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Assessment of Groundwater Vulnerability Contamination Potential of Konya, Turkey, Using Hydrogeological Specifications and GIS

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The aims of this study to assess the potential groundwater contamination impacts on unconfined aquifer from which most of the drinking water in a part of Konya is withdrawn. For assessing the vulnerability, 7 hydrogeological maps are used. These maps, depth to the groundwater, net recharge, aquifer media, soil media, topography, impact of the vadose zone and hydraulic conductivity are established and overlaid in GIS for the area. The overlaid (DRASTIC index) map indicates high vulnerability potential at central areas of the city. Groundwater samples are collected from different vulnerable areas. Chemicals (As, Cd, Ni and Pb) are analyze for testing of contamination degree. It is observed that the vulnerability category determines the contamination degree. The model is a useful and correct technique for assessing the aquifer safety.

Key Words: Groundwater contamination, Groundwater protection, DRASTIC, GIS, Turkey.

INTRODUCTION

Development of the information systems, especially among the ones using different disciplines, geographic information systems (GIS) gained importance. GIS can be used for almost all applications related to groundwater such as hydrogeological database management, groundwater targeting, resource estimation, groundwater recharge estimation, evaluation of ground water exploitation impact on environment, evaluation and re-evaluation of groundwater resources for urban and rural fresh water supplies[1-3].

The aim of applying GIS was not only the progress in the quality of representation but also the adaptation of spatial analysis. GIS can efficiently store, update, manage, spatially analyse and acquire the effective protection of groundwater. Processing of hydrogeological features and the evaluation of vulnerability has been made with the help of Arc View GIS 3.3, in the study. Each object is defined by points (wells), lines (borders) and polygons (rocks and soils).

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The hydrogeological settings that have 7 parameters and are formed on the basis of the hydrogeological characteristics of the 110 wells that belongs to KOSKI in the investigation area, can be determined, established and analyzed quickly with GIS. In this way each layer can be analyzed with individual emphasis by assigning a proper weight and finally all 7 layers can be overlaid on 1 layer. This one layer consists of the groundwater vulnerability map and is called the DRASTIC map. This model is widely used all over the world in the field of groundwater contamination[4-10].

The objective of this study is to assess the potential of groundwater contamination in Konya city, which is one of the largest cities in Turkey. Groundwater is the major source of the potable water supply of the city, by constituting *ca.* 90 % of the total (Fig. 1).

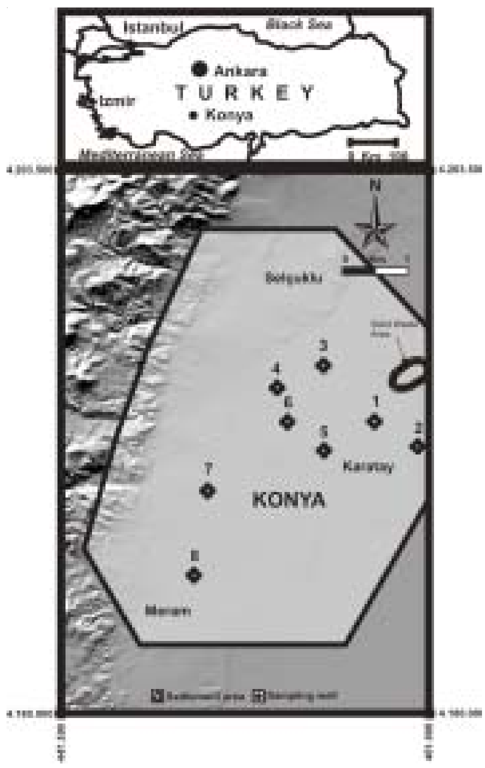

Fig. 1. 3-D Visualization of the study area

The western part of this area is mountainous and the eastern part has plain morphology. That morphology is limited with a fault zone. The peak of mountains is *ca.* 1925 m and the plain part is 1010 m. The mountains consist of volcanic, metamorphic and sedimentary units. The plain is Quaternary aged and has semi consolidated sedimentary rocks[11,12].

In the study, efforts were restricted to evaluating potential pollution impacts on the unconfined aquifer from which 90 % of the potable water in this part of the Konya city is withdrawn. Annually, 70×10^6 m^3 groundwater is delivered in this way[8,13]. In addition, there are around 3000 wells that are drilled and operated by individuals.

