Regional assessment of groundwater vulnerability in Tamtsag basin, Mongolia using drastic model

Fanomezantsoa Hasiniaina[1], Jianwei Zhou, Luo Guoyi

[1]School of Environmental Studies, China University of Geosciences (Wuhan)

Lumo Road 388, Wuhan City, 430074 Hubei Province, P.R. China.

hasiniainaf@hotmail.com

ABSTRACT: Groundwater is one of the most valuable natural resources and for that reason, its protection and management is vital for human evolution, socio-economic development and ecological diversity. Because of the known health and economic impacts associated with groundwater contamination, steps to assess groundwater vulnerability must be taken. This study aimed to assess groundwater pollution potentials of the north-eastern part of the deep confined aquifer of block XIX, Tamtsag basin, Mongolia. The normal DRASTIC model was applied to the study area with the help of GIS. DRASTIC parameters were calculated from geological data, soil and elevation contour maps, and groundwater level data of the study area. ArcInfo/GIS was used to demarcate vulnerable zones based on their vulnerability index. Finally, a sensitivity analysis of the parameters constituting the model was performed in order to evaluate the relative importance of the each DRASTIC model parameters. The aquifer vulnerability map revealed that only 2% of the study area is under moderate vulnerability to contamination, the remaining zone was determined to be in a low risk category. GIS greatly facilitated the implementation of the sensitivity analysis applied on the DRASTIC vulnerability index which otherwise could have been impractical. Appropriate methods for keeping groundwater resource sustainability in the study area have been suggested.
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1. INTRODUCTION

Mongolia is a landlocked country between the Russian Federation and the People's Republic of China with over 3 million population and 1,565 thousands square kilometers territory. The country is rich in underground mineral resources. Currently, there are more than 80 proven minerals, including coal, copper, tungsten, fluorite, gold, silver, molybdenum, aluminum, tin, iron, lead, zinc, uranium, manganese, phosphorous, salt, petroleum and so on. The animal husbandry is a traditional economic sector and is the foundation of the national economy; the mining industry also has great potential. Scarcity of arable land and harsh climate make Mongolia unsuitable for agriculture production despite its large territory (seventeenth largest country in the world).

Mongolia belongs to not rich country in terms of water resources. The country's total water resource (30% of which is groundwater) was estimated to be 609.5 cubic kilometer in 2000 (Batsukh N.). Domestically, surface and ground water resources play vital roles in Mongolia's economy, supporting agriculture, forestry, fishery, livestock production, industrial and domestic water demand and sanitation operations. Water demands are mainly met from the groundwater sources: 80% of the total water consumption. Mongolia's freshwater ecosystem is under increasing threats of degradation and resource depletion. Water shortage and scarcity is becoming inevitable with alarming numbers of dried-out rivers and lakes (WWF Mongolia Program Office). In 2005, UNDP commissioned a "Study on Economic and Ecological Vulnerability and Human Security for Mongolia", which pointed out water shortage as a major socio-economic problem that may soon create serious economic challenges throughout the country.

Despite its limited and finite nature, Mongolia's water has been subject to both natural and anthropogenic factors. Global climate change, which adversely impacts the natural dynamics of freshwater ecosystems, is one of leading natural factors. In some areas, water levels rise due to glacier and permafrost melting. In other, arid areas, lower water tables are due to drought and loss of water retention capacity in riparian areas that have been heavily deforested. Anthropogenic activities causing excessive extraction and depletion of water resource include mining/gravel extraction; deforestation and wasteful irrigation systems. Socio-economic implications of water scarcity are gravest for those vulnerable to the poverty trap and water scarcity also escalates adverse change on an ecosystem level (WWF Mongolia Program Office). Mining also uses vast quantities of groundwater (rivers and underground water) which reduces the water table. If this process continues in long term, there might be a possibility that the future generation would be facing with scarcity and its ecological balance (Dolgorsuren G.)

In his book "Groundwater inventory", A. Zaporozec stipulates that groundwater is one of the most valuable natural resources, because it:

- represents some 98 percent of the planet's freshwater resources (polar ice excluded),
- is extensively used for low-cost rural water supply,
- is increasingly developed for both large- and small-scale irrigation,
- is generally reliable in periods of drought because of its large storage capacity,
- is cheap to develop because of its widespread occurrence and its generally good natural quality.

Moreover, groundwater is the main source of water consumption of natural vegetation in arid regions. All ground water is vulnerable (The USA National Research Council, 1993). Even owing a function of self- remediation; it will be very difficult to be remediated once it was polluted. Therefore, a sustainable groundwater management should be based on prevention of contamination. An assessment of both the existing and potential sources of contamination and the spatial extent of the existing groundwater contamination is needed before considering methods to prevent future groundwater quality problems (A. Zaporozec et al. 2002)

This study aimed at assessing the vulnerability of groundwater to contamination in the vicinity of an oilfield exploration in Block XIX of Tamtsag Basin, Eastern Mongolia using a DRASTIC model (Aller et al., 1987) combined with a Geographic Information System (GIS). Many papers on the effects of oilfield on groundwater are available in the scientific literature, as are several comprehensive reviews. In their study of the impact of oilfield exploitation on eco-environment of the Daqing lakes, Yu S. et al. (2003) demonstrated that oilfield exploitation may harm its vicinity. Their paper stated that the impacts became more evident with passage of time, and the intensity varied with areas. Actually, in any industrial activity, equipment can fail and employees may err; and groundwater pollution may result. Thus, it is important to evaluate sensitive areas to contamination is essential in order to prevent and control groundwater contamination.

The term 'vulnerability of groundwater to contamination' was introduced by Jean Margat in the late 1960s (Vrba and Zaporozec, 1994). He used the term "vulnerability" to mean the degree of protection that the natural environment provides against the ingress of pollutants to groundwater. Vulnerability assessment has been recognized for its ability to delineate areas that are more likely than others to become contaminated as a result of anthropogenic activities at/or near the earth's surface (Babiker et al., 2007) The concept of groundwater vulnerability is based on the assumption that the physical environment may provide some degree of protection to groundwater against natural impacts, especially with regard to contaminants entering the subsurface environment. Consequently, some land areas are more vulnerable to groundwater contamination than others (Napolitano, 1995). Vulnerability assessment and vulnerability maps represent an important preliminary tool in decision-making pertaining to the management of groundwater quality. They provide a useful framework within which to designate priorities for the implementation of pollution protection and control measures. The vulnerability maps also serve to inform and educate the public, because non-professional people can readily understand their concept. They also create public awareness about potential pollution problems of groundwater, a situation needed for effective implementation of future protection programs (Rubhera, 2002).

