Risk assessment of groundwater contamination based on Geographic Information System in the southern suburb of Yinchuan, China

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Abstract. Groundwater contamination risk assessment is a useful tool for groundwater prevention and control. In this study, groundwater risk assessment model was used to assess the risk to groundwater contamination in the southern suburb of Yinchuan city, north-western China. The high and higher contamination risks of the groundwater are mainly distributed in the southern part of the study area. The proportion of groundwater distribution risk in extremely low and low areas is relatively large, most of which are located on the east and west sides of the water source area. Groundwater depth, net recharge and pollution loading are main factors affecting the contamination risk on the study area. The evaluation results have practical significance for urban planning and construction, groundwater management and protection, and sustainable utilization of water resources.

1. Introduction
Groundwater is an important source of water supply for urban and rural areas, which plays an irreplaceable role in maintaining the healthy development of economy and society [1,2]. Reasonable assessment of groundwater contamination risk is of great significance for formulating water resources management plan, pollution prevention and control measures and regional sustainable development.

The DRASTIC model is widely used groundwater vulnerability and pollution risk assessment in various countries [3,4]. However, DRASTIC model has some limitations in the selection of indicators due to the great differences of hydrogeological conditions in different regions. Many scholars have developed the evaluation methods, such as GOD (Groundwater occurrence, Overall aquifer class and Depth to groundwater table), AVI (Aquifer Vulnerability Index), PI (Protective cover and Infiltration conditions), etc in Europe and FAVA (Florida Aquifer Vulnerability Assessment) model in Florida [5,6]. At present, there is no standard for groundwater contamination risk assessment in China. Most scholars still use DRASTIC model. In addition, DRASTIC model reflects the intrinsic vulnerability of groundwater. However, under the influence of human activities, groundwater contamination risk may change greatly. Therefore, new assessment models incorporate the impacts of pollution sources or land use, such as U.S. Geological Survey method by the National Geological Survey of the United States and SI (Susceptibility Index) proposed by the Portuguese Geological Information Center [6,7]. Many scholars, such as Antonakos and Lambarakis, Brindha and Elango, Saha and Alam, have taken land use types as an important factor to study groundwater contamination risk [8-10]. Wu et al also considered...
the impact of potential point pollution sources (such as gas stations) and important pollution sources (such as aquaculture farms) on groundwater pollution while considering land use types [2]. In addition, some scholars consider the value of groundwater in contamination risk assessment from the perspective of groundwater exploitation and utilization [11,12].

This paper chooses the water source area in the southern suburb of Yinchuan City, Ningxia, as the research area. This area has a history of irrigation from the Yellow River for more than 2000 years. Obviously, it is inappropria te to only use the intrinsic vulnerability of groundwater to assess the risk of contamination on these areas. The relationship between human beings and groundwater must be considered on the basis on the evaluation of the intrinsic vulnerability of groundwater.

2. Study area
The study area is located in the southern suburb of Yinchuan, Ningxia, north-western of China and covers an area of about 195 km² (figure 1). Groundwater is the main water supply source in the study areas. The annual average precipitation (AP) and temperature in this area is 192.25 mm is 9.2°C, respectively. It belongs to temperate continental climate. The annual evaporation in this area is 1575.55 mm, more than nine times AP. Geomorphology is divided into aeolian dunes and alluvial-lacustrine plain from southwest and northeast. The study area is a multi-layer aquifer system, including shallow phreatic aquifer, upper confined aquifer and lower confined aquifer. The shallow groundwater is provided for the suburb and rural private, while urban areas is supplied by confined groundwater.

