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A GIS-based EPIK Model for Assessing Aquifer Vulnerability in Irbid Governorate, North Jordan

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ABSTRACT

Vulnerability assessment has become an important element for wise resource management and land use planning. This work examined the sensitivity of karstic aquifers, in the area of Irbid governorate northwest Jordan, to surface contamination by applying the EPIK method, and then compared this susceptibility evaluation to water-chemistry data collected from wells and springs within the area. An additional objective was to demonstrate the combined use of the EPIK and geographical information system (GIS) as an effective method for groundwater pollution risk assessment.

Using this method of investigation, the pollution susceptibility map classifies 3% of the study area as having low pollution susceptibility, 63% as having moderate pollution susceptibility, 33% as having high pollution susceptibility, and 1% as having very high pollution susceptibility. The northern and southern parts of the study area were dominated by very high and high vulnerability classes; while the eastern and western parts were characterized by moderate vulnerability classes.

When comparing these modeling results to water-chemistry data from wells within the study area, two samples with the highest concentration of major cations and anions are found within regions of high pollution potential, and many wells with high nitrate contamination are found within regions of moderate pollution potential. This confirms the usefulness of the predictive modeling approach for assessing aquifer pollution susceptibility. Excessive concentrations of chemicals in water samples are explained by the intensive agricultural activities and wastewater contamination. The GIS technique has provided efficient environment for analyses and high capabilities of handling large spatial data.

KEYWORDS: Vulnerability, Groundwater, EPIK, GIS, Irbid.

INTRODUCTION

Jordan is known for its very limited surface and groundwater resources. While development activities in agriculture, industry, housing and tourism sectors are an economic imperative, it is equally true that there are adverse environmental impacts. These activities have led to increasing water use and overexploitation that caused a serious deterioration of water quality. One important impact is the increasing levels of chemical and biological water quality parameters in many of the shallow springs in central and northern Jordan (Kolb et al., 2004). Nitrate contents of more than 100 mg/L and the increasing mineralization of the groundwater in some of the

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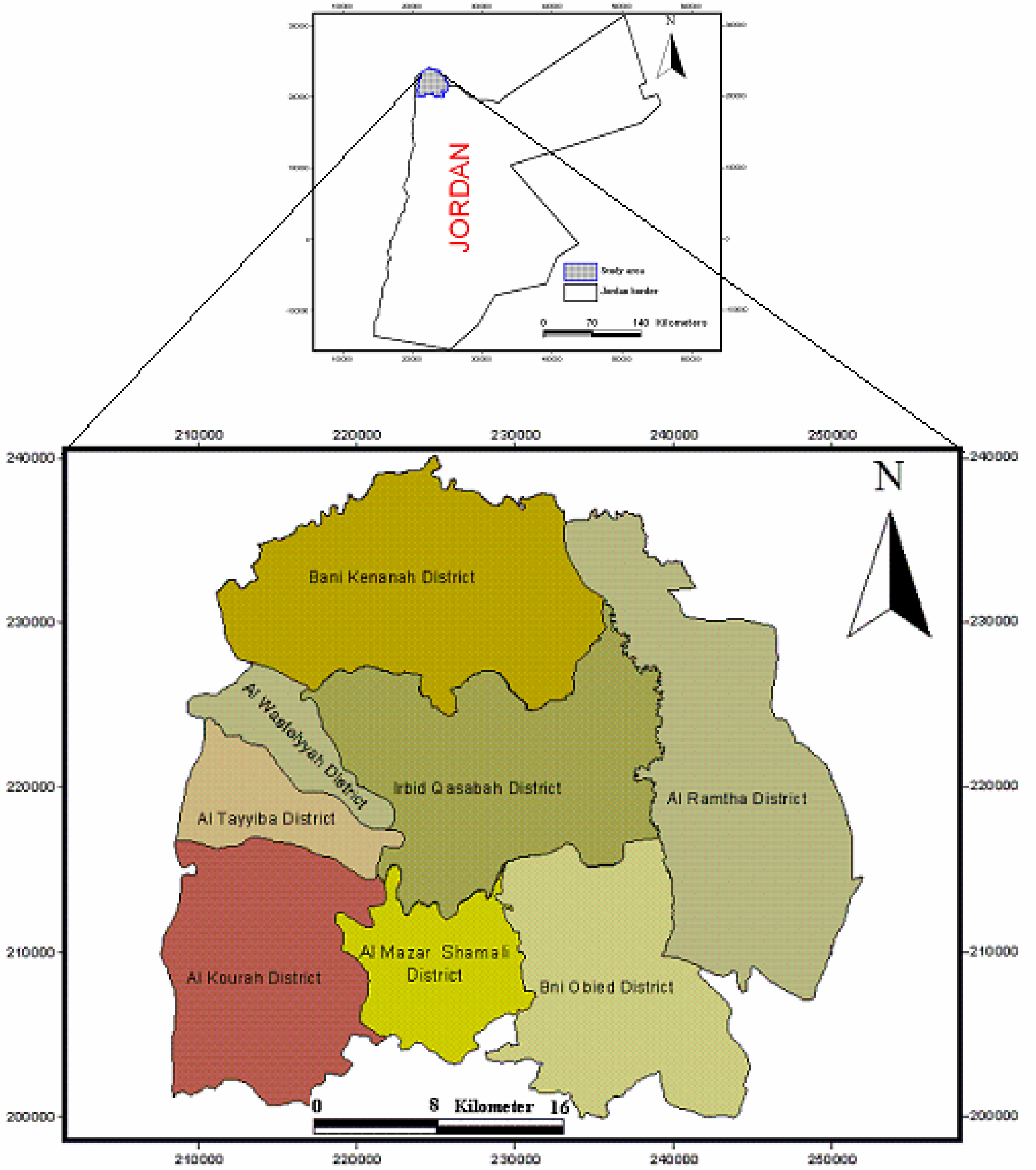
intensively cultivated areas indicate that groundwater is already polluted to an alarming extent (Margane et al., 1999). Wastewater dominates as the source of pollution, while urban runoff, fertilizers from agricultural return flows and solid waste disposal were found to be secondary sources (Kolb et al., 2004). Pollution sources are non-point making the identification of specific source locations and mitigation measures difficult. The karst hydrogeology in the area adds complexity to an already complicated situation (Margane et al., 1999).