Because of ever-growing residential zones, industrial zones and solid waste, there is a substantial threat against the ground water of Konya. With respect to the DRASTIC map that is formed in this study, 8 groundwater wells have been selected for sampling that have different levels of vulnerability. The validity and use of the model that is applied to Konya have been tested by analyses of the groundwater and careful investigation groundwater vulnerability map.

DRASTIC MODEL

The groundwater contamination potential of an area can be assessed by the DRASTIC method, which is developed by U.S. Environmental Protection Agency (EPA) and the National Water Well Association (NWWA)[14]. This useful method includes 7 hydro geologic parameters *i.e.*, depth to water table, net recharge, aquifer media, soil media, topography, impact of the vadose zone media and hydraulic conductivity of aquifer. The acronym DRASTIC is composed of the capital letters of these parameters. These different factors are transferred to the GIS media as separate layers and on the bottom. The DRASTIC layer is formed as a summary layer (Fig. 2).

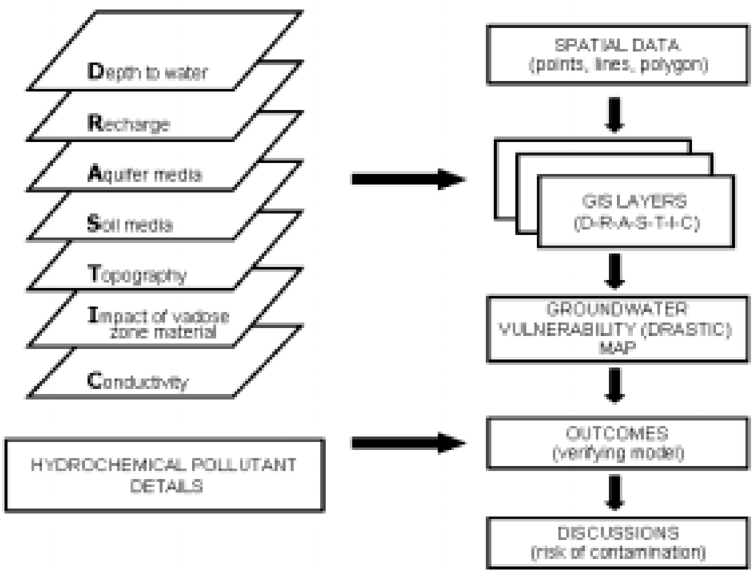

Fig. 2. Technique of DRASTIC with GIS layers

DRASTIC is the most widely used groundwater vulnerability assessment method[4-10,15]. This method includes the most important mappable geological and hydrogeological factors that control the groundwater pollution potential. Hydrogeological factors of an area are obtained from field investigation and laboratory works.

DRASTIC is a numerical ranking system to assess groundwater vulnerability in hydrogeological settings. It has been devised using depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone media and hydraulic conductivity factors[14]. Each DRASTIC factor has been assigned a relative weight ranging from 1 to 5 (Table-1). The most significant factors have weights of 5 and the least significant have weights of 1.

TABLE-1
ASSIGNED WEIGHTS FOR DRASTIC FEATURES

DRASTIC Features	Weight
Depth to water table	5
Net Recharge	4
Aquifer media	3
Soil media	2
Topography	1
Impact of the vadose zone media	5
Hydraulic Conductivity	3

Each DRASTIC factor has been divided into either ranges or significant media types which have an impact on contamination potential. Each range for these factors has been evaluated with respect to the others to describe the relative emphasis of each range with respect to contamination potential (Table-2). These features are rated from 1 (the least significant) to 10 (the most significant).

TABLE-2
RANGE AND RATINGS FOR DRASTIC FEATURES

DRASTIC Features	Range	Rating
Depth to water table (feet)	0-100 <	10-1
Net recharge (inches)	0-10 <	1-10
Aquifer media	Massive shale-gravel/karst limestone	1-10
Soil media	Clay-thin/absent	1-10
Topography (slope %)	0-18 <	10-1
Impact of the vadose zone media	Confining layer-karst limestone	1-10
Hydraulic Conductivity (gpd/ft^2)	1-2000 <	1-10

These ratings and weights are used at the DRASTIC index (DI), calculated using the formula:

$$DI = D_r \times D_w + R_r \times R_w + A_r \times A_w + S_r \times S_w + T_r \times T_w + I_r \times I_w + C_r \times C_w$$

The capital letters represent the corresponding feature of the DRASTIC settings. The subscript 'r' refers to the rating and 'w' refers to weight. The higher the DRASTIC index the greater the groundwater contamination potential. On the other hand, DRASTIC has 4 major assumptions. These are (1) The contaminant is introduced at the ground surface; (2) The contaminant is flushed into the groundwater by precipitation; (3) The contaminant has the mobility of water; (4) The area evaluated using DRASTIC is 0.4 km^2 (100 acres) or larger[14].