![Figure 1. Study area and sampling locations.](image-url)

In the study area, about 65.2% of the precipitation falls in July, August and September, which was in the period of irrigation, and there always is water standing in low-lying area. Irrigation surplus water need drain out through the drainage, it means that the chances of precipitation infiltration to groundwater is very limited. Groundwater recharge mainly comes from infiltration of irrigation and groundwater runoff from southwest boundary. Underdeveloped irrigation system and poor seepage control conditions lead to low water use efficiency. Irrigation water infiltration raises the groundwater level and transports pollution to groundwater. The hydraulic gradient of groundwater in the areas is small and the flow is slow. Once groundwater is polluted, it will be difficult to recover.
3. Methodology
This study used the northern suburb of Yinchuan as a case study. Overkay and index method is the most popular used to evaluate groundwater vulnerability and pollution risk [13]. Based on the characteristics of hydrogeology and human activities, combined with intrinsic vulnerability, pollution loading and groundwater value, the risk of groundwater contamination is evaluated by using Geographic Information System (GIS).

3.1. Intrinsic vulnerability
The intrinsic vulnerability of groundwater reflects the self-purification capacity of the aquifer when pollutants enter. It is irrelevant to the pollution source or pollution type, and only depends on geology and hydrogeology, which are natural properties of an aquifer. The DRASTIC model is developed for intrinsic vulnerability. Qian et al [1] developed the OREADIC model, which is based on the DRASTIC model, in order to assess the intrinsic vulnerability of Yinchuan Plain. The modified model described by Qian et al [1] removed the indexes of Topography (T) and Impact of the vadose zone media (I), and added Organic matter content of the soil (O) and Extraction of phreatic water (E). Thus, according to the actual conditions of the study area, this paper used the indexes of Depth to water (D), Net recharge (R), Aquifer media (A), Impact of the vadose zone media (I), Organic matter content of the soil (O) and Hydraulic conductivity (C) to assess the intrinsic vulnerability.

3.2. Pollution loading
Land use types are various land use with different characteristics formed in the process of transformation and utilization of land for production and construction. Land use types determine the quality of groundwater infiltration from the surface and are used as indicators by many vulnerability models [1,2]. Pollution loading assessment is characterization of the possibility of groundwater pollution and load caused by human activities and various pollution sources. Potential pollution sources described by land use are commonly used in studies. The thirty-three kinds of land use in the study are divided into 10 types based on the results of second land survey. The proportion of paddy fields and irrigable land in the study area is high. Because of the long-term recharge of groundwater from those land, the groundwater level has been greatly raised, and the mechanical filtration, volatilization, dispersion, biodegradation and chemical reaction of pollutants in the aeration area have been reduced. Meanwhile, agricultural pollution such as chemical fertilizers and pesticides has been dissolved by irrigation water and carried into groundwater. Therefore, the scores of paddy field and irrigable land are 10 and 9, respectively. In addition, residential areas such as cities and villages usually produce a large amount of living garbage and excrement, which can easily cause groundwater pollution in areas.

3.3. Value of groundwater
The value of groundwater is the total economic value or socio-economic value of resources. It is very laborious to quantify [11]. The indexes for evaluating the value of groundwater can be divided into the quantity and quality of groundwater. Groundwater has abundant reserves and excellent quality, which has high value. However, the value of groundwater with poor quality and limited use is low. Irrigation infiltration is the main source of groundwater recharge in the study area. Shallow groundwater is seriously polluted by intensive human activities. Therefore, in order to simplify the analysis, groundwater quality (Q) is used to approximately replace the value of groundwater.

3.4. Assessment model
The structure of the assessment model is summarized in figure 2. Six factors (D, R, A, I, O and C) are used to represent the intrinsic vulnerability. Land use and water quality are used to represent pollution loading and value of groundwater, respectively.
Figure 2. The structure of the assessment model.

The contamination risk index (CRI) is expressed as

\[ CRI = D \times D + R \times R + A \times A + I \times I + O \times O + C \times C + L \times L + Q \times Q \]

where, subscripts \( r \) and \( w \) are rating and weights of indices \( D, R, A, I, O, C, L \) and \( Q \), respectively. The rating of \( L \) was shown in table 1, and other were shown in table 2.

