the South, the middle region in the centre and the hilly ranges in the small areas in North and North-East parts (Statkraft Groner, 2000). The upper part of the Walawe basin is located at the southern foot-hills of the central highlands of Sri Lanka, at an elevation of more than 2000 m above mean sea level. The basin drops from the central highlands in a general southerly direction, towards the lower basin which consists of very gentle and flat lands. The flood plains of the Walawe river and its tributaries have thick alluvium. Therefore, Walawe river basin is fortunate to have extensive groundwater resources and it also has well-developed alluvial tracts and deltas with extensive sand and gravel aquifers. Significant part of the lower basin includes alluvium deposits. Alluvium is limited in the mid-basin areas and very rare in the upper basin. Mainly two rock series have been identified as Vijayan series in the left part of the basin and Highland series in the right. The upper basin and the western border of the Walawe basin belong to the Highland Series of basement crystalline rocks, while the Vijayan series underlies the eastern mid basin. Highland series basement rocks has a significant number of major rock structures such as faults, joints, and shear zones, which provide deep semi-confined aquifers (Kulatunga, 1998). The typical aquifers of the Walawe basin are identified by geophysical explorations and their hydro-geological features. Walawe river basin has been selected as one of the benchmark basin proposed by International Water Management Institute (IWMI) as an approach to understand and beneficially influence water resource development in selected basins in a variety of agro-ecological zones (Hemakumara et al., 2001). Walawe river basin has been divided into several sub-basins for the monitoring and observation purposes (Statkraft Groner, 2000). Three major sub-basins in the downstream of Udawalwe reservoir (Sooriyawewa, Udawalawe and Ridiyagama) have been selected for this assessment, according criteria including intensive agricultural activities and extensive availability of hydrogeological data regarding aquifer properties (Figure 1). Also, the selected part of the basin is located in the dry zone, which has annual rainfall less than 1500 mm and the area involves significant local abstraction of groundwater resources for drinking, irrigation and industry.

Groundwater Quality in Walawe River Basin

In the rural areas of Sri Lanka the majority of the population totally depends on untreated surface and ground water for drinking and domestic purposes. Health problems of these rural communities are mostly related to their drinking water quality of the natural and aquatic environments of the areas concerned. The studies have shown very high levels of nitrate in ground water in some areas in the southern part of Sri Lanka including Walawe river basin (ECL, 1995). Reported findings of groundwater contamination in Walawe river basin led the Sri Lankan government to conduct a wide survey on well contamination in the basin and the water quality problems relating to high levels of chemicals have been observed (JICA, 2002). The survey concluded that many tube wells that have been drilled by the Sri Lankan government, have been abandoned due to the deteriorated water quality in the Walawe river basin and surrounding areas. Therefore measures should be taken to study the occurrence of ground water as well as the spatial pattern of its quality and related health effects in order to overcome such situation and to recommend remedial measures.

Nitrogen in ground water in the form of nitrates is a large problem in the Walawe river basin. It is as much as twice the WHO standard of 40 mg/l^{-1} NO_3^- (Dissanayake and Chandrajith, 1999; Chandrajith et al., 2000). Most of this nitrogen comes from agricultural sources. The problem of groundwater nitrate is function of the long-term use of artificial and natural fertilizers, with excessive amounts of manure applied to agricultural land in rotation. Agriculture is the primary source of the elevated nitrate levels although in some rare cases certain geologic units can be the source of the nitrate. Hence, groundwater contamination by nitrates due to application of fertilizers and livestock waste in agricultural management systems is of wide concern. In recent years, intensive agricultural practices in Sri Lanka have increased in response to the population growth, and have resulted in very high inputs of artificial fertilizers containing more than 40% nitrates (Wijayathilake, 2001). The data of National Fertilizer Secretariat in Sri Lanka reported that the maximum usage of fertilizer in Sri Lanka is for paddy cultivation and it was estimated as 257,745 tonnes/year in year 2000. In Walawe river basin, paddy is the main cultivation and it uses considerable amount of fertilizers as well.