2. STUDY AREA

The study area (116°04'31" to 116°21'34" E and 46°50'01" to 47°04'17" N.) is located in the northeastern part of block XIX, Tamtsag basin. Situated in the eastern part of Mongolia, with an area of 381km2; it is located in the high plain zone with the altitude of 600～730m. The landform is relatively flat, the topography gradually rises from west to east, and it's in an undulant plain landform from a macroscopic view. There are no rivers in the study area but some small lakes in the northwestern part which are all dry in arid seasons.

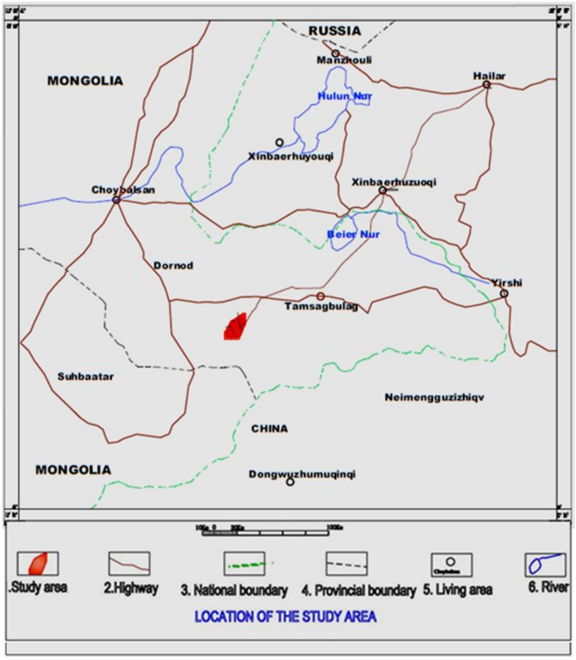

Figure 1 Location map of the study area

Climatically, the zone belongs to an arid area with an annual average precipitation of 276.4mm; an annual evaporation is 1518.7mm and an annual average temperature of -6.6°C～3.9°C. It's a typical arid and semi-arid continental climate. Geologically, the top of the strata lithology is constituted by (1) a quarternary silty sand soil and silty clay, with partial sandy layer at the top; (2) a quarternary sandstone as water bearing layer and (3) cemented and loose sandstone, medium-sized coarse sandstone and fine sandstone.

Most of the working area is covered by sand soil, and the area has a very high sandy degree. It is also characterized by high alkali content. In the eastern part of the project zone, there exists an approximately south-north tectonic fracture. As a result, there is a huge water-rich difference on both sides of the fault zones which reflects the water-rich distribution of underground water. A water-rich belt of about 12-km-long and 8-km-wide is situated in the western part of the study area. A representation of the West-East (AA') cross-section and the South-North cross-section (BB') of the aquifer is illustrated in figure 2.

3. METHODS AND APPROACHES

3.1. Model theory

The DRASTIC model was developed in USA for the purpose of protecting the groundwater resources (Aller et al., 1985; 1987). DRASTIC is an empirical groundwater model that estimates groundwater contamination vulnerability of aquifer systems based on the hydrogeological settings of that area (Aller, et al., 1985, 1987).

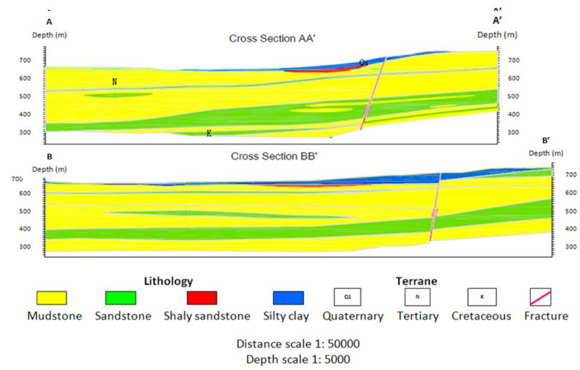

Figure 2 Simplified Cross Sections of the aquifer

The DRASTIC hydrogeologic vulnerability ranking method uses a set of seven hydrogeologic parameters to classify the vulnerability or pollution potential of an aquifer. The parameters are:

- Depth of groundwater (D);
- Recharge rate (R);
- the Aquifer media (A);
- the Soil media (S);
- Topography (T);
- the Impact of the vadose zone (I); and
- the hydraulic Conductivity of the aquifer (C)

Table 1 DRASTIC parameters assigned weights (Aller et al., 1987)

	Factor	Weight
D	Depth to top the of the Aquifer	5
R	Net Recharge	4
A	Aquifer Media	3
S	Soil Media	2
T	Topography	1
I	Impact of the Vadose Zone	5
C	Hydraulic Conductivity of the Aquifer	3

Each parameter is assigned a relative weight from one to five based on its relative susceptibility to pollutant (Shamsuddin, 2000) (Table 1). Similarly, parameter rankings are assigned on a scale of one to ten and are based on its significance to pollution potential in an assessed area (Dickerson, 2007) (Table 2 and 3).The set of variables that are considered for the DRASTIC model can be grouped according to three main categories: land surface factors, unsaturated zone factors and aquifer or saturated zone factors. The aquifer media properties and the hydraulic conductivity are the critical factors identified for the saturated zone. The depth to water and the properties of the vadose zone characterize the water/contaminant path down to the saturated zone (Dirk et al., 1997). In soil and the unsaturated zone, some mechanisms may affect the contaminant concentration much more than in the saturated zone (Gogu et al., 2000).

Table 2 Typical ranges and ratings of D, R and A

Depth to water (ft)		**Net recharge (Inch)**		**Aquifer media**		
Range	Rating	Range	Rating	Type	Rating	Typical Rating
0-5	10	0-2	1	Massive Shale	1-3	2
5-15	9	2-4	3	Metamorphic/igneous rocks	2-5	3
15-30	7	4-7	6	Weathered metamorphic/igneous	3-5	4
30-50	5	7-10	8	Thin bedded sandstone, limestone, shale sequence	5-9	6
50-75	3	>10	9	Massive Sandstone	4-9	6
75-100	2			Massive Limestone	4-9	6
>100	1					

Table 3 Typical ranges and ratings of S, T, I and C

Soil media		**Topography (percent slope)**		**Vadose zone media**			**Hydraulic Cond. (GPD/FT^2)**	
Range	Rating	Range	Rating	Range	Rating	Typical Rating	Range	Rating
Thin or absent	10	0-2	10	Silt, clay	2-6	3	1-100	1
Gravel	10	2-6	9	Shale	2-5	3	100-300	2
Sand	9	6-12	5	Limestone	2-7	6	300-700	4
Peat clay	8	12-18	3	Sandstone	4-8	6	70-1000	6
Shrinking or aggregated clay	7	>18	1	Bedded limestone, sandstone, shale	4-8	6	1000-2000	8
Sandy Loam	6			Sand and gravel with significant silt and clay	4-8	6	>2000	10
Loam	5			Metamorphic/igneous	2-8	4		
Silt loam	4			Sand and gravel	6-9	8		
Clay loam	3			Basalt	2-10	9		
Humus	2			Karst limestone	8-10	10		
Non-shrinking and non-aggregated clay	1							

The DRASTIC Index was computed by summing the weighted factors of each subdivision of the area. Generally, higher DI value indicates greater susceptibility to groundwater pollution

$$DrasticIndex = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \quad (1)$$

Using the above equation, DRASTIC index values were obtained. According to the ranges, the degree of vulnerability of each area was concluded; a groundwater vulnerability map was then designed to show the vulnerability toward contamination of each area.