Depth to water table (D): 77 Wells have been identified that can represent the groundwater system that is under investigation. The distance between earth level and the bottom level of groundwater reach has been measured in meters (or feet) in these wells.

The proximity of the groundwater to the earth level increases the risk of contamination. Therefore this distance is important for assessing contamination risk. In this regard, Table-3 is proposed by Aller *et al.*[14].

The water table map is prepared by measuring the depth of water from selected wells in the area. Groundwater table in the east and southeast parts of the area are closer to the surface than the other part. Therefore, these areas are more vulnerable than the others. According to the depth to water level map (D) of the area, vulnerability of aquifer sensitivity increases from west to east (Fig. 3).

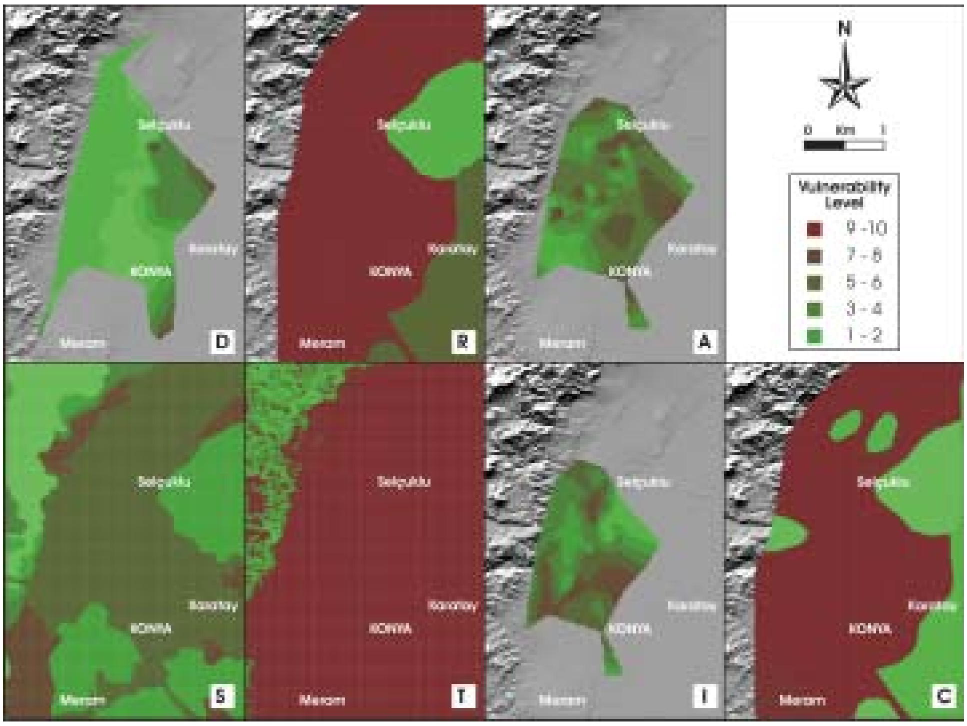

Fig. 3. Vulnerability maps of 7 hydrogeologic settings

Net recharge (R): Precipitation is the primary source of groundwater contamination because of infiltration. Net recharge represents the annual amount of water per unit area of land which infiltrates the ground surface and reaches the water table. The recharge helps the contaminant transportation from surface to the ground and reaching to the groundwater. Hence the greater recharge causes greater vulnerability of the aquifer.