Fgure (1): Location map of the study area.

Table (1): EPIK Vulnerability Classes and Protection Zones Based on Protection Factors.

Protection Factor (Fp)	Vulnerability Class
Fp < or = 19	Very high
Fp = 20 – 25	High
Fp > 25	Moderate
Presence of P4	Low

Vulnerability maps can serve as a tool for land use management as they show areas of potential groundwater contamination and identify areas of high natural protection against pollution based on geological and hydrogeological conditions. Areas with a better natural protection of the groundwater against pollution could be suitable as locations for industrial areas, wastewater treatment plants and waste disposal sites. However, more detailed studies of the geological and hydrogeological conditions are a requirement in order to ensure the suitability of a particular site for a specific use. The assessment of vulnerability takes into account parameters (geological and hydrological) that are important for groundwater pollution mapping. Such simplifications allow for an assessment of groundwater vulnerability of large areas at relatively low cost and in a comparatively short amount of time. Studies of the specific vulnerability could then be performed at a later stage in sensitive areas, where groundwater pollution is expected to occur in the near future or already exists.

Irbid area in the northwestern part of Jordan was selected as the study area, where part of the area is intensively cultivated and industrial development is expected to increase rapidly.

The EPIK method was used, which is especially developed for karst aquifers (Doerfliger and Zwahlen, 1998) to assess the intrinsic vulnerability of groundwater contamination potential. The resulting vulnerability map was tested against hydrochemical data (groundwater quality data) to assess the potential risk of groundwater to pollution.

STUDY AREA

The study area, situated in the extreme northwestern part of Jordan, covers about 1330 square kilometers and comprises Irbid governorate with all its districts except Al-Aghwar Al-Shamaliyah district (Figure 1).

Irbid governorate is one of the most developed regions in Jordan, and was recently announced by his Majesty King Abdullah II as a Zone of Economic Development. The urbanized areas are mainly located in the middle and northeastern parts of the study area and are characterized by a high population density, while in the remaining parts of the study area the low population communities are sparsely distributed. The climate of the study area is Mediterranean with more than 370 mm mean annual rainfall that is decreasing gradually from the west (450 mm/year) to the east (200 mm/year). Mean winter air temperature ranges from 5 to 9 °C, and mean summer air temperature ranges from 22 to 29 °C (Khresat et al., 1998). The topographic features are variable with elevations ranging from less than 150 m below sea level in the lower Yarmouk Valley in the north up to about 1000 m near Ajlun area in the southern part, and from about 500 m in the eastern parts to lower than zero below sea level in the western highlands. The west and north facing scarp slopes are deeply dissected by perennial or intermittent wadis that flow into the Jordan Valley and Yarmouk River (Margane et al., 1999).

Hydrogeologically, the study area is divided into two main aquifer systems; the Upper Cretaceous Amman-Wadi Es Sir B2/A7 Aquifer and the Tertiary Umm Rijam and Wadi Shallala B4/B5 Aquifer systems. The B2/A7 Aquifer forms the most important aquifer in the southern part of the study area and is the main water supplier for Irbid governorate and its surrounding areas, while the B4/B5 Formation is the uppermost shallow aquifer underlain by thick (B3) marly limestone aquitarde in the northern part of the area. The study area is mainly dominated by sedimentary rocks of Upper Cretaceous to Quaternary in age. The sediments comprise mainly sandstone, limestone, chalk, chalky limestone, chalky marl, chert, bituminous marls, phosphate and phosphatic chert (The Natural Resources Authority, 2000).