3.2. Data acquisition

Information about the seven parameters and all the necessary data were obtained from Daqing Tamtsag Co.,Ltd of China Petroleum. The data, in text (.doc), table (.xsl), drawing (.dwg), and ESRI shapefile (.shx, .dbf and .shp) formats include:

- Hydrogeological Reconnaissance report
- Geographical Prospecting Report on Underground Water Resources
- Hydrogeological Map of Hydrogeological Survey for Block 19 in Tamtsag Basin
- Underground Water Level Contour Map
- Underground Water Chemical Type diagram
- Well logs
- Aquifer roof elevation isoline diagram

These data are the result of different survey made by the Mining Group Co., Ltd. of Heilongjiang Province on the demand of Petrochina Daqing Tamtsag of China Petroleum. The works were undertaken between June 2007 and November 2008. Some of the data were ready to use but some others were in Chinese and needed a translation to English. Due to time constraint and the location of the study area, it was not possible to go to the site. However, a travel to Daqing was done in order to acquire technical advisory from knowledgeable individuals working for the Daqing Company. During the data manipulation, a close contact with a technical advisor from the company was necessary for the confirmation of the estimation of certain parameters.

Other information includes the Soil Map of the People's Republic of Mongolia and the Atlas of Mongolia which were published by the European Commission Joint Research Center (JRC) and the U.S Northern Circumpolar Soils Map respectively.

3.3. Development of the DRASTIC parameters

Factor 1: Depth to water

Depth to water refers to the distance the contaminant travels before reaching the aquifer. Hence, it gives an insight of the contaminant's contact time with the surrounding media. Due to the presence of confining clay layers, the aquifer in the study area is classified as a confined aquifer. For a confined aquifer depth to water refers to the depth to the top of aquifer (DTTA). Because of the low permeability of the confining media, the contaminants travel to the aquifer is retarded; potential pollutants released from the ground surface cannot reach the aquifer easily. Therefore, confined aquifers have more natural protection from contaminants and are less vulnerable to pollution than unconfined aquifers. As the degree of confinement decreases, the pollution potential of the aquifer increases.

The depth to the top of the aquifer feature was obtained by combining the contour map of the ground elevation with that of the top of the aquifer (Eq.2).

$$DTTA = \text{Groundwater elevation} - \text{Top of the Aquifer elevation} \quad (2)$$

The resulting map has shown that the DTTA varies between 179.7m and 280.6m which implies that most of the underground water in the study area is deep water.

Factor 2: Net recharge

Net Recharge represents the amount of water per unit area of land penetrating the ground surface and reaching the water table. It is thus influenced by the amount of surface cover, the slope of the land surface, the permeability of the soil and the amount of water that recharge the aquifer. The dispersion and dilution of contaminants depend greatly on the volume of water available in the vadose zone as well as in the saturated zone and thus on the net recharge. Additionally, the recharge water has the ability to carry contaminants to the water table and within the aquifer. Hence, a great recharge corresponds to a high potential for groundwater pollution. Net recharge is thereby an important factor in the contamination attenuation and is given a weight of 4. Regarding to the net recharge, the pollution potential of an area with confined aquifer is lesser than that of an unconfined one because of the presence of a confining layer.

The primary source of ground water is precipitation which infiltrates through the surface of the ground and percolates to the water table. Because the deep underground water in the project zone is isolated by the aquiferous stratum roof, the vertical infiltration of the local atmospheric precipitation replenishment cannot be directly received. Thus, the aquifer mainly receives the lateral flow replenishment from the upper reaches. The replenishment source of the Quaternary underground water of the study area and the replenishment mainly come from the jacking from the deep underground water to the top aquiferous stratum. The methodology prescribes that in this case, the recharge is negligible. Low recharge values were thereby chosen for aquifer.

Values of the net recharge are more difficult to obtain than the values of the six other parameters. As suggested by the model, more accurate estimates of net recharge should be done based on the available features which are believed to be important to the recharge component. The values were thus generated using the estimation formula that Piscopo established in 2001 and that Al-Adamat et al. applied in 2003 for their study of the Azraq basin, Jordan. Nevertheless, for the purpose of this study, the weighting factor of the normal DRASTIC was kept as all the parameters constituting the model were used. Because the major underground water resource volume in the zone is replenished with lateral runoff, the recharge map was constructed according to the following formula:

$$\text{Recharge value} = \text{Slope}(\%) + \text{Rainfall} + \text{Soil permeability} \quad (3)$$

Table 4 Range and factors of the features controlling the recharge value (Piscopo, 2001)

Slope		Rainfall		Soil permeability	
Slope (%)	Factor	Rain (mm)	Factor	Range	Factor
<2	4	>850	4	High	5
2–10	3	700–850	3	Mod-high	4
10–33	2	500–700	2	Moderate	3
>33	1	<500	1	Slow	2
				Very slow	1

First, a digital elevation model of the study area was generated from the 1m elevation contour map. Using the "surface analysis" function of the 3D analyst tool, the slopes values were deducted from the DEM and then classified according to the criteria cited in table 4. The slope values of the study area vary between 2 and 4% while the infiltration replenishment by precipitation is very slow, the annual evaporation being 5-7 times of the annual precipitation. The average rainfall of the study under investigation is 276.4mm (<500mm). With careful attention to the specific features of the study area cited in the above paragraphs, the soil permeability was estimated based on the typical classification of permeability given in table 5.

The next step consisted of classifying the soil permeability map into four classes: very slow (26%), slow (53%), moderate (16%) and high (5%). The thus obtained map was converted into grid coverage; then, a raster addition was performed using the 3D analyst tool of ArcGIS. The result which ranges from 3 to 10 was classified into ranges according to table 2.The final map of the net recharge was obtained by assigning the rating values as new values for each reclassified range.

The aquifer media has been chosen as the starting parameter because on it depend the values chosen for the other parameters. The aquifer medium determines the materials with which, the contaminant is in contact in the aquifer. Hence, it plays a significant role in the concentration attenuation process. Besides, it governs the groundwater flow system and consequently, affects the route and path length that the contaminant follows. These factors are important because they give an insight into the chance for the attenuation processes to occur. The pathways for groundwater flow are strongly influenced by the grain size of the medium, fractures or openings within the aquifer. The presence of a fracture implies a higher contamination potential because of the degree of secondary permeability it provides. Larger grain size and more fractures or openings imply a higher permeability and thus, a lower pollution attenuation capacity. Similarly, the presence of clay materials in the aquifer lowers the pollution potential. Hence, the rating for each aquifer medium was evaluated based on the specific features of the aquifer.