Application of DRASTIC Model

Seven DRASTIC parameters can be divided into either ranges or media types. The depth to groundwater table, recharge, topography and hydraulic conductivity has been divided into numerical ranges whereas the aquifer media, soil media and impact of vadose zone have been divided into media types. Each parameter is then subsequently divided into corresponding weights and ratings as based upon specific regional data, utilizing input of either ranges or significant media types which have an impact on pollution potential. 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. The weight factor expresses the relative importance of each DRASTIC parameter to groundwater vulnerability of the area. It accommodates that least significant parameter receives weight of 1 and highest significant parameter receives a weight of 5.

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

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

$$\mathrm{DI} = \sum_{i=1}^{7} W_i R_i \quad (2)$$

where subscripts W is the weighting factor and R is the rating factor.

Evaluation of the DRASTIC Parameters for Walawe River Basin

The assessment utilizes Geographic Information System (GIS) technology. DRASTIC Index computes by summation of the products of rating and weights of each seven factors. To create the DRASTIC Index map, study area has been divided into 500 m × 500 m grids. The seven DRASTIC parameters have been evaluated on 500 m × 500 m resolution in GIS environment, using the available hydrogeological data. To interpolate the point data whole basin area, kriging algorithm has been utilized by SURFER computer code. 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 are modified according to the local hydrogeological 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 seven DRASTIC parameters have been evaluated for groundwater vulnerability, using the available hydrogeological data. The groundwater level in Walawe river basin has been monitored by several researchers and most of the data has been compiled in IWMI database (Jayaweera, 1999; Ranjan, 2002). The ranges in depth to water have been determined based on these data where the potential for groundwater pollution significantly changes (Table 1). Annual average groundwater depth has been taken into account to define the ranges and ratings for 'depth to ground water'. 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 (Table 1).

The data related to the aquifer media was obtained from the collected data of the geological maps, geology exploration reports and bore-hole logs (Panabokke, 2002). The aquifer types available in the Walawe basin were classified into seven groups (Table 2). With reference to the soil maps of the area the soil types of the Walawe basin have been classified into groups (Coorey, 1982; Geological Survey and Mines Bureau, 1996; Barber, 2000). According to the DRASTIC rating scheme with reference to US Soil Conservation Service, suitable ratings were assigned to each soil group (Table 2). A Digital Elevation Map (DEM) of the area has been used to represent the topography of the study area. The basin drops from the central highlands in a general southerly direction, towards the lower basin, which consists of very gentle and flat lands. The prominent features are—having high elevations on the western part of the basin and very flat plains with elevations of 100 to 200 m found in the eastern part of the basin (Kulatunga, 1998). When compared to the ranges given in DRASTIC scheme, the steepness of the topography in Walawe basin is very low and high pollution potential can be suspected. Therefore, higher ratings have been assigned (Table 1). The vadose zone is defined as the zone above the water table which is unsaturated or discontinuously saturated (Aller et al., 1987). The vadose zone has been classified to several groups according to the data obtained from soil maps and well log records. Considering relevant properties of each group, the relative ratings have been assigned (Table 2). To estimate the distribution of hydraulic conductivity in Walwe river basin, several pumping tests have been carried out in the study area. Even though the number of pumping tests was less, the available nine hydraulic conductivity values were used to interpolate the hydraulic conductivity for 500 m × 500 m resolution grid using kriging interpolation. The interpolated values have been grouped into ranges and the ratings were assigned where high conductivity is associated with high pollution potential (Table 1).

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				

Develop the DRASTIC Index Map

After assigning the ratings for seven DRASTIC features, the next step was to develop the DRASTIC index according to the importance of the parameters to the pollution. Each DRASTIC parameter has been evaluated with respect to others in order to determine the relative importance of it. The DRASTIC Index, a measure of the pollution potential, is computed by summation of the products of rating and weights of each factor. Thus, each parameter has a predetermined, fixed, relative weight that reflects its relative significance in affecting pollution potential and the relative importance to vulnerability. The most significant factors have weight of 5; the least significant weight of 1. Since the relative hydrogeological behaviour of the DRASTIC parameters in Walawe river basin is almost compatible with the conditions described by Aller et al. (1987), the same weight scheme was used for the evaluation. Depth to ground water and impact to vadoze zone was assigned as 5; recharge was assigned as 4; aquifer media and hydraulic conductivity was assigned as 3; soil media was assigned as 2 and topography was assigned as 1.