METHOD

The concept of groundwater vulnerability to contamination is a useful tool for environmental planning and decision-making. A vulnerability map identifies areas susceptible to contamination and enables the design of monitoring networks. The concept of groundwater vulnerability is based on the assumption that the physical environment may provide some degree of protection to groundwater against the natural and human impacts, especially with regard to contaminants entering the subsurface environment. Water infiltrating at the land surface may be contaminated but is naturally purified to some degree as it percolates through the soil and other fine grained materials in the unsaturated zone (Vrba and Zaporozec, 1994) that act as natural filters. Therefore, some areas are more vulnerable to groundwater contamination than others. Vulnerability assessment requires a complete knowledge of hydrogeological and hydrochemical data and location of potential contamination sources (Hötzl et al., 2004).

Table (2): Ratings for the classes of the Epikarst parameter (Doerfliger and Zwahlen, 1998).

Epikarst	Ratings	Karst morphological features
Highly developed (E1)	1	Shafts, sinkholes or dolines (from all kinds of genesis), karren fields, cuesta, outcrops with high fracturing) along roads and railways, quarries).
Moderately developed (E2)	3	Intermediate zones in the alignment of dolines, dry valleys. Outcrops with medium fracturing.
Small or absent (E3)	4	No karst morphological phenomena. Low fracture density.

Table (3): Ratings for the attribute classes of the protective cover (Doerfliger and Zwahlen, 1998).

Protective cover	Ratings	Characterisation	
		Soil lying directly on limestone or on some high permeability coarse detritus layers, e.g. rock debris lateral glacial tills.	Soil lying on low permeability geological layers, e.g. lake silt, clays.
Absent P1	1	0-20 cm of soil	0-20 cm of soil on layers that have a thickness of less than 1 m.
↓ P2	2	20-100 cm of soil	20-100 cm of soil on layers that have a thickness of less than 1 m.
P3	3	100-200 cm of soil	<100 cm of soil or >100 cm of soil and >100 cm of layers of low permeability.
Present P4	4	> 200 cm	>100 cm of soil and thick detritus layers of very low hydraulic conductivity or >8 m of clay and clayey silt.

Vrba and Zaporozec (1994) distinguished two types of vulnerability: intrinsic (or natural) which was purely defined as a function of hydrogeological factors, and "specific" that is related to specific pollutants, such as agricultural nitrate, pesticides or atmospheric deposition. Groundwater hazards are defined as potential sources of contamination resulting from human activities taking place mainly at land surface (Hötzl et al., 2004).

Many methods have been proposed for vulnerability mapping of aquifers as given in Gogu and Dassargues (2000) and previously in Vrba and Zaporozec (1994), among which are; DRASTIC (Aller et al., 1987); EPIK

(Doerfliger and Zwahlen, 1998); GLA-method (Hölting et al., 1995) and its modification, called PI method (Goldscheider et al., 2000); GOD (Foster, 1987); SINTACS (Civita, 1994); and AVI (Van Stempvoort et al., 1993).

