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AQUIFER VULNERABILITY ASSESSMENT USING ANALYTIC HIERARCHY PROCESS AND GIS FOR UPPER PALAR WATERSHED

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ABSTRACT

Ground Water is inherently susceptible to contamination from anthropogenic activities and remediation is very expensive and often impractical. Prevention of contamination is hence critical in effective ground water management. Aquifer vulnerability assessment aims at predicting areas, which are more likely than others to become contaminated as a result of activities at or near the land surface. Once identified, these areas could then be enforced with restricted land use or becomes focus of attention at preventing contamination of the underlying ground water resources. The upper palar watershed in Tamil Nadu, India is having conglomeration of tannery industries in Ambur and Vaniyambadi Towns. The effluent let out from these tannery industries leads to contamination of the Upper Palar Aquifer consisting primarily of Gneiss, Charnockite and Recent alluvium.

In this paper, an attempt has been made to assess the Aquifer Vulnerability of Upper Palar Watershed using the DRASTIC Model. The DRASTIC Model uses the following seven thematic maps: Depth to Water, Recharge, Aquifer Media, Soil Media, Topography, Impact of Vadose Zone and Hydraulic Conductivity. The land use and soil map have been prepared using Geocoded IRS-1C Satellite Imagery. The topography layer is created using Survey of India 1:50,000 Scale Topographic Maps. The field data regarding water level in control wells is obtained from three user departments and have been converted to the same datum to compute the depth to water level. The Soil Map prepared by the Soil Survey and Land Use Organisation is used as the base map to prepare the Soil and Impact of Vadose Zone maps. The Hydraulic Conductivity values have been obtained from the field using pump test details and for certain areas where pump test details have not been available, representative values for the respective formation has been used. The Recharge layer is derived using the land use and soil map and these seven layers have been integrated using Arc View GIS Software.

Analytic Hierarchy Process (AHP) has been used to arrive at the weights and ranks of the criteria and alternatives of the seven layers. A Visual Basic Software AHP has been written to compute the weights and ranks of the above thematic layers based on the relative weights input. The output from AHP generates a MS Access database for these thematic layers, which is then interfaced with ArcView using Avenue Codes. This paper aims at developing a user-friendly VB software interfaced with GIS for estimation of Weights and Ranks of the thematic layers for Aquifer Vulnerability Assessment and the results are presented.

INTRODUCTION

One fifth of the world's total fresh water is in the saturated zone of the terrestrial sub-surface (Dunne and Leopold, 1978) and hence needs to be protected from contamination. This source of water is all the more important in areas where surface water resources are scarce. The Upper Palar Watershed is one such area where the demand for fresh water is met mostly from Ground Water Sources. In this study area, the water quality is a major issue, as it faces a serious threat, from the effluents of tannery industries and fertilizers and pesticides used in the crop land and agricultural plantations. Ground water remediation is very expensive and hence prevention of pollution is the key to the solution. Hence, in this paper an attempt is made to assess the ground water vulnerability so that the vulnerable areas could be enforced with strict land use restrictions.

In general, the ground water vulnerability can be defined as the tendency or likelihood for the contaminants to reach a specified position in the ground water system after introduction at some location above the uppermost aquifer. However, ground water vulnerability is categorised as intrinsic and specific based on whether one assesses the vulnerability including the risk of the ground water system becoming exposed to contamination loading or not. (Jaroslav Vrba and Alexander Zoporozec, 1994).

