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# Assessment of Groundwater Vulnerability: Need of Hour

**Sandeep Kaur[1], N K Khullar[2], Ashwani Kumar Soni[3]**

*[1]M. Tech Student, Department of Civil Engineering, Punjab Agricultural University, Ludhiana*
*[2]Department of Civil Engineering, Punjab Agricultural University, Ludhiana*
*[3]School of Renewable Energy Engineering, Punjab Agricultural University, Ludhiana*
*E-mail: [1]dhaliwalsandeep91@gmail.com, [2]khulrdce@gmail.com, [3]ashwanisoni@pau.edu*

**Abstract—***Water is essential for the survival of life and for the sustainable development. It maintains the ecological balance and contributes to the social, recreational and cultural activities. Major source of water are surface water i.e rivers, lakes, ponds etc and groundwater. But the groundwater quality is exploited day by day due to increased agricultural practices and industrialization. In order to protect the groundwater and to retain this resource for our future generations, it is necessary to define guidelines for its management. Assessment of vulnerability of an area to groundwater pollution is the most feasible step towards the control of pollution and management of groundwater. The present paper reviews various groundwater vulnerability assessment methods. Different methods exist in literature i.e overlay and index methods, process based methods and statistical methods but review has been limited to overlay and index methods because of their large applicability in study areas.*

**Keywords***: Groundwater vulnerability overlay and index methods*

## 1. INTRODUCTION

Due to continuous deterioration of groundwater quality all over the world, the vulnerability of groundwater has become a burning issue for the scientists. In general, the groundwater vulnerability can be defined as tendency or likelyhood for the contaminant to reach a specified position in the groundwater system after its introduction at ground surface. Vulnerability can be categorized as intrinsic and specific vulnerability. Intrinsic vulnerability refers to vulnerability of groundwater due to contaminants released by human activities and is characterized primarily by geological, hydrological and hydrogeological characteristics of an area, but is independent of nature of contaminants and Specific vulnerability is the assessment of vulnerability associated with a particular kind of contaminant and takes into consideration the contaminant's characteristics and its connection to the various components of intrinsic vulnerability [1]. In the vulnerability study, the vulnerability map of the study area is prepared using different parameters affecting the vulnerability. The vulnerability map prepared then can be used in land use planning. All groundwater resources are vulnerable to contamination. For the assessment of vulnerability of an area, data regarding the different hydrogeological parameters i.e. water table depth, precipitation, topography, type of soil and recharge to the groundwater etc. are collected. Lot of research has been carried out in past to assess groundwater vulnerability using various methods. All these methods gives numerical index called vulnerability index and based upon that index we can classify the area into different zones i.e low, moderate and high vulnerable zones. Different types of groundwater vulnerability assessment methods are discussed below.

**Process based methods:** These are computer based models which consider physics and chemistry of pollutant transport into sub-surface. The limitations of process based method are availability of adequate data and accurate description of physical, chemical and biological reactions which occurs from surface through the groundwater regime.

**Statistical methods:** These are least common groundwater vulnerability assessment methods available in literature. These methods require sufficient data for factors that affect groundwater vulnerability such as soil properties, hydraulic conductivity, precipitation, depth to water table and land use pattern.

**Overlay and index methods:** These methods are based on geological, hydro geological setting and other factors that control the movement of pollutant from ground surface to saturated zone. Basic steps of these methods include analysis of raw data; assign ratings to the features on the map, integration of maps and classification of integrated map based upon classes of vulnerability. These methods are applicable from regional to global scale and should be supplemented with field visits and validation to produce reliable results. These methods are particularly suitable for use in conjunction with computerized GIS, which is digital form of map making. These methods rely on data which is available from various private and government agencies. Commonly used overlay and index methods are: DRASTIC, SINTACS, SEEPAGE, GOD and EPIK.

## 2. REVIEW OF LITERATURE

Goggu and Dassargues [2] assessed the vulnerability to contamination of small karstic aquifer in Belgium, by using the EPIK method. Vulnerability index in the study area varies between 11 and 28. Area having vulnerability index in the range 11 and 17 is classified as low vulnerable to groundwater pollution, area having vulnerability index in the range 17 and 23 was classified as medium vulnerable to groundwater contamination and area with vulnerability index in the range 23 and 28 was classified as high vulnerable to groundwater pollution. Senstivity analysis was also carried out based upon 'unique condition sub-area' was performed to evaluate the impact of each parameter on vulnerability index. Results of map removal sensitivity analysis indicated that most sensitive parameter is epikarst (E) and least sensitive parameter was karst network (K). Results of the single parameter sensitivity analysis indicated that most sensitive parameter is epikarst while least sensitive parameter is protective cover.