Groundwater table variation level (Δh_i) is determined by measuring the investigated area. Different lithological areas (A_i) have been determined and the storage coefficient of these areas (Sy_i) is calculated. Consequently net recharge (R) is calculated from the following formula;

$$R = A_i \times Sy_i \times \Delta h_i$$

With this formulation ratings of the investigated area that correspond to each recharge value are calculated (Table-4). Net recharge map (R) is prepared from rating data with respect to these criterions[14] (Fig. 3). According to this map, big part of the area has excessive recharge. Because of this reason, aquifer vulnerability of contamination is higher in most areas.

TABLE-3
RANGE AND RATINGS FOR DEPTH TO WATER (FEET)

Range	Rating
0-15	9-10
15-30	7-8
30-50	5-6
50-75	3-4
75-100	1-2

TABLE-4
RANGE AND RATINGS FOR NET RECHARGE (INCHES)

Range	Rating
0-2	1
2-4	3
4-7	6
7-10	8
10 +	9

Aquifer media (A): Aquifer media represents the consolidated or unconsolidated rocks, which are maintained as aquifer. Because water is contained in aquifers within the pores of granular and clastic rocks and in the fractures and solution openings of non-clastic and non-granular rocks, aquifer media serves the mobility of the contaminant through the aquifer.

Lithological properties of 110 wells are studied to determine the aquifer environment of the investigated area. The proportions in Table-2 help in the generation of the aquifer media map (A) of the investigated area (Fig. 3). According to this map, the most sensitive locations for the aquifer are limited areas in the eastern, northern and western parts.

Soil media (S): Soil media is composed of various textural classification of soil, *e.g.*, clay, silt, sand, loam which has different water holding capacity and permeability. Soil has a significant impact on the amount of recharge and hence on the travel time of the contaminant into the vadose zone.

The soil media map of the investigation area was prepared with the help of documentation of General Directorate of rural services and Konya city land classification maps[16]. Calculations for soil media is done according to the proportions given on Table-2 and the soil media map (S) of investigated area was established (Fig. 3). According to that map, some areas at the edge parts of investigated area have higher risk for the aquifer.

Topography (T): In this study, topography defines the slope changes of the surface. The hydrogeological setting helps to control the likelihood that a contaminant will run off or remain on the surface in an area long enough to infiltrate. Such infiltration situation raises groundwater pollution potential. Slopes are calculated from topographic map (T) of the area and topography map was prepared according to the proportions given on Table-2 (Fig. 3). According to the map, plain part of the area, settlement area of Konya, is the most vulnerable part of the aquifer.

Impact of the vadose zone media (I): The vadose zone refers to the texture of the media in the unsaturated or discontinuously saturated zone between the bottom of the soil media and the top the water table. Using lithology data of the wells, which are dispersed to the area, following formula is applied;

$$R = D / \sum_{i=1}^{n} d_i / r_i$$

where, R : average rating; D: total thickness of 'n' number units; r_i : rating for each lithology which is obtained from Table-2; d_i: thickness of each unit.

According to the results, which are obtained from formula above, impact of the vadose zone media map (I) is produced for the area (Fig. 3). The northeast and centre of the study area show high potential risk of contamination.

Hydraulic conductivity of the aquifer (C): Hydraulic conductivity defines the ability of ground water movement in the aquifer. Thus, hydraulic conductivity controls the degree and fate of the pollutants. Hydraulic conductivity map (C) of the investigated area was prepared using proportions given on Table-2 (Fig. 3). According to this map most of the investigated area is under higher vulnerability risk.

The DRASTIC index map: All prepared maps (D, R, A, S, T, I and C) are digitized in computer environment and stored in Arc View GIS 3.3 software as separate layers. The DRASTIC rating for each hydrogeological setting was multiplied by the DRASTIC weight (Table-1). Thereafter, these 7 layers are overlaid to a single map using GIS. As a result the overlaid layer of GIS, the DRASTIC index map, is determined for the study area (Fig. 4). The vulnerability is classified from 0-2 to 9-10. According to these five categories, vulnerability is increasing gradually. For that reason, eastern parts of the study area show higher vulnerability risk (classified as 9-10).

Outcomes: The constructed vulnerability model can be tested by making various chemical analyses to the groundwater from an area where DRASTIC model is applied[6,8]. DRASTIC model, is carried out to study the area is compared with contamination analysis that are done on water samples taken from groundwater. Eight sampling wells (Fig. 1) are chosen from defined areas on which the aquifer is either vulnerable or not vulnerable according to the DRASTIC index map (Fig. 4). And they are chosen whether they are close or not close to the solid waste area (Fig. 1). In addition, all wells that are selected for sampling are taken from areas that have different risk levels according to DRASTIC Index category. Furthermore, As, Cd, Ni and Pb are analyzed from the leachate and the groundwater samples by ICP-AES (Table-5).