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 as shown in Figure 2. After processing the seven DRASTIC parameters into cell vector map layers using ARC/INFO, the layers were converted to ERDAS GIS raster format. A model using DRASTIC index formulation was designed in ERDAS using the different raster layers and their respective weights to produce a final groundwater vulnerability map. The step-by-step procedure was followed to overlay each of the

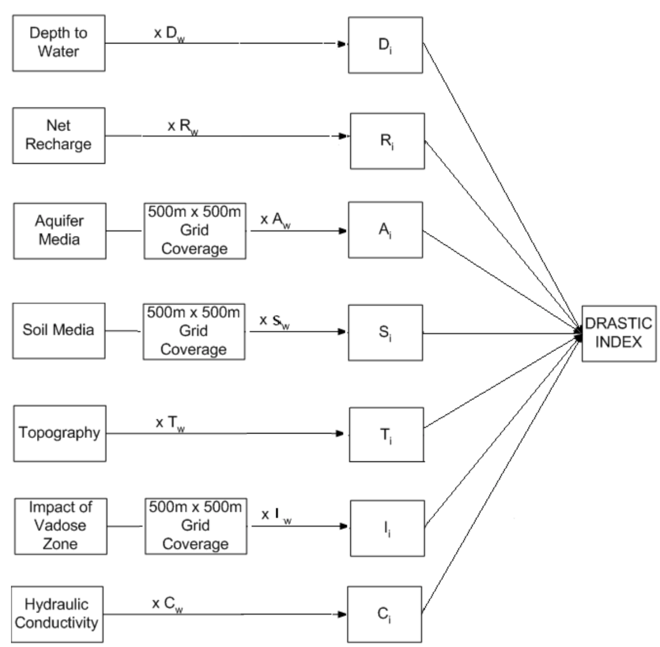

Figure 2: Flow chart of DRASTIC process.

features as explained in the methodology. The ultimate result is a numerical value, the DRASTIC Index (DI), for each cell (500 m × 500 m grids) calculated using the additive equation.

Results and Discussions

Distribution of DRASTIC Index

The final DRASTIC coverage depicts the distribution of DRASTIC vulnerability index over the study area (Figure 3). The DRASTIC index ranges between 89 and 197 which are compatible with the range given by Aller et al. (1987) (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)
- Moderate vulnerability (125 <DI <150)
- Moderately high vulnerability (150 <DI < 180)
- High vulnerability (DI > 180)

The DRASTIC indexes are relative values and a site with 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 DRASTIC index. Figure 3 reflects the overall view of the pollution potential in the study area and shows that the values of the DRASTIC index clusters around moderate and moderately high vulnerability with very few points in the very low and high vulnerability ranges. Distribution of vulnerability over the basin further shows that the lower part of the basin is exposed to high vulnerability while the upper eastern part has very low and low vulnerability. The central region of the basin covers with moderate and moderately high vulnerability. From the physical point of view, it can be understood that the lower part of the area which shows low groundwater depth and low surface slope having mostly distributed alluvial deposits in the flat lands, leads to higher potential for groundwater contamination. Upper part of the area has steep slope and higher depth to groundwater level and hard rock formation may lead to low potential for groundwater contamination and low capacity to pollution. When we consider the distribution of each vulnerability group in the basin, the statistical analysis on the distribution of vulnerability index further concludes that most of the pixels estimate a moderate and moderately high DRASTIC index (Figure 4).

Comparison of Groundwater Vulnerability and Land-use Pattern

To incorporate the impact of land-use activities with aquifer vulnerability, land-use data of the Walawe river basin has been obtained from the maps of Geological Survey and Mines Bureau, Sri Lanka. The land-use coverage can be classified into nine main groups; paddy fields, other agricultures (sugar cane, banana and upland crops), dry-land cultivation (chena cultivation), gardens,