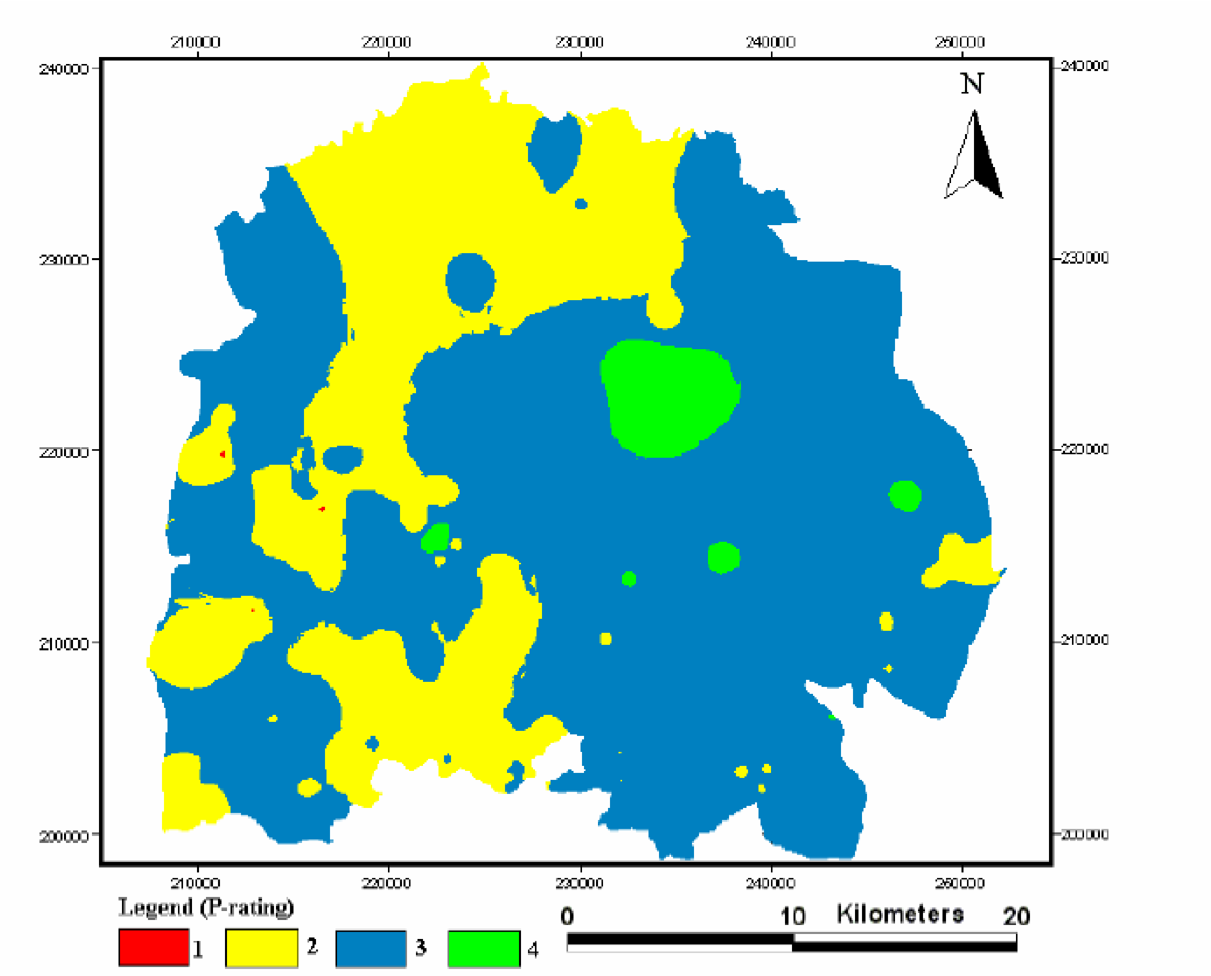


Figure (2): The ratings distribution of the protective cover in the study area.

Karst aquifers are highly heterogeneous and generally considered to be particularly vulnerable to pollution. Due to thin soil, flow concentration in the epikarst and point recharge via swallow holes, contaminants can easily reach the groundwater (Goldscheider, 2003). The Wadi Es-Sir Limestone forms a well developed, about 200 m thick karst aquifer. Jointing and fracturing of the B2/A7 aquifer is moderate to high and the degree of karstification is regarded as moderate, while the B4/B5 aquifer is moderately jointed and fractured and the degree of karstification is low (BGR and WAJ, unpublished manuscript, 2001). It receives water directly from rainfall and discharges it through springs, some of them can be considered as karst springs.

To assess the intrinsic vulnerability of groundwater contamination potential in Irbid governorate, the EPIK method was adopted, which is especially developed for karst aquifers (Doerfliger and Zwahlen, 1998). EPIK is a multi-parameter weighting-rating approach based on the concept of intrinsic vulnerability that was developed by the Swiss Agency for the Environment, Forests and Landscape (Doerfliger and Zwahlen, 1998).