METHODOLOGY

Several Aquifer Vulnerability assessment methods have been developed but all of them can be grouped into three major categories such as Overlay and Index Methods, Process Based Methods and Statistical Methods (Anthony et. al., 1998). In this paper, DRASTIC model which falls into the category of overlay and index methods is used. DRASTIC model of aquifer vulnerability was developed by EPA, USA (Aller et. al., 1987) which is a Standardised System for Evaluating Ground Water Pollution Potential of Hydrogeologic Settings. This model produces a numerical value called DRASTIC INDEX which is derived from the Ratings and Weights assigned to the parameters used in the model. DRASTIC is an acronym for the seven thematic maps used in the model. The seven thematic maps required for the DRASTIC Model are:

D	**Depth to Water** - The more the depth to water the lesser the chance for the contaminant to reach it as compared to shallow water table
R	**Recharge** - It is the process through which the contaminant is transported to the aquifer and hence more the recharge more vulnerable the aquifer is.
A	**Aquifer Media** - It reflects the attenuation characteristics of the aquifer material reflecting the mobility of the contaminant through the aquifer material
S	**Soil Media** - Soils of different types have differing water holding capacity and influence the travel time of the contaminant
T	**Topography** - High degrees of slope increases runoff and erosion which is composed of the pollutant
I	**Impact of Vadose Zone** - It reflects the texture of the soil in the unsaturated zone above the water table
C	**Hydraulic Conductivity** - The amount of water percolating to reach the ground water through the aquifer is influenced by the hydraulic conductivity of the soil media

DRASTIC model defines Ranges, Ratings for the classes associated with each of the above thematic maps and Weights for the each thematic maps. The significant media types/classes which have bearing on the vulnerability, in each map are the ranges and has an associated rating in 1 to 10 point scale. The relative importance of each of the above thematic maps on vulnerability is reflected in terms of Weights. These ratings and weights are used in arriving at the DRASTIC INDEX, which is calculated using the following formula:
DRASTIC Index = $D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w$, where the capital letter indicates the corresponding map and the subscript "r" and "w" refer to the rating and weights respectively. In this paper the DRASTIC INDEX is calculated using the ratings and weights of the maps derived using Analytic Hierarchy Process.

ANALYTIC HIERARCHY PROCESS

Analytic Hierarchy Process (AHP) was developed by Satty (Satty, 1980), in which the hierarchy of components of the decisions were used in decision making process. The AHP is essentially an interactive one where a decision-maker or group of decision-makers relay their preferences to the analyst and can debate or discuss opinions and outcomes (Wendy Proctor, 2000). The AHP is based upon the construction of a series of 'pair-wise comparison' matrices which compares all the criteria to one another. This is done to estimate a ranking or weighting of each of the criteria that describes the importance of each of these criteria in contributing to the overall objective. The AHP decomposes the given problem of decision making, into hierarchy structure. The elements at a particular hierarchy level are compared in pairs as described above. The criteria are broken down into a number of sub-criteria and the pair wise comparisons are repeated for each level of the hierarchy (Evangelos Triantaphyllou and Stuart, 1995). A pair wise comparison of *J* criteria *(*G1 … *GJ*) to reflect the importance or weighting of each criteria in influencing the overall objective, involves constructing a *J* by *J* matrix *(*G) which shows the dominance of the criteria in the left hand side column with respect to each criteria in the top row, as shown below:

	CRITERIA				
CRITERIA	1	G_{12}	G_{13}	….	G_{1j}
	$1/G_{12}$	1	G_{23}	….	G_{2j}
	$1/G_{13}$	$1/G_{23}$	1	….	G_{3j}
	….	….	….	1	….
	$1/G_{1j}$	$1/G_{2j}$	$1/G_{3j}$	….	1

The pair wise comparisons are translated from linguistic/verbal terms to numerical numbers using the fundamental Satty's Scale for the comparative judgments, as shown in Table 1.

Numerical Values	Verbal Terms	Explanation
1	Equally Important	Two elements have equal importance regarding the element in higher level
3	Moderately more Important	Experience or Judgment slightly favours one element
5	Strongly more Important	Experience or Judgment strongly favours one element
7	Very strongly more Important	Dominance of one element proved in practice
9	Extremely more Important	The highest order dominance of one element over another
2, 4, 6, 8	Important Intermediate values	Compromise is needed

Table 1. Fundamental Satty's Scale for pair wise comparison

The ranking of these factors in each sub-criterion is determined by raising the pair wise matrix to its power that is iteratively squared each time. The row sums are calculated and normalised. The iteration is stopped when the difference between sums calculated in two successive iterations fall below a threshold value.

