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A REVIEW ON GROUNDWATER VULNERABILITY ASSESSMENT USING GIS-BASED DRASTIC MODEL APPROACH

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Abstract

Population growth, Agricultural activities and rapid industrialization has resulted in the growing demand of the world most precious resources, especially, ground water. Therefore, its quality needs to be monitored for sustainable portable drinking water. Groundwater pollution is a major issue, because it is susceptible to contamination from land use and other anthropogenic impacts. Some common overlay & index methods such as DRASTIC, DRASTI, SEEPAGE, SINTACS, GOD, WMCDSS, GALDIT, OREADIC and EPIK are used for assessing ground water vulnerability, in which the DRASTIC method is the most recognized across the globe. The success of the method depends heavily on the ability of the seven environmental factors in order to adequately represent the groundwater pollution potential and the extent to which reliable data are available for each environmental factor. The present paper reviews the concepts, significance, and applicability of GIS based DRASTIC method for groundwater vulnerability assessment that would be required to identify for future research. The paper highlighted the application of DRASTIC method for groundwater vulnerability assessment, moreover, some comparison between DRASTIC and other related methods are presented. The GIS techniques provide the great facilities to accomplish and handle the complex and extensive databases for groundwater vulnerability assessment.

Keywords: *GIS, Vulnerability, Convectional Drastic Model, Modified Drastic Model*

Introduction

Population growth, Agriculture and rapid industrialization have resulted in the growing demand of the world most precious resources, especially the ground water. Therefore, its quality needs to be monitored for sustainable portable drinking water (Pradhan, 2009). The vulnerability to the groundwater pollution by anthropogenic activities and land use (Yin et. al., 2013), natural surface processes (Leal et. al., 2012), saline water intrusion (Elewa et. al., 2013; Sophiya and Syed, 2013) has been considered the primary basis for the management of this major water resource by implementing preventive policies. Groundwater vulnerability is considered as an intrinsic property of groundwater that relies on its sensitivity to human and natural impacts, and can be defined as the possibility of percolation and diffusion of contaminants from the groundwater surface into the groundwater system (Babiker et al. 2005). Groundwater vulnerability assessments are widely used to prevent groundwater contamination as they can provide valuable information for locating vulnerable areas (Antonakos and Lambrakis 2007; Sener et al. 2009). The introduction of potential contaminants to a location on top of an aquifer at a specified position in an underground system is defined as groundwater vulnerability. Neshat et. al., (2013) mentioned that the Vulnerability assessment must be based on scientific, accurate, and objective evidence. Various methods have been used to assess the groundwater vulnerability. In most cases, these procedures consist of analytical tools intended to correlate groundwater contamination with land activities. There are three categories of assessment processes and procedures: the process-based simulation models, the statistical methods (Harbaugh et. al., 2000), and the overlay and index methods (Dixon, 2004). Process-based models generally require a large amount of primary and secondary data to apply the mathematical models for creating the principal tool. Such methods seem more complex and difficult to use on a regional scale. Statistical methods use data on the known areal contaminant distribution and describe the

contamination potential for a specified geographical region using the available data in the regions of interest (NRC 1993). Overlay and index methods emphasize on the combination of different regional maps. Both methods are applied in geographic information systems (GIS), particularly in the regional level. Though, Overlay & index methods are the most suitable method for groundwater vulnerability assessment overcoming all the limitations of the other models. Some common overlay & index methods are DRASTIC, SEEPAGE, SINTACS, GOD, WMCDSS, GALDIT, OREADIC and EPIK, in which the DRASTIC method is the most recognized worldwide for groundwater vulnerability assessment as in Hajeb-jelma, Central (Saidi et al. 2010); in ordos plateau, China (Yin et. al., 2013). Huan et al. (2012) in jilin city of northeast China, in Beijin plain, China and many more. Moreover, DRASTIC is based on the assumption that some known major factors control the groundwater vulnerability and that those can be weighted. DRASTIC method is more economic and less time consuming to assess a wide range of regional groundwater vulnerability, overcoming sloppy, uncontrolled development of land, and undesirable activities. This method was first developed (Aller et. al., 1985) for the US Environmental Protection Agency. Then the method has been modified by many researchers and scientists based on geological or hydrogeological settings, climate conditions, and other special situations. Geographic Information System (GIS) is a very efficient tool for analyzing, interpreting, manipulating and incorporating the geological, hydrogeological and geomorphological data.