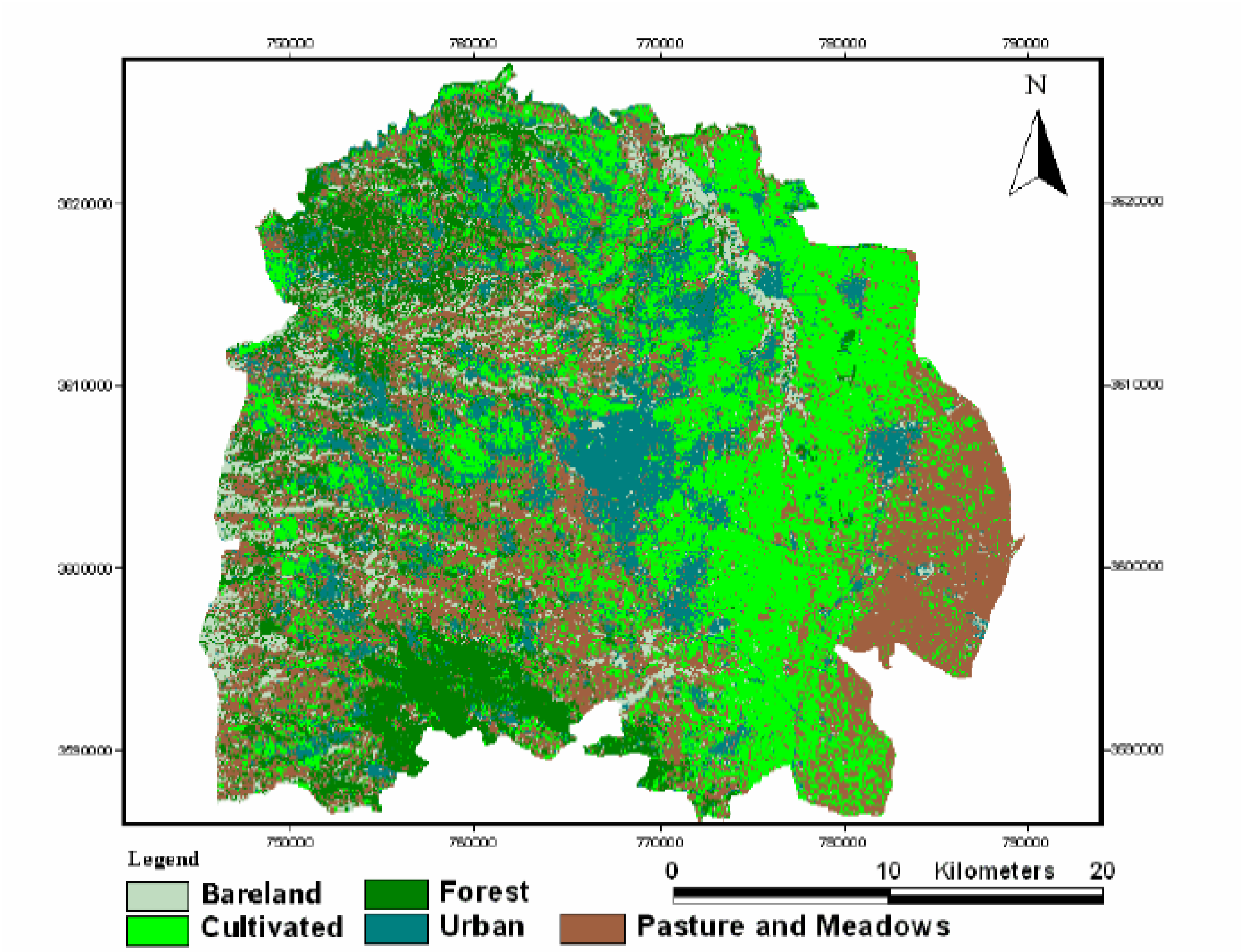


Figure (3): Land use land cover map of the study area (UTM coordinates).

The EPIK method is based on specific geological, geomorphological and hydrogeological factors. The acronym EPIK refers to the following four parameters:

E- Epikarst: the surface and subsurface karstic features;

P- Protective cover: the distribution of the soil thickness;

I- Infiltration condition: the relation between the slope and the different land use pattern in the watershed; and

K- Karst network: the degree to which the karst network is developed.

Each of these parameters is assigned a weight between 1 and 3 and subdivided into a range of classes that is assigned a rating value between 1 and 4. The protection factor (Fp) is calculated by summing the ratings for each class of a given parameter multiplied by the assigned weight as shown in the following equation:

$$Fp = 3E + 1P + 3I + 2K$$

The minimum value of protection factor is 9; whereas the maximum is 34. The lower values of Fp point to higher vulnerability, because the vulnerability index is converse to the protection factor. The protection factor can be divided into four vulnerability classes: low, moderate, high and very high (Table 1).

DERIVATION OF THE VULNERABILITY MAP

Epikarst Parameter (E)

Epikarst is a high permeability zone found in the top meters of limestone directly below the soil cover. The zone is fractured due to the relaxation of tectonic constraints linked to its emplacement (Dodge, 1982). The epikarst may contain a temporary perched aquifer at its base, where its hydraulic conductivity is significantly greater than the underlying strata (Mangin, 1975). Epikarst is found in both buried and exposed karst areas and is not necessarily laterally extensive, and it can exist under soil cover without any morphological expression.

Table (4): Ratings for the attribute classes of the infiltration condition (Doerfliger and Zwahlen, 1998).

Infiltration Condition	Ratings	Characterisation
Concentrated I_1	1	Perennial or temporarily swallow hole -perennial or temporarily stream supplying a swallow hole or a sinkhole (doline)- areas of the water catchment containing artificial drainage.
I_2	2	Areas of a water catchment area without artificial drainage system and where the slope is greater than 10% for cultivated areas and greater than 25% for meadows and pastures.
I_3	3	Water catchment areas without artificial drainage system and where the slope is less than 10% for cultivated areas and less than 25% for meadows and pastures. Areas at the bases of slopes which collecting runoff water and slopes feeding those low areas (slope greater than 10% for cultivated areas and greater 25% for meadows and pastures.
Diffuse I_4	4	Rest of the catchment area.