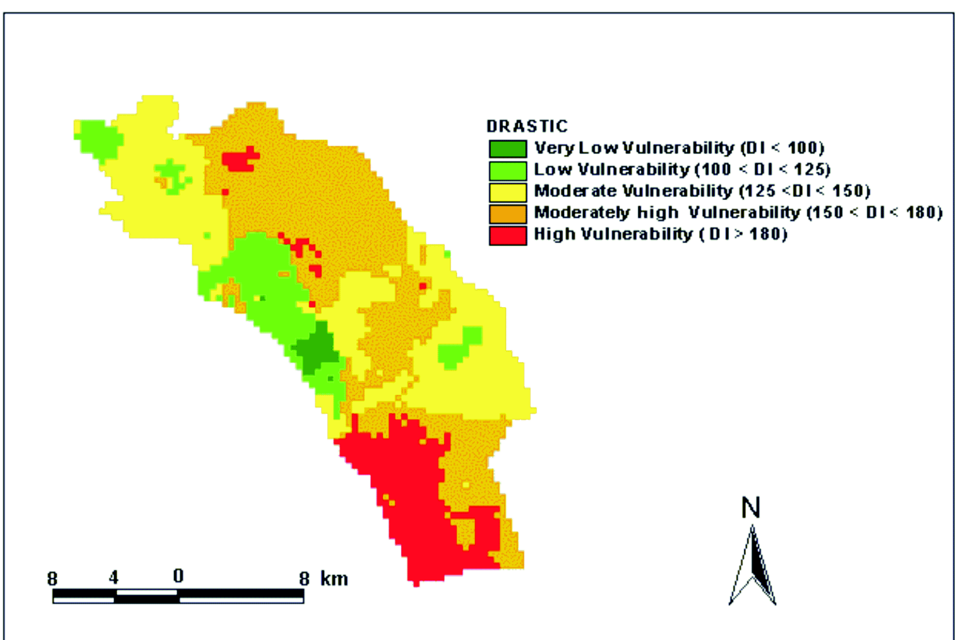

Figure 3: Resultant DRASTIC map.

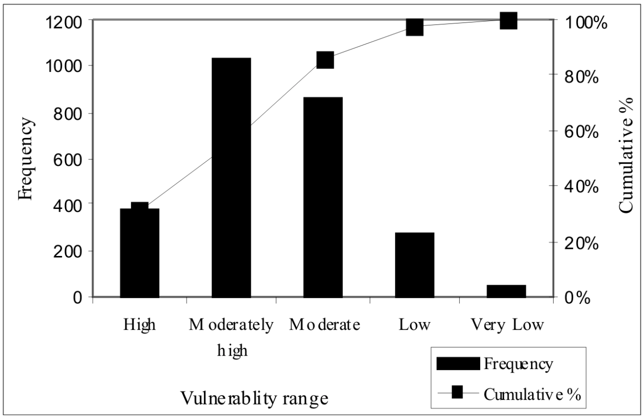

Figure 4: Statistical analysis of the distribution of DRASTIC vulnerability groups.

impervious areas, scrubs and mild forests, thick forests, reservoirs and other waterways. To compare the distribution of land use and DRASTIC index, land-use map also has been converted into 500 m × 500 m resolution cell vector map layer using GIS technology (Figure 5). Five DRASTIC vulnerability groups (as shown in Figure 3) have been assigned for five vulnerability indexes; high vulnerability is index 5; moderately high vulnerability has index 4. Moderate vulnerability, low vulnerability and very low vulnerability have been assigned as index 3, 2 and 1 respectively. The land-use patterns also have been reclassified into five main groups based on land-use infiltration and usage of fertilizers. Human activities in agricultural fields, mainly the overuse of fertilizers and pesticides, affect the groundwater contamination and agricultural areas can be considered as areas with the highest potential for groundwater pollution. Therefore, paddy fields which have the highest fertilizers and pesticides use have been classified as index 5 and the other agricultural lands (including dry land cultivation lands) have been classified as land-use index 4. Taking live stock wastes, sewerage facilities and septic tanks and solid waste dumping fields into account, the gardens and impervious areas has been classified as index 3. Reservoirs and other water bodies are assigned to index 2. Forests (both mild and thick forests), which have less anthropogenic stress, have been classified as land-use index 1.

Comparison of vulnerability index map and land-use index map shows that the lower part of the basin is exposed to higher vulnerability index and also higher land-use index (Figure 5). This means that paddy fields and other cultivation areas overlapped with the regions, which shows the highest potential for the vulnerability. In these areas, percolation of pollutants to groundwater is enhanced due to accumulative effects of the various parameters involved in the DRASTIC model and on the other hand, the use of pollutants such as fertilizers and pesticides is also higher. Therefore, the areas with both higher vulnerability index and extensive agricultural usage have the maximum potential for groundwater pollution.