Table 1. Classification and rating of land use types.

| Rating | Land use types                                      |
|--------|----------------------------------------------------|
| 10     | Paddy field                                        |
| 9      | Irrigable land                                     |
| 8      | Urban, designated town, village, pond              |
| 7      | Saline-alkali soil, dry land                       |
| 6      | Tame pasture, orchard, ditch, other perennial plantations |
| 5      | Rural road                                         |
| 4      | Other grassland and forest land, airport           |
| 3      | Sandy land, Swamp, Ridge, Railway, Scenic and special land, Highway and Farmland |
| 2      | Mining lease, bare land, building,                |
| 1      | Grassland, forest, River, Laker, shrub forest, reservoir |

Table 2. Classification and rating of land use types.

| Rating | D(m) | R(mm/year) | A   | I     | O     | C(m/d) | Q   |
|--------|------|------------|-----|-------|-------|--------|-----|
| 10     | ≤2   |            | gravel | gravel | 0     | ≥100   | I   |
| 9      | (2,4] | (0,51]     | Sand gravel | Sand gravel | *   | (80,100] | -   |
| 8      | (4,6] | (51,71]    | Coarse sand | Coarse sand | 0-0.7 | (60,80] | II  |
| 7      | (6,8] | (71,92]    | Medium sand | Medium sand | 0.7-1 | (40,60] | -   |
| 6      | (8,10] | (92,117]   | Fine sand | Fine sand | - | (35,40] | -   |
| 5      | (10,15] | (117,147]  | Silty-fine sand | Silty-fine sand | 1-1.5 | (30,35] | III |
| 4      | (15,20] | (147,178]  | Silt sand | Silt sand | - | (20,30] | -   |
Weight reflects the relative importance of each factor to contamination risk, and has a great impact on the vulnerability evaluation results. Analytic Hierarchy Process (AHP) is more suitable for decision-making problems with hierarchical and staggered evaluation indexes and the objective value is difficult to quantitatively describe. This study uses AHP to determine the weight, and the details of the method can see in Qian et al, and Wu et al [1,2].

4. Results and discussion

The study area was divided into sub-regions with a fine grids of 50x50 m, and the scores were assigned to each unit to construct a distribution maps of the eight factors (figure 3). Afterwards, the raster calculator in GIS is used to generate the contamination risk map. Finally, equal interval method was used to classify contamination risk into five classes [14]. The result of groundwater contamination risk is showed in figure 4.

![Figure 3. Distribution maps of the eight factors.](image)

It can be seen from figure 4 that groundwater contamination risk map is obvious distribution based on geological, hydrogeological and human activities. The results show that the groundwater
The contamination risk is mainly divided into extremely low (15.1%), low (32.0%), moderate (23.2%), high (14.7%) and extremely high (15.0%). In general, the extremely high-risk areas are in the south and some in central parts of the study areas while low-risk prevails along the periphery, particularly in the north.

![Figure 4. The map of groundwater contamination risk.](image)

The larger the depth to groundwater, the smaller the formation porosity and water recharge, therefore, groundwater pollution resistance becomes stronger. The high and higher contaminations risks of the groundwater are mainly distributed in the southern part of the study area. The three main factors affecting the contamination risk of the area are shallow groundwater table, high net recharge and high pollution loading. The main land use types in the south region are paddy field and irrigated land, which causes high pollution loading. Therefore, pollution mainly comes from agricultural activities. Most of groundwater depth in southern part is below 4 meters, and the net recharge is above 178 mm/year, which makes it scored higher. The land use types are paddy area and irrigated land in these areas, which makes pollutants easily enter groundwater. Under the comprehensive influence of these factors, the contamination risk of groundwater in this area is very high.

The proportion of groundwater distribution risk in extremely low and low areas is relatively large, most of which are located on the East and west sides of the study area. The groundwater table in the western part of the water source area is 6-10 m deep, which is larger than that in other areas. In addition, most of the areas with low risk are wasteland, and there is no crop cultivation, therefore the net recharge is relatively small. The moderate risk area is mainly located in the middle of the study area, and the comprehensive effect of various factors is the result, of which the zero content of soil organic matter has a significant impact on it.

From the above analysis, it can be seen that the contamination risk of groundwater is related to many factors. Only by thoroughly understanding the influencing mechanism, the magnitude and the relationship among the factors on the contamination of groundwater, then, can we grasp the main contradictions, and select the main evaluation factors reasonably of pollution prevention and control.