Babiker *et al* [3] studied the groundwater vulnerability of Kakamigahara heights (Japan), by employing the DRASTIC model. Groundwater vulnerability map of the study area was obtained by overlaying the seven hydrogeological parameter layers in GIS environment. Vulnerability map of the study area indicated that the western part of the study area was under high vulnerability to groundwater pollution while eastern part was under medium vulnerability. The elevated northeastern part of study area was under low vulnerability to groundwater pollution. Sensitivity analysis was also carried out to evaluate most sensitive parameter. Results of the map removal sensitivity analysis showed that groundwater vulnerability was highly sensitive to net recharge followed by soil media and topography but least sensitive to aquifer media. Single parameter sensitivity analysis indicated that net recharge and hydraulic conductivity are most sensitive parameters.

Dubey *et al* [4] investigated the susceptibility to groundwater pollution of Rewa town (Madhya Pradesh), using GIS based DRASTIC approach. DRASTIC vulnerability index in the study area varies between 162 and 217. Area with DRASTIC index range between 67-140 was classified as low vulnerable to groundwater pollution, area with DRASTIC vulnerability index range between 141-181 was classified as medium vulnerable and area with DRASTIC index range between 182-217 was classified as high vulnerable zone.

Neukum *et al* [5] evaluated the aquifer vulnerability of Southern Germany, by using the four different methods i.e DRASTIC, GLA, PI, and EPIK. Groundwater vulnerability maps were created by using all these four methods in GIS environment. They also validated the models. In order to validate the models they compare groundwater vulnerable zones with water quality maps. Study showed that highest accuracy was achieved by DRASTIC and PI methods.

Rahman [6] identified the groundwater vulnerable zones in Aligarh (India), by using the DRASTIC model. ILWIS 3.0 (Integrated land and water information system) and ArcView 3.2a software were employed to carried out the study. The results of the study showed that 56.43% study area was under high vulnerability, 23.57% was under medium vulnerability and 20% study area was under low vulnerability. Two Sensitivity analysis were carried out i.e map removal sensitivity analysis and single parameter sensitivity analysis. Results of map removal sensitivity analysis showed that groundwater vulnerability in the study area was highly sensitive to net recharge followed by depth to water table, topography and hydraulic conductivity. Statistics of single parameter sensitivity analysis showed that vulnerability was sensitive to net recharge, depth to water table, topography and hydraulic conductivity because their effective are higher than that of theoretical weights.

Wen *et al* [7] applied the DRASTIC model for the assessment of groundwater vulnerability of Zangye basin. ArsGIS software was used to create the layers for seven DRASTIC parameters and overlaid to obtain groundwater vulnerability map. DRASTIC vulnerability index in the study area varies between 61 and 183. The study area was classified into three zone i.e low, medium and high vulnerable zones. About 62% study area was under low vulnerability (DRASTIC index 61-119), 21% study area was under medium vulnerability (DRASTIC index 120-140) and 17% study area was under high vulnerability (DRASTIC index 141-183). The study also suggested that assessment of groundwater vulnerability is an important tool for decision making and land use planning.

Abdullahi [8] concluded that choice of most appropriate method for groundwater vulnerability assessment of an area depends upon the availability of data, scale of map, distribution of data, spatial distribution of data and sub-surface geology of an area. However more accurate map can be created if more data is available for the study area. In areas where availability of data is low but sub-surface geology is known DRASTIC model might suitable method.

Martínez-Bastida *et al* [9] investigated the groundwater vulnerability to contamination of Central Spain by using the DRASTIC and GOD models. They have also calculated the nitrate pollution potential index at regional scale. Results of the study indicated that similarity exist between groundwater vulnerability maps produced by DRASTIC and GOD models. Also specific vulnerability map was consistent with actual nitrate distribution in the study area. The study also suggested that DRASTIC and GOD models have some limitations related to lack of parameters that consider effect of groundwater flow direction on distribution of vulnerable zones.

Al-moush *et* al [10] assessed intrinsic aquifer vulnerability of Jordan by employing the SINTACS model. The aquifer in the study area consists of sand, gravel and clay. Layers for different hydrogeological parameters of SINTACS model were created in ArcGIS 9.2. Groundwater vulnerability map of the study area indicated that 36% was under very low vulnerability, 22% area under low vulnerability, 37% area under high vulnerability and 5% area under very high vulnerability. Sensitivity analysis was also carried to evaluate the impact of each parameter on vulnerability index. Results of the analysis showed that overburden attenuation capacity (T) and depth to groundwater (S) are most sensitive parameters.

Samake *et al* [11] assessed the groundwater vulnerability of Datong Basin, Northern China. The result of the study showed that DRASTIC vulnerability index in the study area varies between 44 and 162. About 23.6% study area was under low vulnerability with DRASTIC index varies between 44 and 85, 43.89% area was under medium vulnerability with DRASTIC index varies between 86 and 111 and 32.50% study area was under high vulnerability with DRASTIC index ranges between 112 and 162. Nearly one third of the study area in under high risk in terms of groundwater pollution potential. Also sensitivity analysis was carried out to evaluated the influence of single DRASTIC parameter on groundwater vulnerability index. One sensitivity analysis namely map removal sensitivity analysis was carried out. The results of the analysis showed that groundwater vulnerability in the study area is highly sensitive to the aquifer media, followed by hydraulic conductivity, topography, depth to water table, soil media, impact of vadose zone and net recharge.