According to Doerfliger and Zwahlen (1998), the epikarst parameter is subdivided into three categories that indicate decreasing vulnerability as shown in Table 2. A map showing the main geologic structures in the study area was used to determine the lineament density as a surrogate for epikarst. The lineament density map (km/km^2) was derived using ArcGIS 9.2. The map was classified into three classes: (1) 0-1 low, (2) 1-2 moderate and (3) >2 high, and then to its relevant ratings as given in Table 2. The rating value of 3 represents about 32.5% of the study area, while the rating value of 4 represents 66.5 %.

Protective Cover (P)

The protective cover includes the soil as well as other geological formations, which may overlie a karstic aquifer. The thickness of a soil is strongly related to water residence time as the thinner the soil, the greater the vulnerability (Doerfliger et al., 1999). Data for 228 soil profiles were obtained from the Ministry of Agriculture (1993) to determine the soil thickness in the study area. The soil thickness over the study area ranged between 15 and 500 cm. Based on soil thickness and geologic information, the ratings for the protective cover over the study area ranged from 1 to 4 (Figure 2). About 67% of the study area has a rating of 3, while 30 % has a rating of 2.

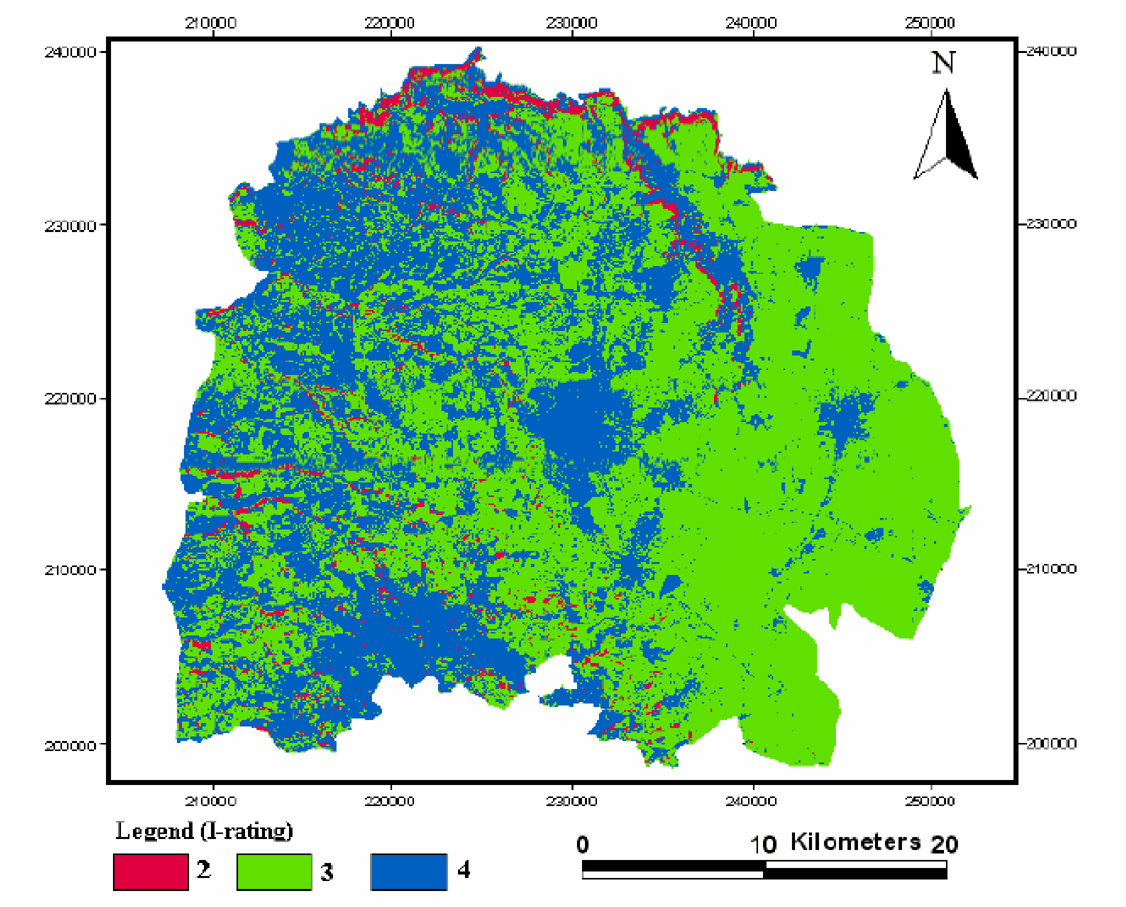


Figure (4): The rating distribution of the infiltration parameter in the study area.