5. Conclusions
Groundwater contamination risk is an important part of groundwater resources protection planning, and it is important to formulate reliable policies for resource management and exploitation. Based on DRASTIC model, considering the impact of human activities on groundwater, the groundwater contamination risk in the southern suburb of Yinchuan is constructed. Intrinsic vulnerability, pollution loading and value of groundwater are overlapped by using GIS based on the overlay index method. The results of this study are more hierarchical than only using intrinsic vulnerability. The high and higher contamination risks of the groundwater are mainly distributed in the southern part of the study area. The proportion of groundwater distribution risk in extremely low and low areas is relatively
large, most of which are located on the east and west sides of the water source area. Groundwater depth, net recharge and pollution loading are main factors affecting the contamination risk on the study area. Contamination mainly comes from agricultural activities. Groundwater is the main source of water supply in the region. The evaluation results have more practical guiding significance for environmental planning, groundwater management and sustainable utilization.

Acknowledgments
This work was supported by the National Natural Science Foundation of China (41572236).

References
[1] Qian H, Li P, Howard K W F, Yang C and Zhang X 2012. Assessment of groundwater vulnerability in the yinchuan plain, northwest china using oreadic Environ. Monit. Assess. 184 3613-28
[2] Wu H, Chen J and Qian H 2016 A modified drastic model for assessing contamination risk of groundwater in the northern suburb of Yinchuan, China Environ. Earth Sci. 75 483
[3] Stigter T Y, Ribeiro L and Dill A M M C 2006 Evaluation of an intrinsic and a specific vulnerability assessment method in comparison with groundwater salinisation and nitrate contamination levels in two agricultural regions in the south of Portugal Hydrogeol. J. 14 79-99
[4] Aller L, Bennett T, Lehr J H, Perry R J and Hackett G 1987 DRASTIC: A standardized system for evaluating groundwater pollution potentials using hydrogeological settings EPA/600/2-87/035 (US Environmental Protection Agency)
[5] Arthur J D, Wood H A R and Baker A E 2007 Development and implementation of a Bayesian-based aquifer vulnerability assessment in Florida Nat. Resour. Res. 16 93-107
[6] Beynen P E V, Niedzielski M A, Bialkowska-Jelinska E, Alsharif K and Matusick J 2012 Comparative study of specific groundwater vulnerability of a karst aquifer in central Florida Appl. Geogr. 32 868-77
[7] Eimers J L, Weaver J C, Terziotti S and Midgette R W 2000 Methods of rating unsaturated zone and watershed characteristics of public water supplies in north Carolina Water-Resources Investigations Report 99-4283 (U.S. Geological Survey)
[8] Antonakos A K and Lambrakis N J 2007 Development and testing of three hybrid methods for the assessment of aquifer vulnerability to nitrates, based on the drastic model, an example from NE Korinthia, Greece J. Hydrol. 333 288-304
[9] Brindha K and Elango L 2015 Cross comparison of five popular groundwater pollution vulnerability index approaches J. Hydrol. 524 597-613
[10] Saha D and Alam F 2014 Groundwater vulnerability assessment using DRASTIC and Pesticide DRASTIC models in intense agriculture area of the Gangetic plains, India Environ. Monit. Assess. 186 8741-63
[11] Wang J J, He J T and Chen H H 2012 Assessment of groundwater contamination risk using hazard quantification, a modified DRASTIC model and groundwater value, Beijing Plain, China Sci. Total Environ. 432 216-26
[12] Zaporozec A 2002 Groundwater Contamination Inventory: A Methodological Guide (Paris: UNESCO)
[13] Focazio M J, Reilly T E, Rupert M G and Helsel D R 2002 Assessing ground-water vulnerability to contamination: Providing scientifically defensible information for decision makers (U.S. Dept. of the Interior, U.S. Geological Survey)
[14] Jenks G F and Caspall F C 1971 Error on choropleth maps: Definition, measurement, reduction Annals of the Association of American Geographers 61 217-44