The present paper reviews the concepts, significance, and applicability of GIS-based DRASTIC method for groundwater vulnerability assessment that would be required to identify for future research.

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Conventional DRASTIC Method

Generally, DRASTIC uses seven hydrogeological parameters to assess groundwater vulnerability. The parameters that form DRASTIC acronym are depth to groundwater table (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I) and hydraulic conductivity (C). The input information such as borehole data, meteorological data, hydrological data, geology data, soil data, lithology data, contour map, and topography map were used to develop GIS database. The method was used to consider various circumstances such as arid or semi-arid regions, agricultural, industrial, municipal, coastal, septic tank, and landfill areas. The DRASTIC model involves (1) the collection of hydrogeological and geologic data (infiltration, soil, aquifer, slope, and hydraulic conductivity); (2) the construction of GIS maps for the DRASTIC model (fig. 1-7); (3) the calculation of DRASTIC index; (4) rating of vulnerability of contamination using quantile classification method(Yin et. al., 2013). The DRASTIC parameters were rated and weighted due to their relative importance to contamination. Weighting and rating ranges are considered from 1 to 5 and 1 to 10, respectively. A multiplier defined as weight was multiplied with each parameter rating for each interval and then the products are summed up to calculate the DRASTIC index as shown in equation (1). This index indicated the relative degree of groundwater vulnerability of an area. Higher index value indicates the greater possibility of contamination. Therefore, final vulnerability map would be generated by integrating all the thematic maps of DRASTIC parameters through the GIS environment (fig.8) (Yin et. al., 2013). ArcGIS software is a powerful tool to generate different thematic maps, GIS database, format conversion, overlaying maps, integrating maps, and so on. Some extension tools (spatial analyst, 3D analyst, and geo-statistical analyst) of GIS software were extensively used in DRASTIC method. Many researchers and scientists assessed groundwater vulnerability based on the above concept.

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$D_i = D_r \times D_w + R_r \times R_w + A_r \times A_w + S_r \times S_w + T_r \times T_w + I_r \times I_w + C_r \times C_w$ equa. (1)

Where;

Subscript r is the rating value

Subscript w is the weight assigned to each parameter

Sensitivity Analysis

To evaluate the influence of a single parameter on the assessment of groundwater vulnerability, the map removal sensitivity analysis was carried out. The map removal sensitivity introduced by Lodwick et al. (1990), identifies the sensitivity (S) associated with removing one or more maps from the suitability analysis and is computed as follows:

$S = (V/N - V'/n)/V \times 100\%$ ……. equa. (2)

Where;

V is the unperturbed vulnerability indices

V' is perturbed vulnerability indices

N is the number of maps used to compute V

n is the number of maps used to compute V'

The actual vulnerability index calculated using all the seven parameters was the unperturbed vulnerability, while the vulnerability obtained using six parameters was considered as a perturbed one(Yin et. al., 2013).

Modified DRASTIC Approach

Although DRASTIC has been used to perform vulnerability assessments in many countries all over the world, the success of the method depends heavily on (1) the ability of the seven

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environmental factors that can be considered to adequately represent the groundwater pollution potential and (2) the extent to which reliable data are available for each environmental factor (Qian et. al., 2012). To overcome these problems a modified version of DRASTIC was developed to better suit local needs. Modifications involved the replacement, addition, subtraction as well as changing the weighing and rating values of one or more factor included in the original DRASTIC. For instance, land use had a potential impact on groundwater vulnerability and risk mapping, which were produced as a consequence of groundwater contamination. Modified DRASTIC method is used to assess the groundwater vulnerability and risk mapping including land use (Secunda, Collin, and Melloul 1998). Al-Adamat, Foster, and Baban (2003) considered D, R, A, S, T, and I parameters because of lacking the hydraulic conductivity data. The vulnerability of Khan, Umar, and Lateh (2010) focused on the land use and impact of vadose zone effect on groundwater vulnerability and risk with DRASTIC method. Land use weight was considered as 5 and hydraulic mean approach (Hussain et al. 2005) was used to calculate the impact of vadose zone parameter. The following Equation (1) was used to achieve the approach and final vulnerability. Al-Hanbali and Kondoh (2008) also used the Equation (1) to assess groundwater vulnerability using. Modified DRASTIC parameters and rating ranges, and is used in most cases of arid and semi-arid regions. Weight and rating ranges were changed due to hydrogeological settings, land use categories, rainfall, climatic and other conditions. In some cases, some parameters of DRASTIC were removed or added to develop the modified DRASTIC method by many researchers. Modified equations, weight and rating ranges were given satisfactory result for groundwater vulnerability assessment in different regions. The new weight values were considered as 5, 4, 3, 5, 3, 3, and 2 for D, R, A, S, T, I, and C factor respectively, based on pesticide contamination (Al-Zabet 2002). A fixed index value of 10 was assumed instead of the parameters depth to water table and impact of vadose zone to calculate DRASTIC