Infiltration Condition (I)

The infiltration condition attribute concerns the type of recharge to the karst aquifer. Evaluation of infiltration conditions is based upon the zones of concentrated and diffuse infiltration that have different vulnerability inferences (Table 4). The diffuse infiltration is characterized by the runoff coefficient, which depends on the slope of the ground surface and land use. Steep slopes and poor vegetation leads to higher vulnerability, because it is assumed that there is more runoff that will infiltrate in the flow relief areas (Doerfliger et al., 1999). According to values of runoff coefficient from Sautier (1984), the limit between low (I_2) and high (I_3) runoff coefficient has been assigned to a runoff coefficient of 0.22 for meadows and pastures and 0.34 for cultivated area. In this study, a 90 m cell size digital elevation model and a land use map derived from satellite imagery (ETM+) (Figure 3) were used to determine the infiltration classes. The ratings for the infiltration condition over the study area ranged from 2 to 4 (Figure 4). About 57% of the study area has a rating of 3, while 39 % has a rating of 4.

Karstic Network (K)

The presence or absence of a karstic network and the degree to which the network is developed is used in evaluation of vulnerability. Caves, swallow holes and active cave systems are considered indicators of the karstic network. The karstic network development and its degree of organization have an important effect on water velocity flow and therefore on the vulnerability. Table 5 shows the ratings for three classes of karstic network development that range from the most vulnerable to the least vulnerable.