Table 5 Typical values of permeability (Cashman et al., 2001)

Soil type	Typical classification of permeability	Permeability (m/s)
Clean gravels	High	$>1 \times 10^{-3}$
Clean sand and sand/gravel mixtures	High to moderate	1×10^{-3} to 5×10^{-4}
Fine and medium sands	Moderate to low	5 x 10-4 to 1 x 10-4
Silty sands	Low	1 x 10-4 to 1 x 10-6
Sandy silts, very silty fine sands and laminated or mixed strata of silt/sand/clay	Low to very low	1 x 10-5 to 1 x 10-8
Fissured or laminated clays	Very low	1 x 10-7 to 5 x 10-9
Intact clays	Practically impermeable	>5 x 10-9

Factor 3: Aquifer media

Based on the geological description of the study area, there are two major aquiferous rock formations: Pre-Quaternary debris rocks and Quaternary loose rocks. The aquiferous stratum consists of medium-fine sands, with a thickness of 4-8 m. The Pre-Quaternary debris rocks are generally distributed in the study area; they consist of middle fine sandstone, medium coarse sandstone and medium sandstone. The map for the Aquifer media ranking was obtained from an interpolation of the lithology of the aquifer of each borehole. The typical ratings for aquifer media given in table 2 were not used; the rating for each medium was adjusted based on the characteristic of the zone. Higher ratings were chosen to indicate the presence of the North-South tectonic fault situated at the eastern part of the study area, the amount of fines and the clay within the aquifer. Conversely, lower ratings were assigned to the fine textured media

Factor 4: Soil media

Soil is the first media the contaminant passes through when it percolates into the ground. Therefore, soil media influence strongly the recharge which percolates into the ground and hence, the contaminant movement. Several attenuation processes can happen within the soil media, namely filtration, biodegradation, sorption and volatilization. These processes depend greatly on the thickness of the media and the material the contaminant is in contact with (type, texture…). Fine textured materials such as silts and clays restrict contaminant migration as they decrease the soil permeability. Similarly, a thick media offers greater chance for the attenuation processes to occur.

Soil ranking distribution was inferred from the soil map of the People's Republic of Mongolia, the Atlas of Mongolia and the written descriptions of the soil cover.

Most of the working area is covered by sand soil with different thicknesses in some areas, and the area has a high sandy degree. According to strata lithologic array, the top is the quarternary silty sand soil and silty clay with partial sandy layer, with the tertiary and cretaceous mudstone, sandstone, medium-sized coarse sandstone and interbedded fine sandstone at the bottom. These horizons of the soil profile were evaluated and the most significant textural layers which can affect the pollution potential were chosen for each zone. For the area where clay layer is the most significant soil texture, the shrink/swell potential was evaluated. The shrink/swell potential is important as it influences the transport of contaminants. Because the soil complexes were not particularly detailed, it was not possible to determine the degree of the shrink/swell potential. However, the drilling samples showed that the surface soils of the drilling samples have a very high hardness and are in a compact state. Thereby, a DRASTIC range of shrinking and aggregated clay was assigned to the clayey areas, as recommended by the methodology for soil with a moderate shrink/swell potential.

Factor 5: Topography

Even if topography is given the lowest weight (1), it has a relative significance as it controls the time during which contaminants remain on the surface. Topography expresses the slope and slope variability of the land surface. A high degree of slopes increases the runoff capacity. As the infiltration probability of contaminant is lessened, the groundwater pollution potential decreases. The topographic unit of the study area is a plateau area, and it belongs to a relatively flat area in Mongolia. It is characterized by a wavy plain relief: The overall topography of the project zone is high in the eastern and southwestern parts have a high topography while the northwestern part is low. The altitude varies between 618 and 717 m and the slopes range from 0 to 4.8%. Since the study area is relatively flat, the range 0 to 2% slope is predominant.

The mapping of the topography was the easiest process because the data required for this parameter were easy to find and didn't need many modifications. The slope map was generated using 3D analyst tool of Arcmap.

Factor 6: Impact of the vadose zone

The vadose zone is the portion of the subsurface in which granular openings are unsaturated or discontinuously saturated. The behavior of contaminants in the vadose zone is a key element in pollution attenuation as the media is the home to many natural organisms which break down many polluting substances into secondary by-products both harmful and harmless. Various attenuation processes may occur between the soil horizon and the water table; namely: biodegradation, neutralization, mechanical filtration, chemical reaction, volatilization and dispersion. The type of vadose zone is thereby of great importance because it determines the contact time for reaction to occur as it influences the path length and the routing of contaminants.

Regardless the presence of other layers composing the media, confining layer was chosen as the vadose zone media since the purpose of the study was to evaluate the confined aquifer. This is highly important because the confining layer is the media which most significantly impacts pollution potential.

Factor 7: hydraulic conductivity

The hydraulic conductivity of an aquifer is a measure of the aquifer's ability to transmit water when submitted to a hydraulic gradient. It is a critical factor because it controls the velocity of groundwater flow; which in turn controls the velocity of contaminant flow within the aquifer. An aquifer with high conductivity is vulnerable to substantial contamination as a plume of contamination can move easily through the aquifer (Rahman A., 2007). Hence, areas with high hydraulic conductivity values are more susceptible to contamination.

Values for hydraulic conductivity estimates were based on well yields and aquifer characteristics because the maps of hydraulic conductivity for the study area were not available in published reports. Thus, the hydraulic conductivity maps were generated using two components of conductivity: transmissivity and saturated thickness based on the formula $T = K.b$ where T represents the transmissivity, K is the hydraulic conductivity and b the thickness of the aquifer

The procedure consisted of digitizing the contour lines of the aquifer thickness, hence creating a “DEM-like” surface image. The transmissivity maps were interpolated from pumping test data of some points of reference. The obtained values were divided by the aquifer saturated thickness on pixel-by-pixel basis using the Raster math tool of 3D analyst tool in ArcView. Generally, the study area has a low hydraulic conductivity (0.3x10-6 ~ 5.3x10-5 m/s). However, the central part of the aquifer has a higher conductivity compared to the rest of the study area.

3.4. Vulnerability mapping

A new raster data file for the DRASTIC Index was created according to Eq. 1 using the weighted sum overlay in spatial analyst tools using the 7 individual raster files created above. The first step was to consider the parameters one by one in order to calculate their respective index values. For each parameter the rating values were multiplied to the appropriate DRASTIC weight (table 1).