DRASTIC INDEX USING GIS AND AHP

The Survey of India 1:50000 Topographic Maps with contour interval of 20m have been used to prepare the Topography Map. The Depth to water table Map is prepared using the field water level values from control wells and interpolated. The Soil Media and Impact of Vadose Zone Maps have been prepared using the Soil Map from Soil Survey and Landuse Organisation and improved upon using IRS-1C Satellite Imagery. The pump test details available from field data was used to prepare the Hydraulic Conductivity Map and wherever such details are not available, the representative values for the formation is used. The Aquifer Media was prepared using the Geological Survey of India Map and IRS-1C Imagery. The AHP is employed considering the thematic maps as criteria and the ranges/classes of thematic maps as sub-criteria. The methodology adopted in deriving the DRASTIC Index using Analytic Hierarchy Process is schematically explained below in Figure 1.

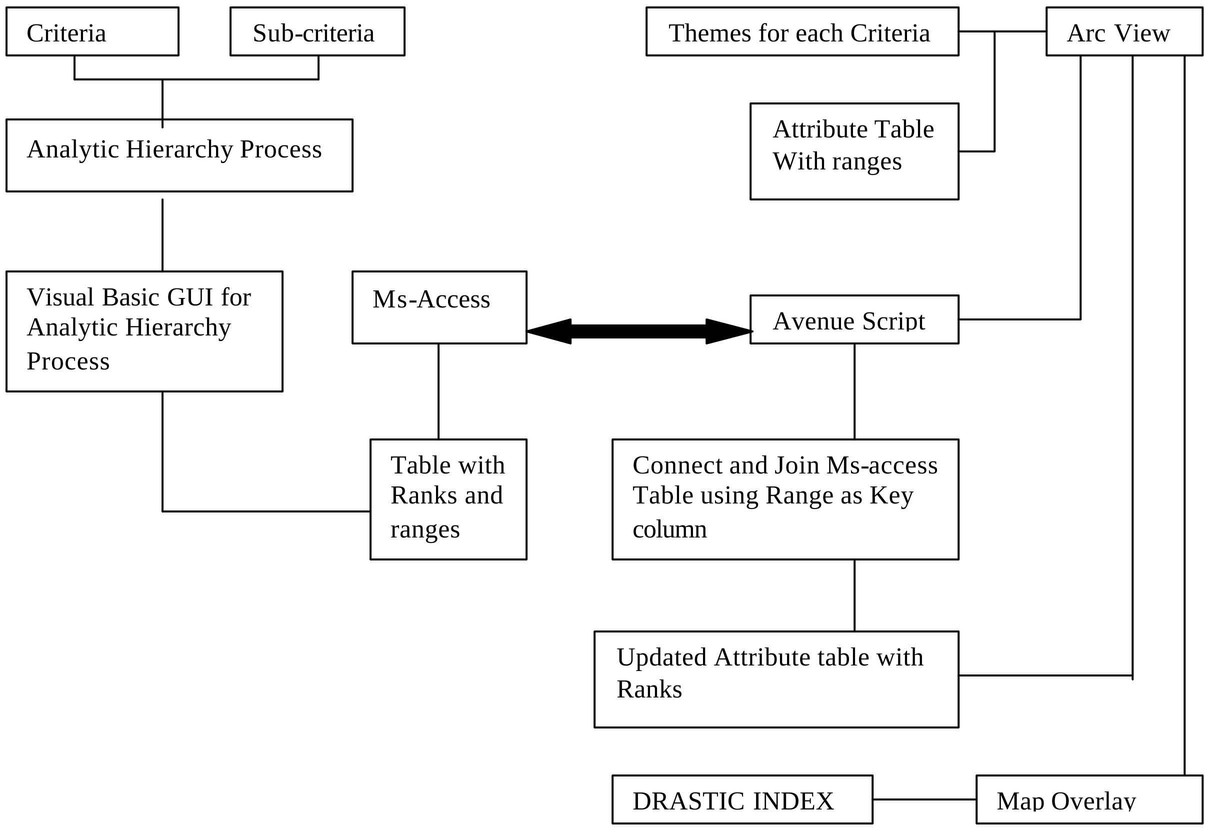

Figure 1 Flow Chart for Calculation of DRASTIC Index using AHP and Arc View

There are seven criteria corresponding to each of the thematic maps used in the DRASTIC Method. Each of the thematic maps has sub-criteria for which the pair wise comparisons are made to determine the Rankings. The criteria themselves are compared pair wise to determine the weights of each of the thematic layers.

GRAPHICAL USER INTERFACE FOR AHP

The Graphical User Interface (GUI) for AHP was developed using Visual Basic and the opening menu is shown in Figure 2. The GUI interactively lets the user to define the criteria and alternatives/sub-criteria, as illustrated in Figure 3.