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index (Hasiniaina, Zhou, and Guoyi 2010). The study area belonged to oil field and minerals region. The conductivity map generated by two components (aquifer thickness and conductivity) and greatly considered the relation below

$$T = Kb \quad \text{..... equa. (3)}$$

Where;

T = transmissivity

K= hydraulic conductivity

b = the thickness of the aquifer

Modified DRASTIC method was applied considering the land use parameter except hydraulic conductivity in Azraq basin (Jasem and Alraggad 2010). The new weighting and rating ranges were used for each DRASTIC parameter. A case study was carried out on aquifer vulnerability assessment to Arsenic pollution using DRASTIC and GIS of North Bengal plain in West Bengal of India (Ckakraborty, Paul, and Sikdar 2007). The assumption was that the contaminants moved vertically downwards with water and reached groundwater table. The new rating ranges were proposed for D, R, T, and I parameters of DRASTIC method. DRASTIC method was applied to assess the groundwater vulnerability for the structural characteristics of fractured-bedrock aquifers (Denny, Allen, and Journeay, 2007). The fractured media was strictly considered identifying its effect on groundwater vulnerability.

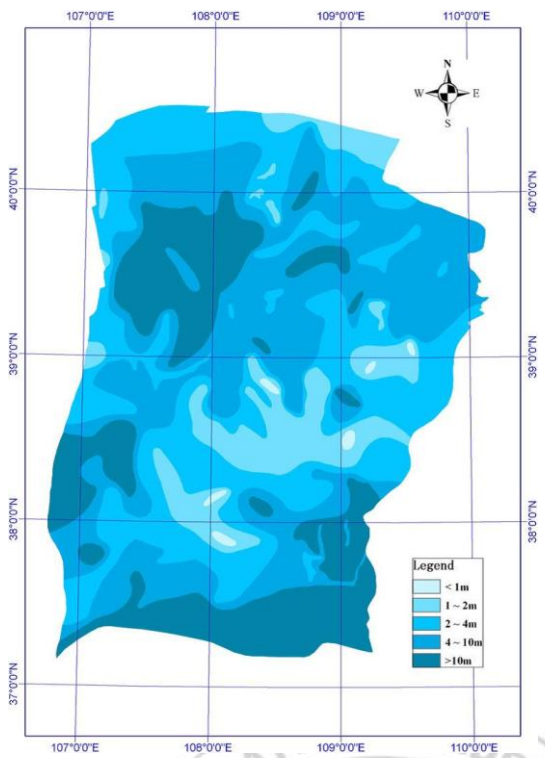

Fig. 1 Depth to water level map

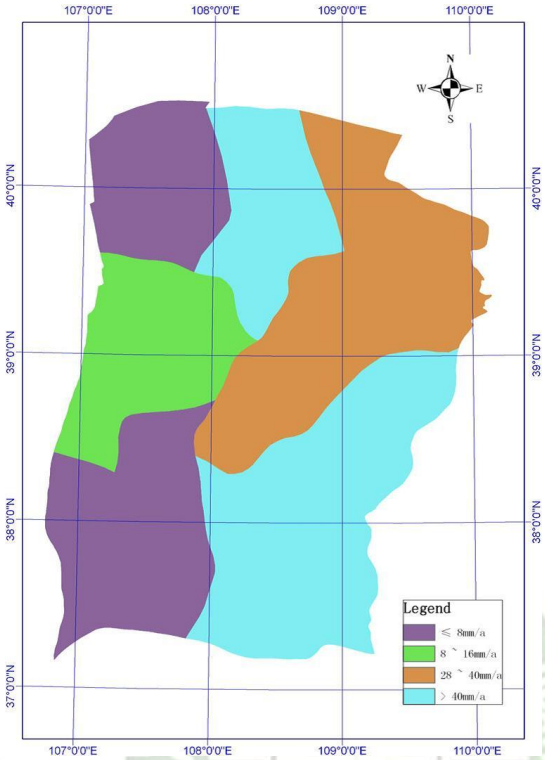

Fig. 2 Net recharge map

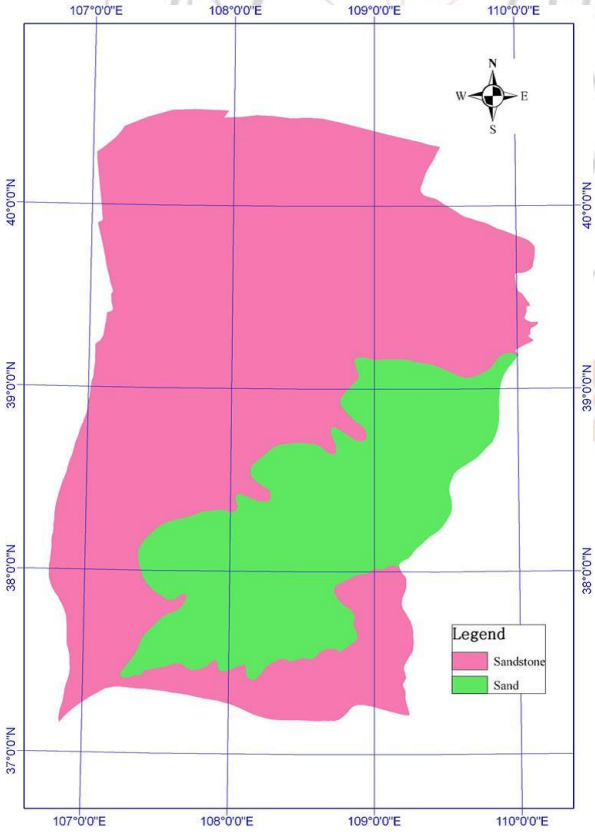

Fig. 3 Aquifer media map

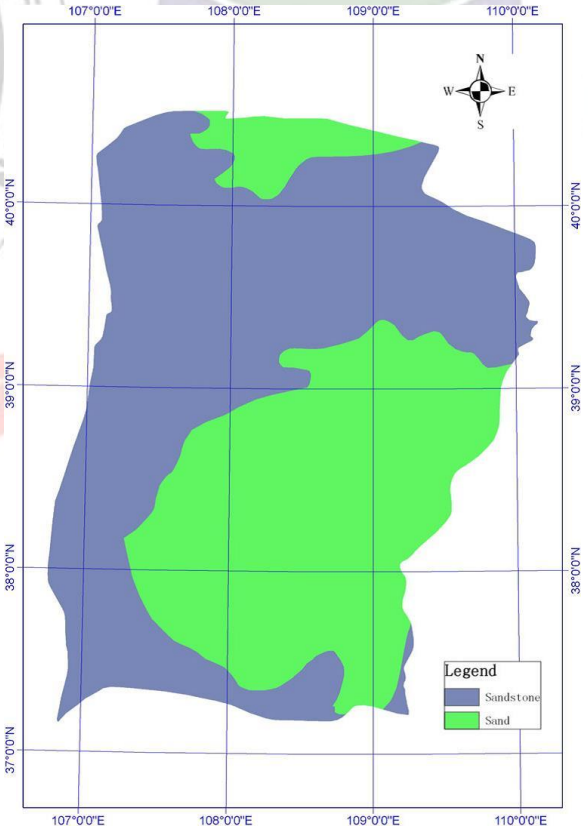

Fig. 4 Soil media map

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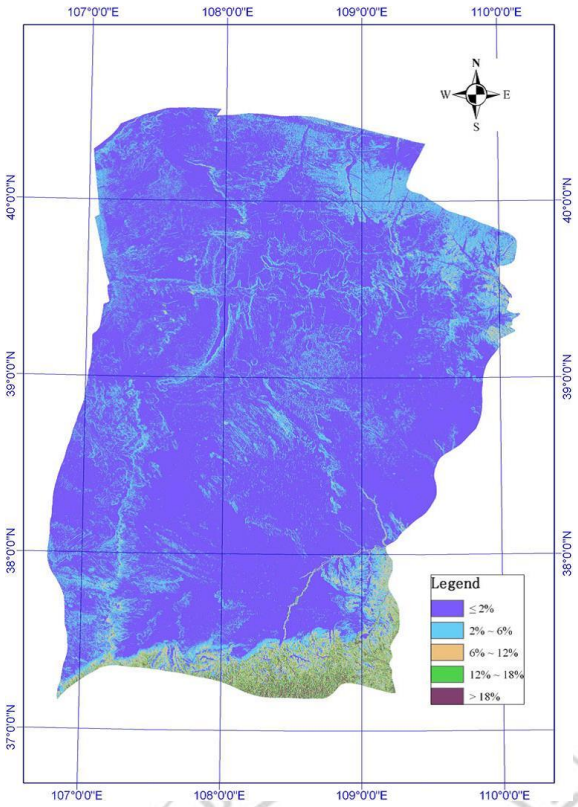