For all the parameters except the DTTA and the Impact of the vadose zone, the obtained index values were in raster format. For the DTTA, the rating value of the whole study area was equal to 1 and based on the weighting system; the result of multiplying Dr by Dw is equal to 5. Similarly, the net recharge index was obtained by multiplying I_r by I_w. 5 was obtained as a result and was also added to the total DRASTIC index as a constant value for all locations in the study area. In sum, a constant value of 10 was added to the final raster grid coverage. For the five remaining parameters, the values for each overlay were summed on pixel-by-pixel basis by running the model in ArcView GIS. The final raster for the Overall Vulnerability Index was created using the raster calculator in Spatial Analyst tools by combining the seven hydrogeological data layers as illustrated in figure 3.

Referring to Aller et al. (1987), the DRASTIC indexes were classified according to the ranges given in table 6. The final step of the vulnerability mapping consists of reclassifying the DRASTIC indexes and assigning to each group its degree of vulnerability; thereafter, groundwater vulnerability map was developed.

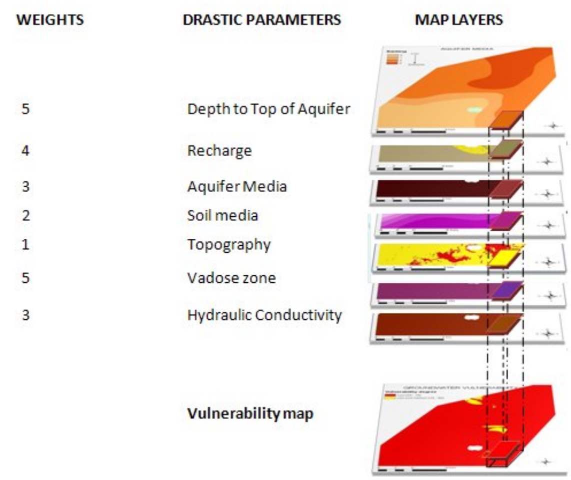

Figure 3 Vulnerability mapping

3.5. Sensitivity analysis

Sensitivity analysis (S.A) is a significant component of any modeling project as it allows evaluation of the accuracy of the result (Baker et al., 2005).

Map removal S.A

The map removal sensitivity analysis was performed to evaluate whether it was necessary to use all the parameters incorporated in the DRASTIC model. The sensitivity measure expressed in terms of variation index S is given by the formula:

$$S = \left(\frac{\left| \frac{V}{N} - \frac{V'}{n} \right|}{V} \right) \times 100 \qquad (4)$$

where V is the unperturbed vulnerability index which represents the actual index used in the primary suitability using N parameters. V’ is the perturbed vulnerability index while a lower number of parameters (n) were used.

The analysis comprised two studies. The first one was performed by removing only one layer at a time, considering each parameter constituting the DRASTIC model. This process aimed at evaluating the sensitivity of the vulnerability values upon the removal of the defined parameter. The second analysis consisted of removing a layer which compels less variation in the final vulnerability index. The thus obtained result was then used for the next removal analysis, and the same steps were followed until only one layer was left. For each new step, the layers assumed to be the most effective were considered each time (Babiker et al., 2005) while the least effective were removed. The computation was done taking into account every sub-areas of the study area. The sensitivity value S was calculated for each grid cell using the Raster math tool of GIS according to the above formula (Eq. 4).

Single parameter S.A:

The next step of the analysis was to compare the effective weight of each parameter in each subarea with the theoretical weight assigned to it by the DRASTIC method. For each grid square element, the effective weight Wpi (in %) was calculated using a theory developed by Lodwick et al. (1990) and effectively used by Napolitano and Fabbri (1996), Rahman (2008), Babiker et al. (2005) among others.

$$W_{pi} = 100 * \left(\frac{P_{ri} * P_{wi}}{DI} \right) \tag{5}$$

Where P_{ri} and P_{wi} are the ratings and the weights respectively of the layer P assigned to the subarea i, and D.I is the vulnerability index. Based on this formula, the effective weight of each subarea was computed using GIS. In the same way as the first analysis, the analysis covered the whole study area and a statistical analysis was performed using the proUCL software for the display and the analysis of the obtained results.

4. RESULTS AND DISCUSSION

4.1. Groundwater vulnerability map

Figure 4 contains examples of the rated maps used to compute the DRASTIC vulnerability index. Regarding to the net recharge, about 72% of the study area has a low contamination risk, 27% is moderately vulnerable and only the remaining 1 % belongs to high vulnerable class. The high vulnerable class is situated in the shallower aquifer in the north-western area. With regards to the aquifer media, the major part of the study area has a relatively high vulnerability index. The northern part of the study area has a relatively high VI. It can be attributed to the coarser grain size of the unit that serves as an aquifer. The vulnerability index associated with the aquifer media indicates that GW resources surrounding the tectonic fault are susceptible to pollution to a high degree.

With a special consideration of the soil media, about 80% of the study area has low or moderate vulnerability toward contamination while almost the whole area is highly vulnerable regarding the topography slope.

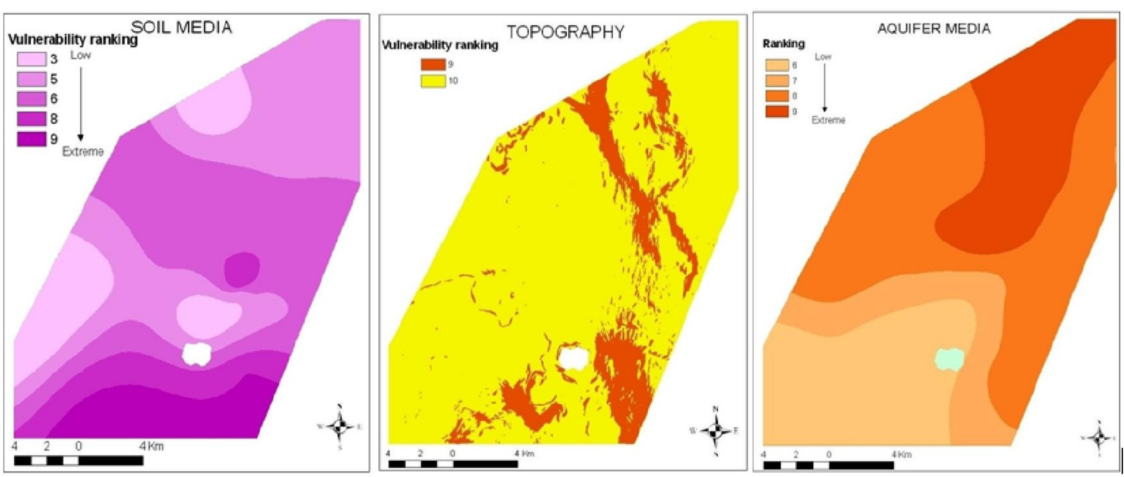

Figure 4 Examples of the rated maps of the DRASTIC parameters

The final integrated map of the groundwater vulnerable zones is presented in figure 5. The resulting DRASTIC values in the study area lay between 58 and 88. According to table 6, two classes of the vulnerability toward pollutants could be identified in the zone. In term of areal extent, almost 98 percent of the area was determined to have a low vulnerability toward contaminants. This can be associated to the presence of the confining layer as it is the media which significantly impacts pollution potential. Only a slight 2 percent, which is located in the water-rich area, are more susceptible to pollutants. These zones are located in the north-western part and at the middle-eastern part of the study area. The vulnerability map offers the possibility to select priorities for restoration and remediation actions in regional planning. It is important as the toxicological index of the area under investigation has shown that the content of Na, Mg, Cl and Mn in the underground water are seriously over standard. It highlights need of establishing underground dynamic observation points to control the behavior of these chemicals.