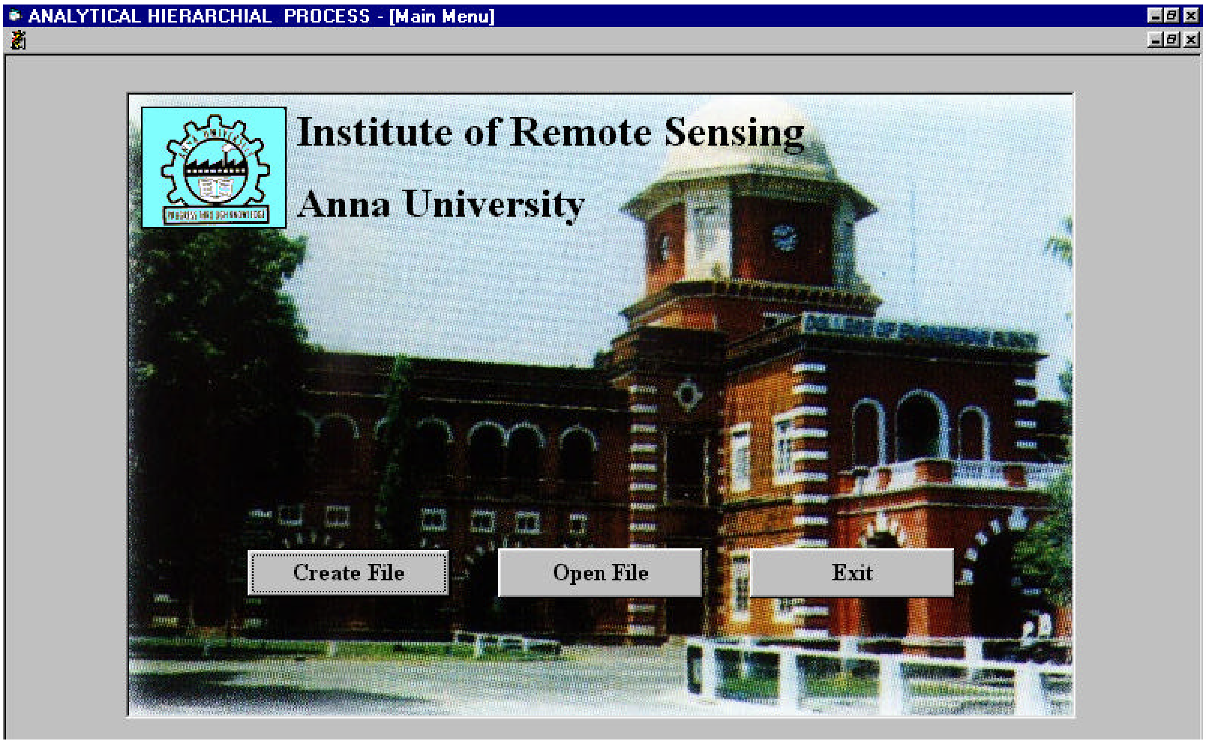

Figure 2. The Opening Menu of GUI for Analytic Hierarchy Process

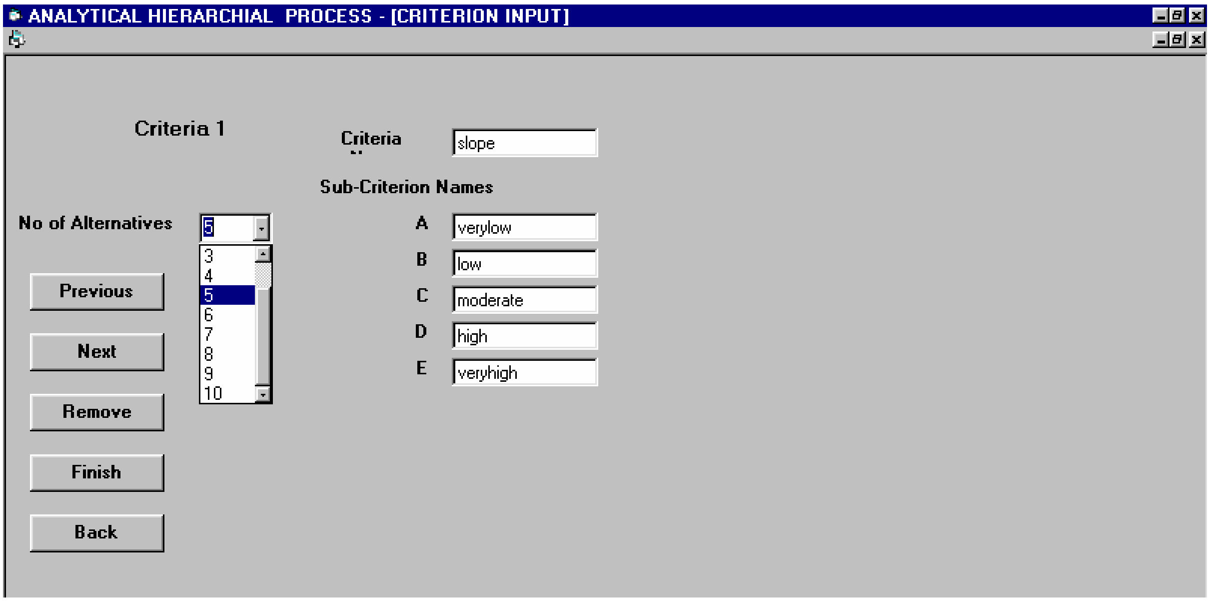

Figure 3 Defining the Criteria and Sub-criteria

Once the number of criteria and sub-criteria are finalised the user is prompted to enter the values in the pair wise comparison matrix, as in Figure 4. The matrix is reciprocal in nature and as the user fills the elements above the diagonal automatically the lower diagonal elements are filled up. The user has the option of saving this data set.

The rankings and weights are determined by running this data set which is displayed in a separate window as in Figure 5, along with the consistency index.