Anornu *et al* [12] investigated the groundwater pollution potential of Densu river basin of Ghana by using the DRASTIC model. This method utilize topographic and geological characteristics of the area to determine its susceptibility to groundwater pollution. Results of the study showed that 10% of study area was low vulnerable zone, 43% study area in medium vulnerable zone and 47% area under high vulnerable zone. The study also suggested that urban area in high vulnerable zone need more careful planning of settlements and sanitation facilities.

Leal *et al* [13] assessed the aquifer vulnerability of Chapala (Mexico), by using the SINTACS model. Vulnerability index in the study area varies between 20 and 80. Study area having vulnerability index between 20 and 40 was classified as low vulnerable, area between 40 and 60 was classified as medium vulnerable and area between 40 and 60 is classified as high vulnerable. However discrepancies between groundwater vulnerability and groundwater quality. Less vulnerable zones in the study area had poor groundwater quality and high vulnerable zone had good groundwater quality. It is because of that SINTACS model works well only when there is vertical movement of contaminant occurs.

Ta'any *et al* [14] applied the DRASTIC model to assessed the contamination risk of Wadi Kufrija. The area covers 112 $km^2$ area. GIS layers for seven hydrogeological parameters were created and were processed to obtain groundwater vulnerability map of the study area. It showed that about 48% of study area was under high vulnerability to groundwater pollution, 31% study area was in medium vulnerable zone and 21% study area was in low vulnerability to groundwater.

Al-Rawabdeh *et al* [15] employed the DRASTIC model in conjunction with GIS to investigated the groundwater vulnerability of Amman-Zerqa Basin. Grounwater vulnerability map of the study area showed that out of total 3792 $km^2$ , 1.19% (45 $km^2$) study area was under no vulnerable zone, 69.20% (2624 $km^2$) was under low vulnerable zone, 29.54% (1120 $km^2$) study area was under medium vulnerable zone and 0.08% (3 $km^2$) study area was under high vulnerable zone. Results of the study showed that about one-third of study area was under medium vulnerable zone. North-east and central parts of the study allowed more contaminants to enter into groundwater due to gentle slope and high depth to water table.

Al-Abadi *et al* [16] applied GIS based DRASTIC model to investigate the groundwater vulnerability of Northeastern Missan governorate, south of Iraq. In order to carried out the study data was collected from different sources. Results of the analysis showed that about 94% study area was under low vulnerability and 6% study area was under medium vulnerability. Senstivity analysis was also carried out. Results of map removal sensitivity analysis showed that net recharge is most sensitive parameter towards the groundwater vulnerability of the area. Results of single parameter sensitivity analysis showed that depth to water table is most sensitive parameter.

Mokhtaripour *et al* [17] studied the groundwater vulnerability of Pashminezar Plain, located in Khuzestan by using the DRASTIC model. Drastic vulnerability index in the study area varies between 76 and 128. It was classified into four vulnerability classes. About 1.31% study area had no risk to groundwater contamination, 51.6% study area was under very low vulnerability, 45.5% study area was under low vulnerability and 1.5% study area was under low to medium vulnerable. Also sensitivity analysis was carried out to found out the most sensitive parameter. Two sensitivity analysis were carried out namely map removal sensitivity analysis and single parameter sensitivity analysis. Result of both the analyses showed that impact of vadose zone is most sensitive parameter.

Parfait and Dauda [18] applied the DRASTIC model to evaluated the aquifer vulnerability of continental terminal, town of Abomey-Calavi. Groundwater vulnerability index in the study area ranges between 36 and 196. It was classified into two vulnerability classes i.e low and medium. Groundwater vulnerability map of the area showed that aquifer vulnerability was medium in area of Togbin which has an aquifer media of fine to medium sand while rest of study area is under low vulnerability because it was protected by clay. This groundwater vulnerability map can be used for land use planning.

## 3. CONCLUSIONS

1) As compare to process based and statistical methods, overlay and index methods require less data for the assessment of groundwater vulnerability of an area.

2) These methods give vulnerability index and based upon that index we can classify study area into different zones viz. low, moderate and high vulnerable zones.

3) The groundwater vulnerability map can be used to protect the groundwater resource as it provides detailed information about different vulnerable zone in the study area.

4) The local authorities, who manage groundwater resource, must monitor medium and high vulnerable zones and to act accordingly.

5) The study may help the planners and policy makers for selecting the site for industries and waste disposal.

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