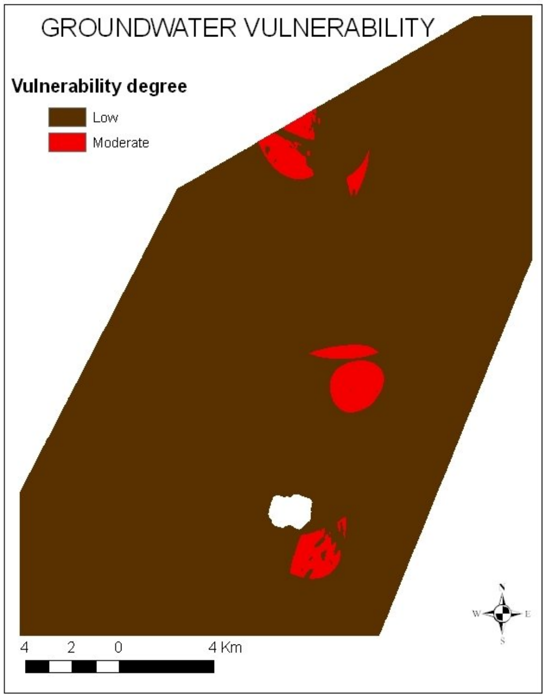

Figure 5 Groundwater vulnerable zones

4.2. Summary of the DRASTIC parameters

A statistical summary of the seven parameters incorporated in DRASTIC model and which were used for the study is presented in Table 7. It shows that aquifer media has the largest impact on the intrinsic vulnerability of groundwater as it has the highest mean (22.8). Then, it is followed by the net recharge (with a mean of 14.24), the soil media (mean = 11.54) and the topography (9.15). The result also reveals that impact of vadose zone and DTTA which have both a mean value of 5 have low contribution to vulnerability index while hydraulic conductivity contributes the least as it has smallest mean value (3.02). Regarding the contribution to the variation of the vulnerability index; a small variation of the net recharge would greatly affect the values of the vulnerability indexes. This is exhibited by the high value of the coefficient of variation associated to this parameter (70.26%). Changes in soil media and aquifer media values (mean = 38.5 and 17.21 respectively) would have moderate impact on the system whereas variation in hydraulic conductivity would barely impact the vulnerability map (mean value = 0.47). Depth to aquifer and the impact of vadose zone both having fix value do not impact the variation of the sensitivity measure.

Table 7 Statistical summary of the DRASTIC parameters map

	D	R	A	S	T	I	C
Min.	5	4	18	6	9	5	3
Max.	5	32	27	18	10	5	6
Mean	5	14.24	22.8	11.54	9.15	5	3.02
SD	0	2.99	3.87	4.77	0.71	0	2.12
CV (%)	0	70.26	17.21	38.5	7.44	0	0.47

SD = Standard Deviation CV = Coefficient of Variation

4.3. Map removal sensitivity analysis

The map removal sensitivity analysis was performed with the aim of establishing the significance of the parameters used for the DRASTIC model. The summary statistics of the map removal sensitivity analysis is displayed in table 8 and 9. Table 8 reveals that topography is the layer that affect least the variation in the final vulnerability index as the variation index has the least average value after its removal (= 0.23%). It is mainly due to the low contamination risk associated with topography (the mean rating value = 1). In contrast, a high variation of the vulnerability index is expected upon the removal of the aquifer media as this layer has the highest variation index (2.99%). It is mainly due to the presence of the tectonic South-North fault located in the eastern part of the study area which has a significant influence on pollution potential. In addition to the relatively high theoretical weight (3), aquifer media has high rating values in almost every subarea. Hydraulic conductivity removal also influences greatly the variation of the vulnerability assessment. It can be explained by the fact that the main recharge of the aquifer comes from lateral replenishment. The hydraulic gradient has therefore a significant impact on the fate of the travel of a plume of contaminant. The vulnerability index also seems to be sensitive to the removal of the impact of the vadose zone and the DTTA (their average variation indexes are both equal to 1.19). It could be attributed to the high theoretical weight (= 5) assigned to both of these layers. Moreover, the high mean value for the impact of the vadose zone confirms the fact that the confining layer is the media which most significantly impact pollution potential and thus the vulnerability of the aquifer; its removal will greatly impact the sensitivity measure of the area. The removal of the net recharge and soil media also have contributed to the variation of the sensitivity value of the aquifer; their mean value being 0.99 and 0.61 respectively.

Table 8 Statistical summary of one map removal sensitivity analysis

Parameters removed	Variation index (in percent)			
	Min	Max	Mean	SD
D	0.94	1.43	1.19	0.15
R	0.21	3.97	0.99	1.01
A	1.51	4.65	2.99	0.76
S	0	1.9	0.61	0.52
T	0	0.66	0.23	0.17
I	0.94	1.43	1.19	0.15
C	1.06	1.79	1.66	0.17

The variation of the sensitivity measure upon the removal of one or more maps from the computation is contained in table 9. It appears from the table that after the removal of the topography layer, the variation index has the least average value. This average variation index changes as more layer data are removed from the computation. However, there is no consistency on the trend of the mean variation index according to the number of parameters removed. This clearly demonstrates that all the seven parameters used to compute the DRASTIC model are all essentials in determining the vulnerability index.

Table 9 Statistical summary of the map removal sensitivity analysis

Parameters used	Variation index (in percent)			
	Min	Max	Mean	SD
D, R, A, S, I, C	0	0.66	0.23	0.17
D, R, A, I, C	0.03	2.26	0.71	0.62
D,A,I,C	0.05	4.22	1.63	1.14
A,I,C	0.06	3.94	0.74	1.29
A,C	0.64	9.15	3.55	3.02
A	6.39	10.75	9.72	1.82

4.4. Single parameter sensitivity analysis

The single parameter sensitivity analysis compares the theoretical weight assigned to a parameter by the DRASTIC model with its real (or effective) weight. The result summarized in table 10 indicates the importance that should be accorded to some factors, namely the aquifer media; soil media and topography. With an average weight of 31.83 against a theoretical weight equal to 23.38, aquifer media mostly influences the vulnerability index. This is in agreement with the result from the map removal analysis which also states that aquifer media is the layer that compel most the variation of the final V.I. The effective weights of soil media together with topography exceed the theoretical weight imposed by DRASTIC. Their mean effective weights (%) are 15.93 and 12.42 respectively while their respective theoretical weight assigned by DRASTIC are both less than 10%. This reflects the importance of the aquifer media, soil media and topography layers in the model and the need to get accurate, detailed and representative information about these factors. The net recharge almost conserves the weight that is assigned by the DRASTIC model: its real weight is just slightly greater than the theoretical weight. It is mainly due to the fact that in some portions of the aquifer, groundwater replenishment mainly comes from the jacking from the deep underground water to the top aquiferous stratum. Recharge of aquifer is thereby negligible in some parts of the study area. DTTA is the least important parameter as it exhibits a very low effective weight compared to the theoretical weight. This agrees with the basic assumption that depth to water is less important for confined aquifers.

