Evaluation of Groundwater Vulnerability to Contamination Based on DRASTIC Model and GIS in Tianjin Plain Area

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Abstract. Assessment of groundwater vulnerability to contamination is the basement approaches for preserving the quality of groundwater. Based on DRASTIC model containing seven hydrogeological parameters and GIS techniques, groundwater vulnerability assessment was carried out in the plain area of Tianjin City, China. The results indicate that the studied area can be divided into five zones: low, slightly lower, middle, slightly higher, and high groundwater vulnerability zones, with coverage area of 1.8%, 24.8%, 53%, 19.6% and 0.8%, respectively. Low vulnerability zone locates in downtown, where the ground is covered by impervious surface. High and slightly higher vulnerability zones mainly locate in the groundwater recharge areas and the suburban areas surrounding downtown. Medium vulnerability zone covers most parts of the plain areas in the south of Baodi fraction. The result is consistent with the actual situation.

1. Introduction
Groundwater plays a vital role in water supply due to the limited availability of surface water resources. Groundwater is also a critical component of the global environment. However, nowadays the usage of groundwater for water supply in many areas has been limited by increasing contamination mainly caused by human activities. Human activities on the surface of aquifers could be considered as potential sources of groundwater pollution. Groundwater is not easily contaminated. Yet once this occurs, it is difficult to restore. Therefore, prevention of groundwater contamination is crucial for effective groundwater management. Groundwater vulnerability map has become a widely accepted tool in the land use planning process that takes into consideration aspects of groundwater protection from pollution. With the help of vulnerability maps, activities that are possibly hazardous to groundwater resources, such as waste disposal sites, sewage treatment plants, industrial plants, and commercial sites can be appropriately located in areas of low contamination risk. At the same time, the monitoring well can be installed in areas of high contamination risk. DRASTIC is a conceptual model defined as a composite description of the most important geological and hydrological factors that could potentially affect aquifer pollution. DRASTIC indexing has become popular, and widely used in the US [1], and worldwide [2] [3] [4], since it is developed by USEPA in the late 1980s [5]. The objective of this study is to assess the vulnerability of groundwater to contamination in Tianjin plain, by using the integration of DRASTIC model and geographic information system (GIS).

2. Study Area
The study area is plain region of Tianjin City, situated in the eastern part of the North China Plain, covering an area of 11919km², extending from 116°42′05″~118°03′31″E and 38°33′57″~40°00′07″N. The study area faces the Bohai Sea in the east and leans against the mountain Yanshan in the north.
Terrain becomes lower gradually from North West to South East. It has a semi-arid climate, the average annual precipitation is 580 mm and average annual evaporation is 1,700 mm. The studied area is filled with large volumes of unconsolidated Quaternary sediments with a big depth. The broad plain region from the foothills to the coast is generally divided by the fracture from Baodi to Ninghe, in the north of which the Geological Structure is mainly alluvial deposits, with storage of a fourth series of pore groundwater and groundwater in the bedrock, while in the south of which has the thick south of Cenozoic, with pore groundwater. For the shallow groundwater, the main types are unconsolidated pore water and clay fissure water. It is mainly recharged by precipitation, irrigation water, river water and discharges in the form of evaporation and man-made drilling. The studied area is mainly filled with unconsolidated Quaternary sediments. The stratigraphic particle becomes smaller gradually from North West to South East.

3. DRASTIC Model

The DRASTIC model was developed by Aller et al (1987) for the U.S. Environmental Protection Agency (EPA) and the object of this model was to provide a potential method for groundwater contamination assessment in any hydrological environment. DRASTIC model includes seven hydrological parameters which are groundwater depth (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of the vadose zone media (I), hydraulic conductivity (C). Each parameter is allocated specific weights and ratings, as Tab.1 (Aller et al.1987).

The DRASTIC index is calculated using Eq. (1), based on which, DRASTIC yields a numerical index map. The higher the DRASTIC index value, the greater the groundwater vulnerability.

| Depth to water (m) | Recharge (mm) | Topography (%) | Hydraulic conductivity (m/d) | Aquifer media | Vadose zone media | Soil media |
|--------------------|--------------|----------------|-----------------------------|--------------|------------------|-----------|
| Range              | Rating       | Range          | Rating                      | Range        | Rating           | Range     |
| 0 - 1.5            | 10           | 254+           | 10                          | 0 - 2        | 10               | Karst     |
| 1.5 - 4.6          | 9            | 235 - 254      | 9                           | 2 - 6        | 9                | limestone |
| 4.6 - 6.8          | 8            | 216 - 235      | 8                           | 6 - 12       | 5                | Basalt    |
| 6.8 - 9.1          | 7            | 178 - 216      | 7                           | 12 - 18      | 3                | Sand and gravel |
| 9.1 - 12.1         | 6            | 147.6 - 178    | 6                           | 18+          | 1                | Massive stone |
| 12.1 - 15.2        | 5            | 117.2 - 147    | 5                           | 0 - 4.1      | 1                | Bedded sandstone |
| 15.2 - 22.9        | 4            | 91.8 - 117.2   | 4                           | Weathered metamorphic igneous Metamorphic igneous | 4 | 3 | Limestone |
| 22.9 - 26.7        | 3            | 71.4 - 91.8    | 3                           | Shale        | 3 | Clay loam |
| 26.7 - 30.5        | 2            | 51 - 71.4      | 2                           | Silt/Clay    | 3 | Muck |
| 30.5+              | 1            | 0 - 51         | 1                           | Karst limestone | 1 | Confirming layer |

| Weight=5 Normalized weight=0.217 | Weight=4 Normalized weight=0.174 | Weight=1 Normalized weight=0.043 | Weight=3 Normalized weight=0.131 | Weight=3 Normalized weight=0.131 | Weight=5 Normalized weight=0.217 | Weight=2 Normalized weight=0.087 |
|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
DRASTIC Index (DI)

\[ DI = D_R \times R_R + A_I \times I_A + S_J \times J_S + T_W \times W_T + I_I \times I_I + C_C \times C_C \] (1)

Where, \( D, R, A, S, T, I, \) and \( C \) are the seven parameters and the subscripts \( R \) and \( W \) are the corresponding ratings and weights, respectively.