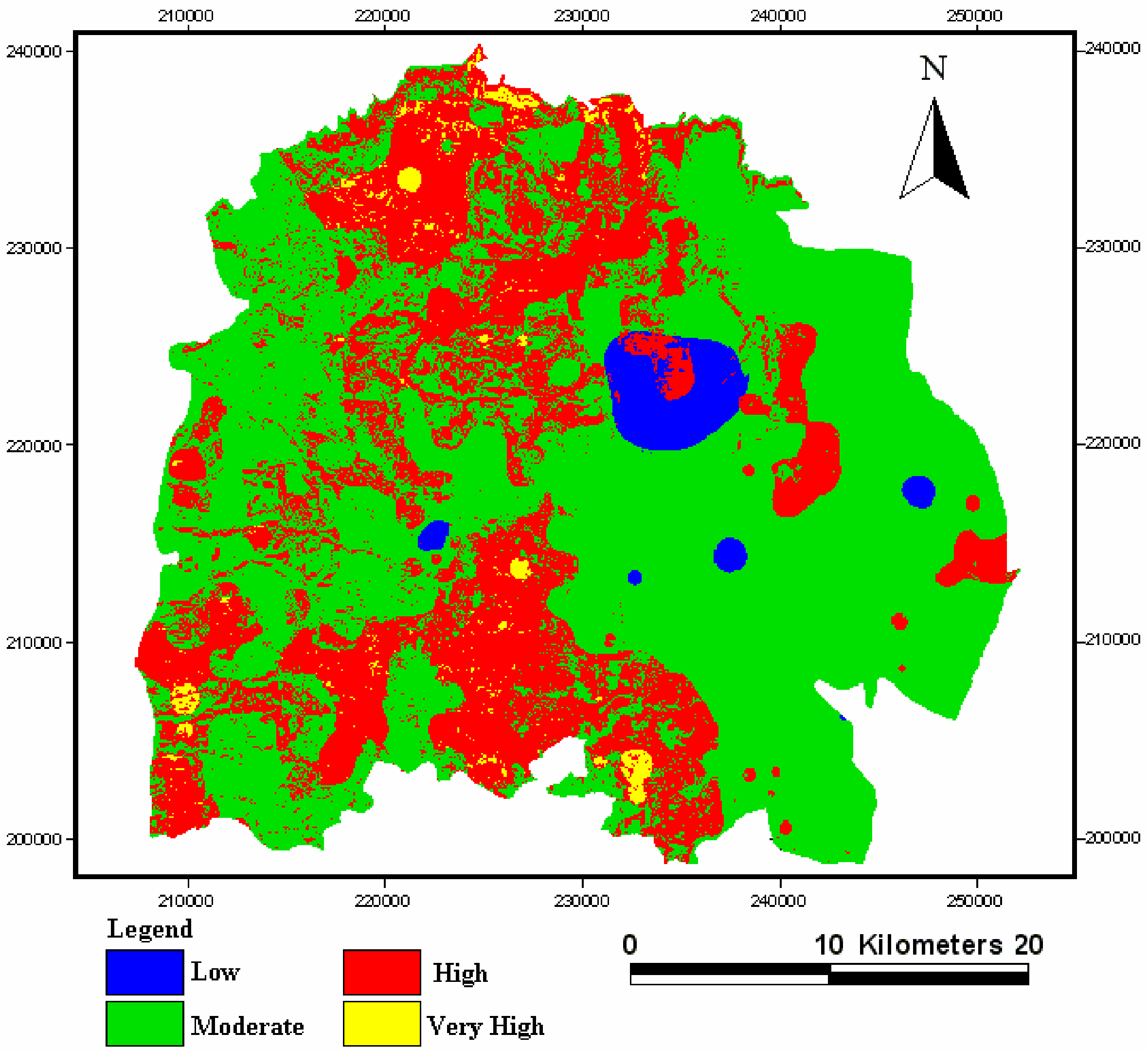


Figure (5): Groundwater vulnerability map of the study area using EPIK method.

Table (5): Ratings for the classes of karstic network development (Doerfliger and Zwahlen, 1998).

Karstic network	**Ratings**	**Characterisation**
Well developed karstic network. K_1	1	Presence of a well development karstic network (network with decimeter to meter sized channels that are rarely plugged and are well connected).
Poorly developed karstic network. K_2	2	Presence of a poorly development karstic network (small conduits network, or poorly connected or filled network, or network with decimeter or smaller sized openings).
Mixed or fissured aquifer. K_3	3	Presence of a spring emerging through porous terrain. Non-karst, only fissured aquifer.

Because detailed mapping of karstic networks is not possible in most cases, one single value per catchment is commonly used (Doerfliger et al., 1999). Salameh and Al-Farajat (1999) found that the karstification in northwest Jordan is very extensive in its nature and distribution. Accordingly, the study area was classified as a well developed karstic network and therefore the lowest rating 1 was assigned.

Overlying layers of the previous four parameters using GIS to calculate a protective factor index (Fp) gave the EPIK vulnerability map (Figure 5). The calculated EPIK index was in the range between 13 and 29, that have been divided into four classes of vulnerability according to Table 1: low, moderate, high and very high. The class of low vulnerability represents about 3% of the study area, moderate class about 63%, high class about 33% and very high class 1%. The very high and high classes of vulnerability are dominant in the northern and southern parts of the study area, whereas the moderate class of vulnerability mostly existed in the eastern and western parts of the area.

WATER QUALITY ASSESSMENT

Water samples from 32 wells and 11 springs were collected during the dry (November 2006) and wet (April 2006) seasons. The chemical analysis (total dissolved solids, sodium, HCO_3^-, chloride, NO_3^- and NH_4) showed that all samples were within the range of World Health Organization and Jordanian standards for drinking water except one well (Mahasi Well no.5) and one spring (Malka Spring) that showed high concentrations of all major cations and anions. In general, the highest nitrate concentrations were found in water samples emerging from the B4/B5 aquifer, and the lowest were found in samples emerging from the B2/A7 aquifer.

DISCUSSION AND CONCLUSIONS

The goals of this investigation were to perform a susceptibility assessment of the aquifers within Irbid governorate and compare the results of the assessment with water chemistry data collected from wells and springs within the study area. The susceptibility assessment was completed using EPIK method within ArcView GIS application. This approach resulted in a pollution susceptibility map of the study area (Figure 5). The vulnerability classes of the study area were low, moderate, high and very high. The different classes occupied 3%, 63 %, 33% and 1% of the study area, respectively. It was found that lineaments density is highest in the north and south of the study area, which may explain the high vulnerabilities in these areas.

The shallow depth to water level in the B4/B5 aquifer and the existing environmental hazards (cesspools and agricultural activities) may explain the high concentrations of nitrates in samples emerged from this aquifer. On the other hand, the B2/A7 aquifer is characterized by high depth to water level, which makes it much less influenced by pollution sources. The two water samples (Mahasi Well no.5 and Malka Spring) with high concentrations of chemical elements were found to lie within the high vulnerability class, whereas other water samples that showed high concentrations of nitrate were located within the class of moderate vulnerability.

The EPIK methodology was successfully applied in an area with basic data available for most areas or can be readily assessed in the field. The derived vulnerability map can contribute to long-term planning of protective measurements for the groundwater. In the very high vulnerability zone, land-use should be limited to water supply and prohibit industrial plants, whereas in the high vulnerability zone construction work is not allowed and rural land-use is restricted (reference). The vulnerability map can be used to find a balance between human activities and economic interests on one hand and groundwater protection on the other hand. Stringent land-use restrictions are recommended in the most vulnerable zones. However, contaminant release should clearly be reduced as much as possible on the entire land surface. In the zones of high vulnerability, the present land-use practices should be changed and hazards should be removed in order to improve the water quality. The vulnerability maps neither replace detailed hydrogeological site assessments for specific issues, nor do they replace water-quality monitoring on a regular basis.

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