Fig. 5 Topographic map

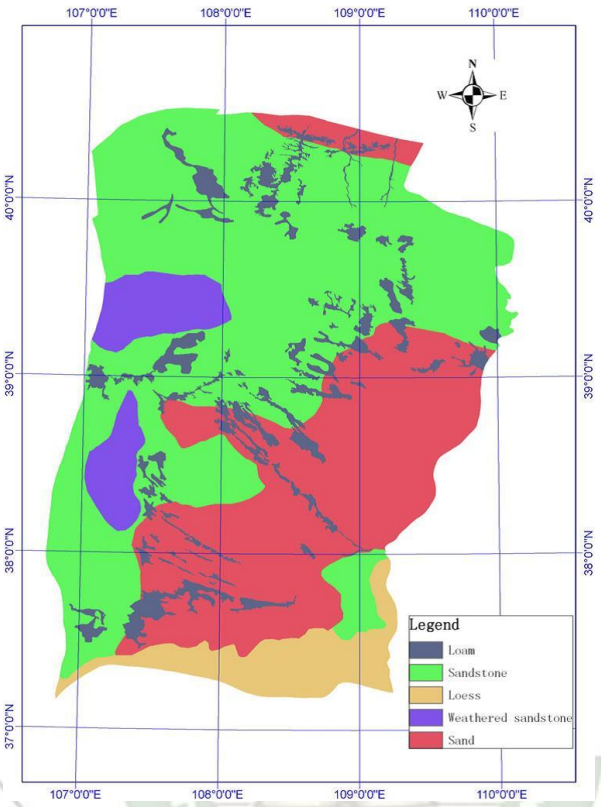

Fig. 6 Map of impact of the vadose zone

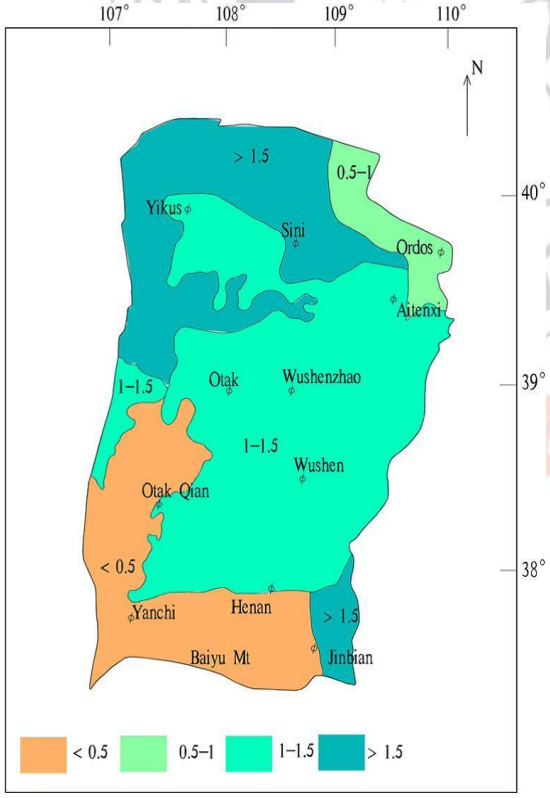

Fig. 7 Hydraulic conductivity map

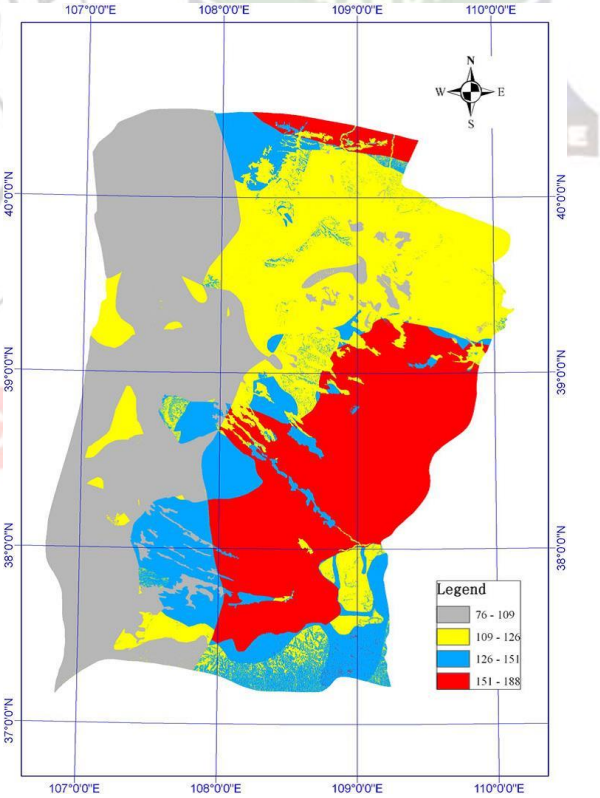

Fig. 8 The DRASTIC aquifer vulnerability map

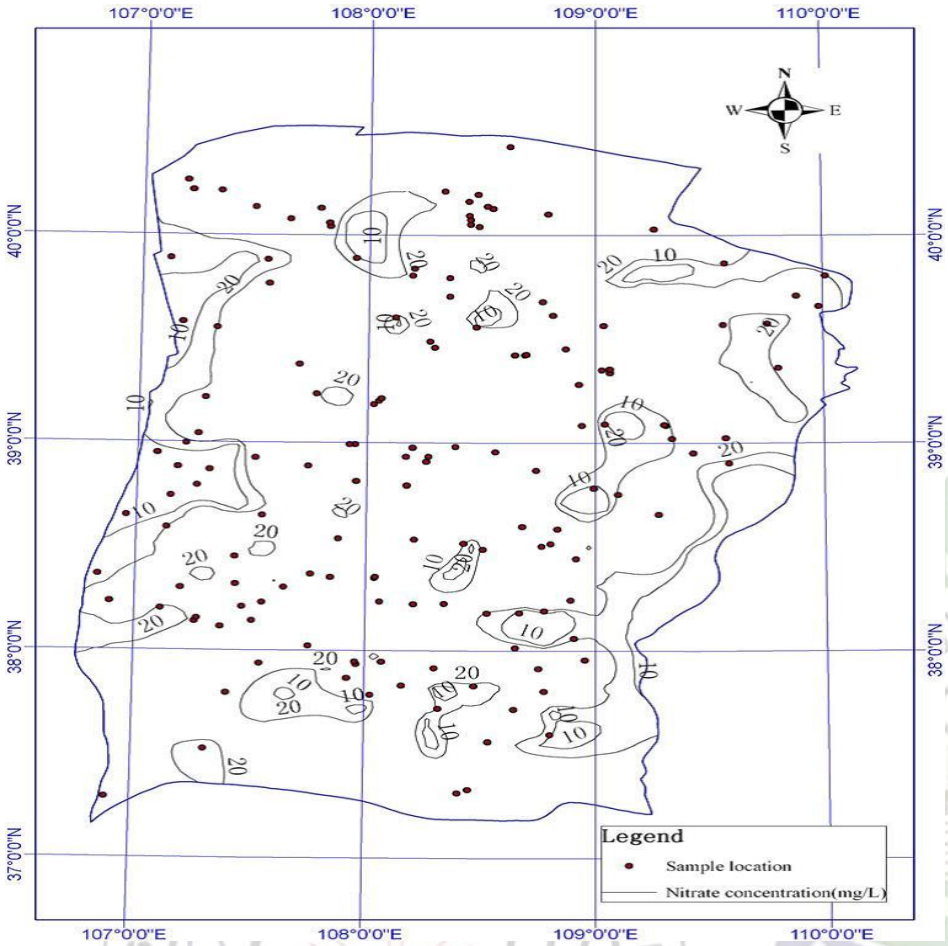

Fig. 9 Well location and nitrate concentration in groundwater

DRASTIC Index Validation

A validation of the DRASTIC method is vital as it is an empirical model; thus, nitrate concentrations were applied to validate the results of the DRASTIC model. Nitrogen in fertilizers is very frequently applied to agricultural areas to enhance crop production, and there are no unknown geological sources for nitrate in the study area. Hence, nitrate can be a good water quality parameter to evaluate the DRASTIC index and has been widely used (Baalousha 2006; Jamrah et al. 2008). The correlation between the DRASTIC index and the nitrate concentrations in groundwater was investigated to check the efficiency of using this approach to assess groundwater vulnerability. Groundwater samples were collected in 353 wells and nitrate concentrations were measured (Wang 2006). Figure 9 shows the contour map of the concentration of nitrate in groundwater based on the ordinary kriging interpolation

of measured data. By visual inspection of Fig. 9, high nitrate concentrations can be observed mostly in the high and moderate groundwater pollution potential areas, which have a good correlation with DRASTIC index (Fig. 8). Therefore, the results of vulnerability assessment using the DRASTIC model were confirmed. In contrast to this, although DRASTIC indicated that the western part was at no risk, nitrate concentrations were higher in some areas, particular along river valleys, such as the Mulin River valley.