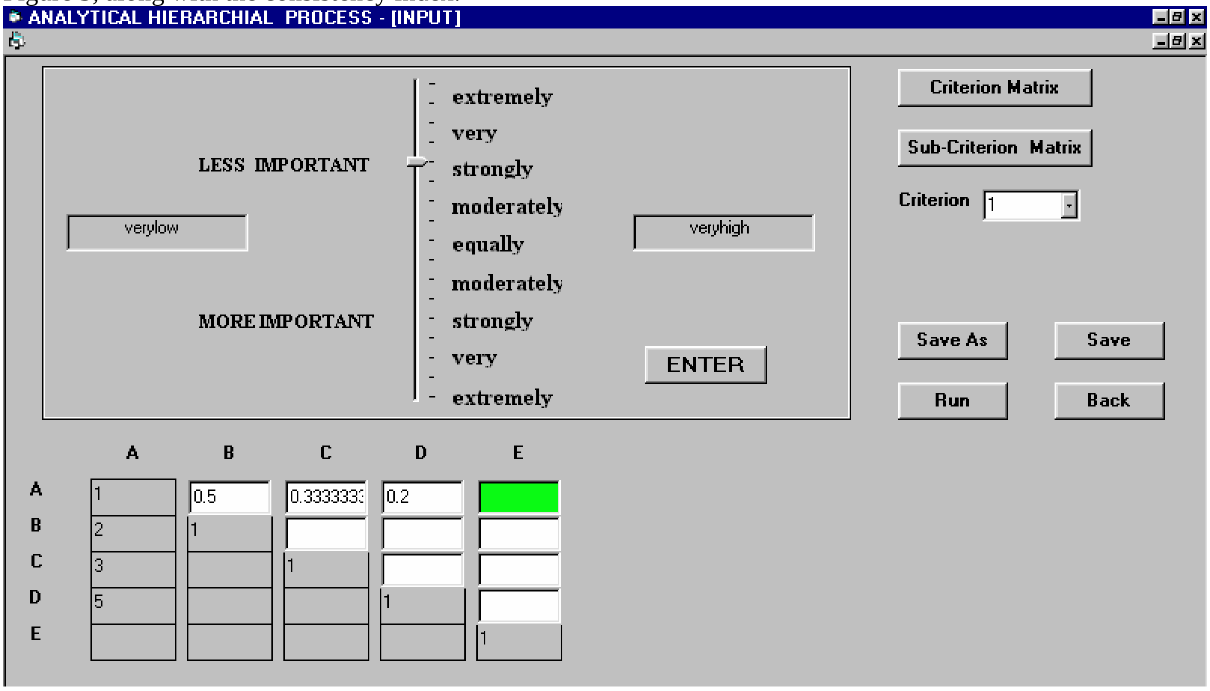

Figure 4 The pair wise comparison of sub criteria

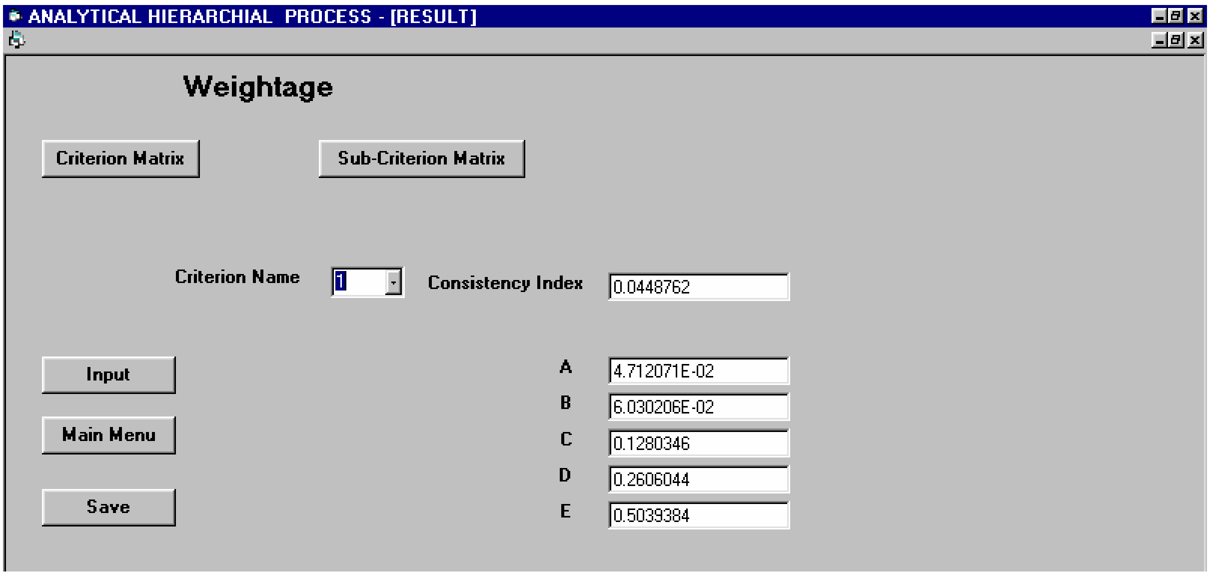

Figure 5 Rankings for Sub-Criteria

If the consistency index is not less than a threshold value, the user can go back to modify the pair wise matrix so as to bring the consistency index within the threshold value. The user is prompted to store these rankings and weights as ms-access database file. An Avenue Script is written to read these rankings and weights of the criteria and links them to the corresponding thematic maps in Arc view.

RESULTS AND CONCLUSIONS

The aim of this research study is to develop a user friendly GUI, which could be integrated with the GIS software. The developed GUI lets the user to define criteria and sub-criteria and also to calculate the rankings and weights for these criteria and sub-criteria. The