4. Result and Conclusion

According to the ratings in Table 1, we derived the maps of different parameters in DRASITC using GIS, shown as Figure 1. Groundwater depth is the distance of contaminants from the surface to the groundwater. In study area the groundwater depth ranges from 0.2 m to 25 m and the parameter \( D \) rating ranges from 1 to 10 (Figure 1a). Net recharge is the annual net water from surface into ground. In this area, the main recharge is precipitation and irrigation. The net recharge ranges from 61.2 mm·a\(^{-1}\) to 270 mm·a\(^{-1}\) and the parameter \( R \) rating ranges from 2 to 10 (Figure 1b). The main aquifer media are sand and fine sand in north part, while silt, muddy-silt and fine silt in the south part. The parameter \( A \) rating ranges from 1 to 10 (Figure 1c). Sediment is mainly fluvial in the north part, lake-alluvial deposits in the central part, and marine deposit in the eastern coastal areas. Correspondingly, soil media are mainly cinnamon soil, fluvio-aquatic soil and saline-alkali soil. Parameter \( S \) rating ranges from 1 to 9 (Figure 1d). The studied area is a flat plain. The slop ranges from 0.01% to 1%. The lithology of vadose in the most area is sandy loam and silt clay, so the parameter \( I \) rating mostly ranges from 3 to 6 (Figure 1e). Hydraulic conductivity determines the groundwater velocity in the aquifer which ranges from 0.1 m·d\(^{-1}\) to 20 m·d\(^{-1}\) in this area by pumping test. The parameter \( C \) rating ranges from 1 to 3 (Figure 1f). In ArcGIS10.2 using the tool of fishnet, we divided the study area into 11613 square grids of 1km×1km. For each grid, based on the original data, we calculate the groundwater vulnerability index (GVI) according to Equation (1) and ratings and normalized weight list in Table 1, groundwater vulnerability index in the study area ranges from 2.5 to 8.1. From the single parameter ratings in Table 1, it is deduced that index value under 3 often represents low vulnerability zone, and GVI ranging from 3 to 4 represents medium vulnerability zone, GVI ranging from 4 to 6 represents slightly higher vulnerability zone, and GVI more than 6 often represents high vulnerability zone, shown as Figure 2. According to Figure 2, distribution of medium groundwater vulnerability zone accounts for 53% of the total area, mainly covering most areas of the broad plain to the south of Baodi fracture. Low groundwater vulnerability zone, with the area percentage of 1.8%, mainly locates in downtown, where the ground is almost covered by impervious surface. Slightly lower vulnerability zone covers 24.8% of the total area, scattered in Tanggu, Ninghe, Jinhai districts, and part of suburban areas. High groundwater vulnerability zone mainly locates in Jixian due to the large recharge, occupying less than 1% of the total area. Slightly higher groundwater vulnerability zone covers 19.6% of the total area, occupying almost the whole part of Jixian, part area of suburban areas, Baodi, Wuqing and Dagang districts. It is consistent with the actual situation.
a) soil media map  

b) vadose zone type map  

c) hydraulic conductivity  

d) groundwater depth map  

е) net recharge map  

f) aquifer media  

Figure 1. Parameter maps in DRASTIC model
Figure 2. Groundwater vulnerability map in studied area

5. Conclusion
Groundwater vulnerability should be accepted as an important tool for contamination. Based on GIS and DRASTIC model, groundwater vulnerability in the plain area of Tianjin was analyzed including several parameters which were depth of groundwater, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity. According to the results, the studied area could be divided into five zones: low, slightly low, middle, slightly higher, and high groundwater vulnerability zones, with coverage area of 1.8%, 24.8%, 53%, 19.6% and 0.8%, respectively.

6. Acknowledgment
Funds for this research was provided by the special project for Jingjinji cooperation, the Key Project of Tianjin Municipal Natural Science Foundation“Methods of groundwater regulation and storage in water-receiving area of water transferring project (No.15JCZDJC41400). Tianjin Agricultural University Foundation (2017YAL012).

7. References
[1] Fritch TG, McKnight CL, Yelderman JC, Arnold JG (2000) An aquifer vulnerability assessment of the Paluxy aquifer, Central Texas, USA, using GIS and a modifiedDRASTIC approach. Environ Manage 25:337–345.
[2] Naqa A, Hammouri N, Kuisi M (2006). GIS-based evaluation of groundwater vulnerability in the Russeifa area, Jordan. Revista Mexicana de Ciencias Geologicas 23(3):277–287.

[3] Saidi S, Bouri S, Dhia HB (2010). Groundwater vulnerability and risk mapping of the Hajeb-jelma aquifer (Central Tunisia) using a GIS-based DRASTIC model. Environ Earth Sci 59(7):1579–1588.

[4] Yin L, Zhang E, Wang X, Wenninger J, Dong J, Guo L, Huang J (2012). A GIS-based DRASTIC model for assessing groundwater vulnerability in the Ordos Plateau, China. Environ Earth Sci 69(1):171–185.

[5] Aller L, Bennet T, Lehr JH, Petty RJ, Hackett G (1987). DRASTIC: a standardized system for evaluating groundwater pollution potential using hydrogeological settings. EPA/600/2–87/035. US Environmental Protection Agency.