Distribution of Aquifer Vulnerability and Land-use Pattern in Walawe River Basin

Vulnerability index expresses the vulnerability of any aquifer based on its hydrogeological behaviour whereas

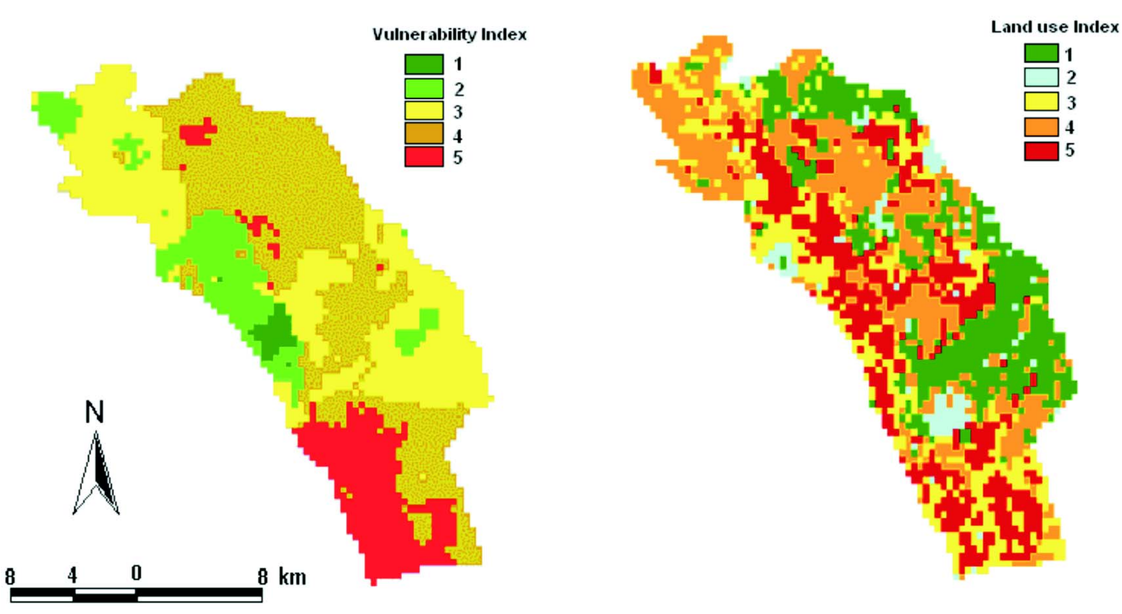

Figure 5: Comparison of vulnerability index and land-use index.

land-use index expresses the potential for groundwater pollution and contamination based on the anthropogenic activities. Combinations of the vulnerability index versus land use index can be used to express the overall behaviour of the groundwater pollution potential of the area. If most of the paddy fields and other type of agricultural areas are located in high vulnerable lands, it means that highly vulnerable regions in respective area overlap with extensive land-use areas. This combination leads to an overall situation of very high potential for groundwater quality degradation. With a lot of forests located in high vulnerability index regions and another lot of paddy fields located on low vulnerability index regions, it leads to an overall fair situation or comparatively low potential for groundwater pollution.

Table 3 presents the distribution of five main land-use index patterns in each vulnerable region. It shows that most of the pixels identified as high vulnerable regions are overlapped with paddy fields. 399 pixels which have been identified as moderately high vulnerable areas have been overlapped with other agricultures. Also it clearly shows that most of the paddy fields are located in high or moderately high vulnerable areas whereas almost 50% of the other agricultural lands are located in the moderately high vulnerable areas. Distribution of forests indicates that higher percentage of forest area is limited to moderate and moderately high vulnerable regions whereas very small amount is located in high and low vulnerable areas. The overall picture of land use in Walawe river basin depicts that extensive land-use activities have occupied significant amount of highly vulnerable areas. Therefore it favourably concludes that Walawe river basin is exposed to higher potential for groundwater quality degradation due to its hydrogeological conditions as well as anthropogenic activities.