interface between the Ms-Access and Arc-view GIS software is established using Avenue Scripts. The customization using Avenue Scripts seamlessly integrates the weights and ranks of each layer and in overlaying using Map Calculator. Using these rankings and weights the DRASTIC Index is calculated. The calculated DRASTIC Index for the upper palar watershed showing the vulnerability index classification is shown in Figure 6. The calculated vulnerability index is to be validated with field data concerning water quality based on whether one considers intrinsic or specific vulnerability. The ODBC connectivity in this GUI, is provided only for Ms-Access and could be further improved to include other RDBMS.

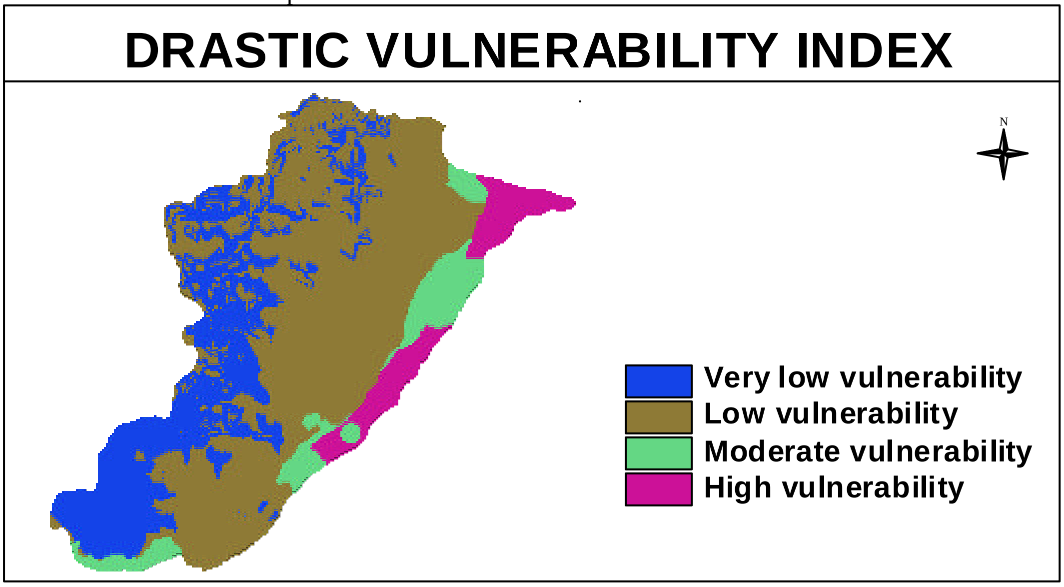

Figure 6. DRASTIC vulnerability index of upper palar watershed

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