Research Needs

The concept of groundwater vulnerability mapping is developed mainly based on hydrogeological settings. The vulnerability mapping assumes that the physical environment (soil–rock–groundwater system) may provide self-purification or natural attenuation. The following research needs are mentioned for further studies:

(1) Further research can be carried out on the relationship between the soil and protective cover such as cation-exchange capacity and-anion exchange capacity and its characteristics.

(2) Contaminant mobility indices and screening models can be developed for groundwater vulnerability assessment based on field observation and comparison with physics-based simulations of coupled solute transport and fluid flow in saturated or unsaturated systems.

(3) More studies should be done on groundwater protection methods and techniques; moreover, some study has been carried out on this regard which is not adequate and well established.

(4) Developing DSS approach to combine with groundwater vulnerability map based on stochastic screening model for groundwater resources management and monitoring.

Summary and Conclusions

Groundwater vulnerability is a widespread problem worldwide. Two main components are considered for DRASTIC method; firstly, the map able units which termed as hydrogeological settings and secondly, the application of numerical values of relative ranking

of hydrogeological factors. The paper attempts to present the application of DRASTIC method for groundwater vulnerability assessment, moreover some comparison between DRASTIC and other related methods are presented. The GIS techniques provided the great facilities to accomplish and handle the complex and extensive databases for groundwater vulnerability assessment. The salient conclusions are summarized below:

(1) The modified DRASTIC method is better than conventional DRASTIC method in the arid, semi-arid, basaltic, and agricultural and land fill regions.

(2) Sensitivity analysis is very helpful for DRASTIC method. It indicates which parameter has the most significant contribution to groundwater vulnerability.

(3) Extensive approaches are established to net recharge calculation based on different geological and hydrogeological conditions.

(4) The DRASTIC method is calibrated by nitrate concentration in groundwater.

(5) To help manage land-use allocation and prevent aquifer contamination, DRASTIC is not recommended

(6) It produces a very valuable tool for policy makers in order to manage and monitor groundwater resources properly

(7) Useful for land use planning and well head protection by providing a low cost means of identifying areas vulnerable to contamination

(8) Valuable tools for environmental planning will be used for predictive management of the groundwater resource

(9) Vulnerability of different areas can be analyzed for the prediction of vulnerability index of future time

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