Table 10 Statistical summary of the single parameter sensitivity analysis

Parameters	Theoretical weight	Theoretical weight (%)	Effective weight (%)			
			Mean	Min	Max	SD
D	5	21.7	6.68	5.68	8.62	1.12
R	4	17.4	19.52	5.97	38.09	9.52
A	3	13.0	31.83	23.38	42.19	5.72
S	2	8.7	15.93	6.82	25.71	5.98
T	1	4.3	12.42	10.34	17.24	2.45
I	5	21.7	6.68	8.62	5.68	1.29
C	3	13.0	3.91	3.53	7.89	1.58

4.5. Conclusion and recommendations

DRASTIC system and GIS were used to analyze the Regional groundwater pollution susceptibility of a part of block 19 of Tamtsag Basin, in Mongolia. Topography, well, geology, soil databases were designed and constructed for the application of the DRASTIC model. Using these databases, hydrogeologic factors such as depth to water, net recharge, aquifer media, soil media, slope, hydraulic conductivity were extracted. The DRASTIC vulnerability index, which is defined as a linear combination of seven hydrogeological factors was computed with the help of GIS. The aquifer vulnerability map indicated that only 2% of the study area is under moderate vulnerability to contamination. The remaining zone was determined to be in a low risk category. GIS greatly facilitated the implementation of the sensitivity analysis applied on the DRASTIC vulnerability index which otherwise could have been impractical. The single-parameter sensitivity analysis has shown that aquifer media, soil media and topography are the most significant environmental factors which dictate the high vulnerability of the study area. This highlights the importance of obtaining accurate, detailed, and representative information about these factors. The map removal sensitivity analysis indicated that the vulnerability index is highly sensitive to the removal of aquifer media, hydraulic conductivity and the impact of vadose zone layers but is least sensitive to the removal of the topography layer. The analysis has also demonstrated that all the seven parameters used to compute the DRASTIC model are all essentials in determining the vulnerability index.

Often only a portion of the groundwater in storage may be exploited without creating undesirable effects. Ground water pollution vulnerability maps, risk maps, groundwater quality maps etc may be used to assist planners, managers, and local officials in evaluating the potential for contamination from various sources of pollution. These maps are useful as preliminary screening tools for policy and decision. To keep groundwater resource sustainability, a reasonable management of the resource should be put forward based on the groundwater resource evaluation and groundwater vulnerability assessment. Therefore, the present vulnerability maps should be regarded as an important tool in prioritization of areas for monitoring purposes. Some precautionary measures should be taken for the more vulnerable zones and detailed study of the groundwater pollution should be carried out if necessary. Additionally, the study suggests that special consideration such as a denser monitoring system should be given to the zones with higher vulnerability. Knowing the vulnerable areas, users can recommend settings that are suitable for the areas which are critical to groundwater contamination.

Groundwater pollution susceptibility assessment is also necessary for systematic management and protection of groundwater resources in the study area for further works and projects (land use, well construction and abandonment for instance). It is suitable to evaluate the impact of a potential pollution source on the aquifer, not only for the oilfield exploitation but also for industries, storage areas, livestock rearing establishments, and any new development proposals in any locality within the same area of study. Although the vulnerability map showed the dominance of “low” vulnerability class, the results suggest that great care should be taken when sitting developments in the moderate vulnerability areas. Without attention, prospecting and exploiting tasks would change the hydraulic balance between the various natural strata; which will cause a connection of underground water of different qualities. This can be a shortcut to artificial pollution.

Due to the large amount of salts in the underground water, negligence in water pollution and prevention might cause a serious soil compaction, land salinization and also a potential harm to the surface soils.

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Corresponding author:
FANOMEZANTSOA Hasiniaina
School of Environmental Studies, **C**hina University of Geosciences (Wuhan)
Lumo Road 388, Wuhan City, 430074
Hubei Province, P.R. China.
E-mail:hasiniainaf@hotmail.com

REFERENCES

1. Ali El-Naqa, Nezar H. and Mustafa K., 2006: GIS-based evaluation of groundwater vulnerability in the Russeifa area, Jordan. Revista Mexicana de Ciencias Geológicas, v. 23, núm. 3, 2006, p. 277-287
2. Aller L., Bennett T., Lehr J.H., Petty R.J. and Hackett G., 1987: DRASTIC: a standardized system for evaluating ground water pollution potential using hydrogeologic settings, United States Environ Prot Agency, Ada, Oklahoma 74820, EPA 600/2-85/018, 455p.
3. Babiker I.S., Mohamed Mohamed A. A.; Hiyama Tetsuya; KATO. 2005: A GIS-based DRASTIC model for assessing aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture, central Japan. Sci Total Environ 345:127–140.
4. Batsukh N (2000) Resource and optimal utilization of fresh groundwater of Mongolia. Summary of papers on groundwater. Novosibirsk
5. Bengtsson, M.L. and L. ROSEN, 1995: A probabilistic approach for groundwater vulnerability assessment. Proceedings of the XXVI International Congress of the IAH "Solutions 95", Edmonton (Canada), June 4-10.
6. Berkhoff K., 2008: Spatially explicit groundwater vulnerability assessment to support the implementation of the Water Framework Directive – a practical approach with stakeholders. Hydrol. Earth Syst. Sci., 12, 111–122,
7. Carter A.D., Palmer R.C. and Monkhouse R.A. (1987) Mapping the vulnerability of groundwater to pollution from agricultural practice, particularly with respect to nitrate. In: Duijvenbooden, W., Waegeninghm HG. (eds)