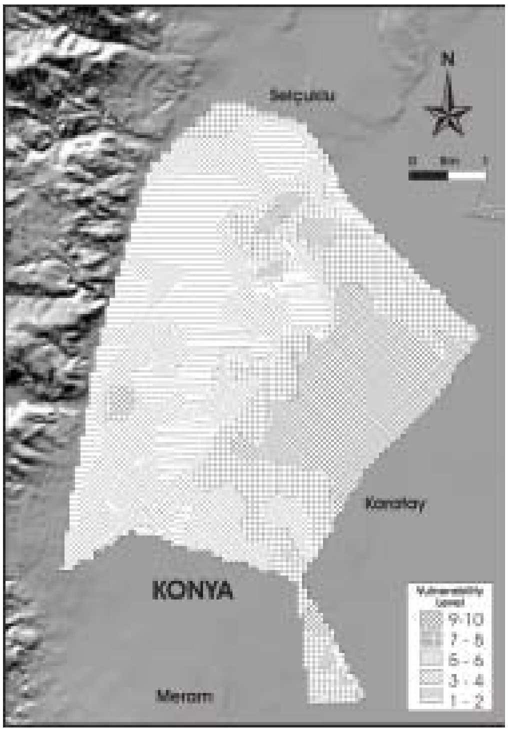

Fig. 4. DRASTIC index map of the study area

TABLE-5
CONTAMINATION ANALYSIS

Sample No.	*DRASTIC category	As**	Cd**	Ni**	Pb**
Leachate	9-10	0.5000	0.0031	1.10000	0.0120
1	7-8	0.0093	0.0009	0.0033	0.0029
2	7-8	0	0.0017	0	0.0024
3	0-2	0	0.0005	0	0
4	9-10	0	0.0028	0.0054	0
5	9-10	0	0.0004	0.0123	0
6	0-2	0	0	0	0
7	0-2	0	0	0	0
8	3-4	0	0	0	0

*The category taken from Fig. 4; **Element concentrations are in ppm.

The analysis results show that, As, Cd, Ni and Pb concentrations decline proportional to the distance from the solid waste area. The analysis results of the samples equidistant to the solid waste area, such as samples 1, 2 and 3 or samples 4, 5 and 6, are variable according to the DRASTIC categories changing from 1-2 to 9-10 (Figs. 3 and 4). The samples of more vulnerable (7-8 and 9-10) areas are more polluted from the solid waste area. Sample 1, collected from DRASTIC category 7-8, contains As, Cd, Ni and Pb but sample 3, collected from the category 1-2, has only Cd. Likewise, the samples 4 and 5, taken from the category 9-10, have Cd and Ni but there is no Cd or Ni in sample 6, taken from category 1-2 (Table-5, Fig. 4).

RESULTS AND DISCUSSION

In this work, the vulnerability of groundwater against contamination of different sections in the investigated area has been analyzed with respect to hydrogeological characteristics. The suggestions of the constructed DRASTIC map has to be considered afterwards in all planning work and inspections to be done, regarding the groundwater that meets 90 % of the potable water demand in Konya. In this way, industrial zones that yield waste and solid waste zones should be allocated to areas that constitute the lowest risk of groundwater vulnerability which should also be suggested in the 2050 city plan.

As a result of heavy metal analysis of groundwater samples taken from vulnerable aquifer for contamination according to the overlaid map, As, Cd, Ni and Pb, concentrations were found higher in high vulnerable for aquifer (DRASTIC categories of 7-8 and 9-10) than low vulnerable for aquifer (DRASTIC category of 1-2). When the DRASTIC map of Konya and the settlement area at present are compared it is seen that the current city plan is not acceptable and has serious risk of contamination to the groundwater since the solid waste areas are located at highly vulnerable zones.

Consequently, this aquifer vulnerability model with the help of GIS for groundwater safety has been necessary to use. And GIS helps users to predict the groundwater vulnerability in the future. The best model for the conservation of groundwater nature is to protect groundwater against contamination before being contaminated.

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