Table 3: Distribution of land-use patterns over the five vulnerable regions

Land use	*Number of pixels in each vulnerability group*					
	Very low	*Low*	*Moderate*	*Moderately high*	*High*	*Total*
Paddy fields	31	69	124	213	153	590
Other agricultures	3	45	268	399	88	803
Gardens	13	98	144	195	79	529
Water bodies	0	5	31	57	35	128
Forests	0	56	295	165	44	560

Aquifer-land-use Composite Vulnerability

A composite results of DRASTIC and land-use vulnerability would be more effective, because it take into account the hydrological realities as well as human activities. Taking DRASTIC index and land-use index into account, the Aquifer-Land-Use Composite Vulnerability Index (ALUCVI) can be defined as follows

$$ALUCVI_i = \text{Vulnerability Index}_i + \text{Land Use Index}_i \quad (4)$$

where *i* indicates each 500 m × 500 m grid.

The distribution of aquifer-land-use composite vulnerability over the Walawe river basin has been produced by accumulating the developed vulnerability index map (ranges from 1 to 5) and land-use index maps (ranges from 1 to 5). Figure 6 depicts the distribution of aquifer-land-use composite vulnerability index (ALUCVI) over the Walawe river basin. It ranges from 2 to 10 showing the future risk for groundwater quality. The distribution clearly shows the lower part of the basin exposed to high risk for natural vulnerability as well as anthropogenic activities whereas eastern part shows low aquifer-land use composite vulnerability. This composite assessment further concludes that, in the lower part of the basin, the anthropogenic stress such as usage of fertilizers and pesticides must be managed and controlled to protect the contamination of groundwater resources. The sites which indicate a high aquifer-land-use composite vulnerability expresses high risk for sustainable groundwater resources and hence, these areas

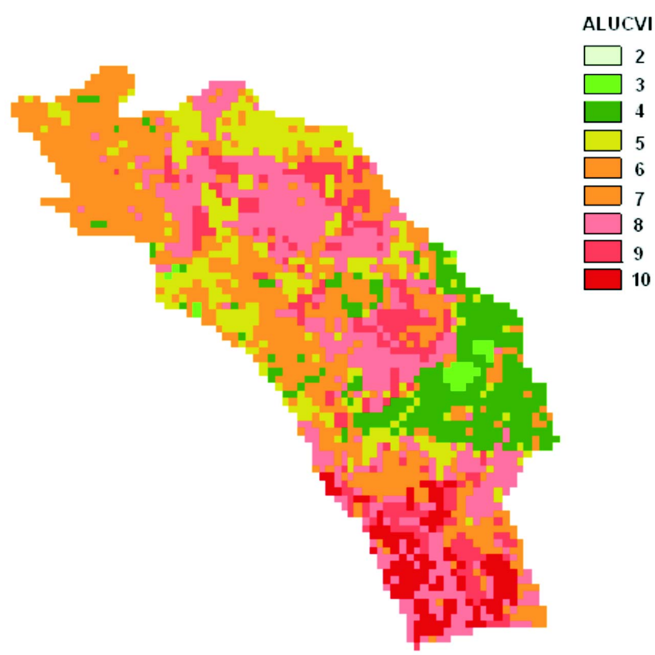

Figure 6: Aquifer land use composite vulnerability in Walawe river basin.

should be frequently reviewed and monitored. Attention must be focused to these areas, mainly the overuse of fertilizers and pesticides for the crops, sewerage facilities, landfills and waste disposal activities. While making the land-use control policies for these areas, the groundwater vulnerability maps are very useful to take appropriate decisions and subsequent measures for pollution prevention and mitigation.

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 moderate to moderately high vulnerability while the lower part of the basin is exposed to higher vulnerability and the upper western part of the basin exposed low and very low vulnerability. Comparison of land-use pattern and groundwater vulnerability map shows that the high vulnerable areas are coincident with the paddy cultivated lowlands with the terraces built from alluvial deposits and shallow groundwater table. Statistical evidences depict that most of the paddy fields are located in high and moderately high vulnerable areas whereas almost 50% of the other agricultural lands are located in the moderately high vulnerable areas. Aquifer-land-use composite vulnerability index was introduced to express the combination of natural state of the aquifer hydrogeological settings as well as anthropogenic conditions. It concludes that lower part of the basin is exposed to high risk for future sustainable groundwater resources whereas eastern part shows comparatively fair situation. In lower part of the Walawe river basin, 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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