Vulnerability of soil and groundwater to pollutants. TNO Committee on Hydrological Research, The Hague, Proc Info, 38, pp.333–342
8. Cashman P. M. and Preene M., 2001: Groundwater lowering in construction: a practical guide.USA and Canada
9. Crosetto, M. And S. Tarantola, 2001: Uncertainty and sensitivity analysis: tools for GIS-based model implementation. International Geographical Information. Science, 15, 5, 415-437.
10. Delleur J. W.1999. The Handbook of Groundwater Engineering. CRC Press LLC.USA.
11. Dickerson R.J., 2007: A modified drastic model for siting confined animal feeding Operations (CAFOS) in Williams county, Ohio. Thesis Submitted to the Graduate College of Bowling Green State University
12. Dirk De K., Marco C.,Marco C., Roberto P.,Ayed A., Abdullah B. M. And Yacine M., 1997: A computerized methodology for aquifer vulnerability mapping: Mean Sea Level aquifer, Malta and Manouba aquifer, Tunisia. Karst Hydrology (Proceedings of Workshop W2 held at Rabat, Morocco, April-May 1997) IAHS Publ. no. 247, 1997. 81.
13. Dolgorsuren G., 2007: Current situation of water resources management in Mongolia."Sub-Regional Preparatory meeting of North-East Asia for the 5th World Water Forum". Beijing,China
14. Edet A.E., 2004: Vulnerability evaluation of a coastal plain sand aquifer with a case example from Calabar, southeastern Nigeria. Environmental Geology (2004) 45:1062–1070
15. Fisher, B. E. A., M. P. Ireland, D. T. Boyland and S. P. Critten, 2002: Why use one model? An approach for encompassing model uncertainty and improving best practice. Environmental Modeling and assessment 7. Kluwer Academic Publishers, pp. 291-299.
16. Fritch, T. G., McKnight, C. L., Yelderman Jr, J. C., & Arnold, J. G. (2000). An aquifer vulnerability assessment of the paluxy aquifer, central Texas, USA, using GIS and a modified DRASTIC approach. Environmental Management, 25, 337–345.
17. Gogu, R.C., & Dassargues., A., 2000 : Current trends and future challenges in groundwater vulnerability assessment using overlay and index methods. Environmental Geology, 39 (6):549-559
18. Heuvelink, G. B. M., 1998: Error propagation in environmental modeling with GIS. Taylor & Francis.
19. Kalinski R., W. Kelly, I. Bogardi, R. Ehrman And P. Yamamoto, 1994: Correlation between DRASTIC vulnerabilities and incidents of VOC contamination of municipal wells in Nebraska. Ground Water, 32, 1, 31-34.
20. Knox, R. C., Sabatini, D. A., & Canter, L. W., 1993: Subsurface transport and fate processes. USA: Lewis Publishers.
21. Lanter, D. and H. Veregin, 1992. A research paradigm for propagation error on layer-based GIS. Photogram. Eng. Rem. Sens., 58, 825-883.
22. Liang He, Zhou A., Sun A. and Zhang Q.: The groundwater vulnerability assessment methods research and application in Nanchang city. (found at http://old.cgs.gov.cn/zt_more/34/zhaiyao/html/09/926.htm)
23. Lodwick, W.A., W. Mouson and L. Svoboda, 1990: Attribute error and sensitivity analysis of map operations in geographical information system: Suitability analysis. Int. J. Geographical Inf. Sys., 4(4): 413-428.
24. Lynch, S. D., 1994: Preparing input data for a national scale groundwater vulnerability map of Southern Africa. http://www.ccwr.ac.za/~lynch2/drastic.html.
25. Miller G.T Lynch, 2004: Living in the environment, thirteenth edition. Brooks/Cole.
26. Napolitano P. and A.G. Fabbri. 1996: Single-parameter sensitivity analysis for aquifer vulnerability assessment using DRASTIC and SINTACS. Proceedings of the Vienna conference on HydroGIS 96: Application of geographic information system in hydrology and water resources management. IAHS Pub. No., 235:559-566.
27. Napolitano, P., 1995, GIS for aquifer vulnerability assessment in the Piana Campana, southern Italy, using the DRASTIC and SINTACS methods: Enschede, The Netherlands, International Institute for Geo-Information Science and Earth Observation (ITC), unpublished M.Sc. Thesis, 172 p.

28. Navulur, K. and B. ENGEL, 1996: Predicting spatial distributions of vulnerability of Indiana state aquifer systems to nitrate leaching using a GIS. Proc. 3rd International Conference/Workshop on integrating GIS and Environmental Modeling, Santa Fe, New Mexico, 23-25 January CD ROM, (can be found at www.sbg.ac.at/geo/Idrisi/GIS_Environmental_Modelling/sf_papers/navulur_kumar/my_paper.html)
29. Office of the Science Advisor, 2009: Guidance on the Development, Evaluation, and Application of Environmental Models. EPA/100/K-09/003.
30. Piscopo G., 2001: Groundwater vulnerability map, explanatory notes, Castlereagh Catchment, NSW. Department of Land and Water Conservation, Australia.
31. Piteau Associates Engineering Ltd. October, 1993: Groundwater Mapping and Assessment in British Columbia. Volume II. Government Publications Order No. 7680000650.
32. Ran Al-Adamat, IDL Foster, SMJ Baban, 2003: Groundwater vulnerability mapping for the Basaltic aquifer of the Azraq basin of Jordan using GIS, Remote Sensing and DRASTIC. Applied Geography, 23(4), 303-324
33. Remesan R. and R.K. Panda, 2008: Remote Sensing and GIS Application for Groundwater Quality and Risk Mapping. The 3rd International Conference on Water Resources and Arid Environments and the 1st Arab Water Forum.
34. Rubhera R.A.M. M., 2002.Groundwater Pollution in Urban Dar es Salaam, Tanzania: Assessing Vulnerability and Protection Priorities.pp.101-137
35. Tintera J.J and Savage L., 2005: Effects of Oil and Gas Production on Groundwater. Texas Water Development Board Reports. Groundwater resources division.
36. USA-National Research Council, 1993: Groundwater Vulnerability Assessment: Predicting relative contamination potential under conditions of uncertainty. National Academy Press, Washington, D.C.
37. Valérie M., Alfonso R., Jacynthe P., Marcelo M. S. and Martine M. S. 2004: Aquifer vulnerability mapping and GIS: A proposal to monitor uncertainty associated with spatial data processing. Geofísica Internacional (2004), Vol. 43, Num. 4, pp. 551-565
38. Wang Y., Merkel B. J., Li Y., Ye H., Fu S. and Ihm D., 2007: Vulnerability of groundwater in Quaternary aquifers to organic contaminants: a case study in Wuhan City, China. Environmental Geology (2007) 53:479–484
39. WWF Mongolia Programme Office. Jan.2007: Freshwater Issues in Mongolia and WWF Mongolia’s planned contribution towards a solution.
40. Yu S., Lu J. and Sun G., 2003: Impact Of Oil Field Exploitation On Eco-Environment Of The Daqing Lakes. Chinese Geographical Science, Volume 13, Number 2, pp. 175 - 181, 2003.
41. Zaporozec A. et al. 2002: Groundwater contamination inventory- a methodological guide. IHP-VI, series on groundwater No.2. UNESCO

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