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# Groundwater Vulnerability Mapping Using DRASTIC Model: A Case Study at the Palas Basin in Turkey

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## Abstract

The study aims to estimate groundwater vulnerability against pollution at the Palas Basin (Turkey) by using geographical information system based DRASTIC model. A DRASTIC model integrates information for seven hydrogeological parameters: depth to water (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I), and hydraulic conductivity (C), and identifies spatial vulnerability. The study area, Palas Basin, is a hydrologically closed, agricultural basin, where groundwater is used for meeting irrigation and municipal water requirements. Seven hydrogeological parameters were combined to classify the basin into three vulnerable zones (as low, moderate, and high). The central part of the basin was identified to be highly vulnerable, while the eastern and southern parts were characterized by moderate to low vulnerable areas. Intensive agricultural activities, widespread in the central basin, create high pollution potential. This study showed that the DRASTIC approach provided a simple and efficient tool for evaluating groundwater vulnerability. The results can be used by water managers in groundwater management in the Palas Basin.

## Key words

Aquifer Vulnerability, DRASTIC, GIS, Palas Basin

## 1. INTRODUCTION

Freshwater resources are limited and not equally distributed throughout the world. Human activities and climate change pose direct or indirect impacts on scarce freshwater resources [1;2]. The number of countries experiencing water scarcity and the population that can reach sufficient amount of water decrease [3;4;5], while water stress increases [6;7]. It is, therefore, crucial to use existing water resources efficiently.

Vulnerability modeling approaches can help determine how vulnerable groundwater is to various stresses. DRASTIC is a geographic information system (GIS) based model that can be applied to shallow groundwater systems [8]. In this method, it is assumed that all pollutants in the basin can infiltrate, be transported, and dissolved in groundwater [8]. Thus, by determining the potential effects of pollutants in the basin, regions susceptible to pollution can be determined. DRASTIC based vulnerability maps can be used in groundwater planning, especially in agricultural basins. The information obtained plays a role in planning activities such as water use, agricultural land use planning, animal husbandry, and fertilization.

 

In this study, we estimated groundwater vulnerability against pollution at the Palas Basin in Turkey. This basin is a hydrologically closed basin where intensive irrigated agriculture takes place. Irrigation and drinking water requirements in the basin are almost entirely met from groundwater. Agricultural activities can pose threats for groundwater quality. In this study, we aim to show how vulnerable is the groundwater system to pollution.

## 2. METHODS

### *2.1. Study Area*

This study was carried out at the Palas Basin (Figure 1). Palas Basin is an agricultural basin, located in Kayseri, in the Central Anatolia Region of Turkey. The basin is a hydrologically closed basin. The altitude of the region range from 1131 to 2119 meters, and its area is approximately 100 $km^2$ [9]. Tuzla Lake is located to the west of the basin. Tuzla Lake is an ecologically important area as it is located in the junction point of routes of birds migrating from Asia, Europe and Africa and hosts endemic plant species [10]. A small stream, named Değirmen Stream, flows towards Tuzla Lake by joining two branches from Koyunabdal and Kahveci locations. The flow in the stream is very low and it is mostly dry during summer months. Therefore, the major water source in the basin is groundwater. Groundwater is used for meeting irrigation and drinking water requirements.

Economic activities in the region are agriculture, animal husbandry, and salt extraction. Average annual air temperature of the Palas Basin is 11°C. The hottest month is July, where the average temperature is 20ºC. In January, the coldest month, the average air temperature is -2.5ºC. Average annual precipitation is 402 mm. [9].

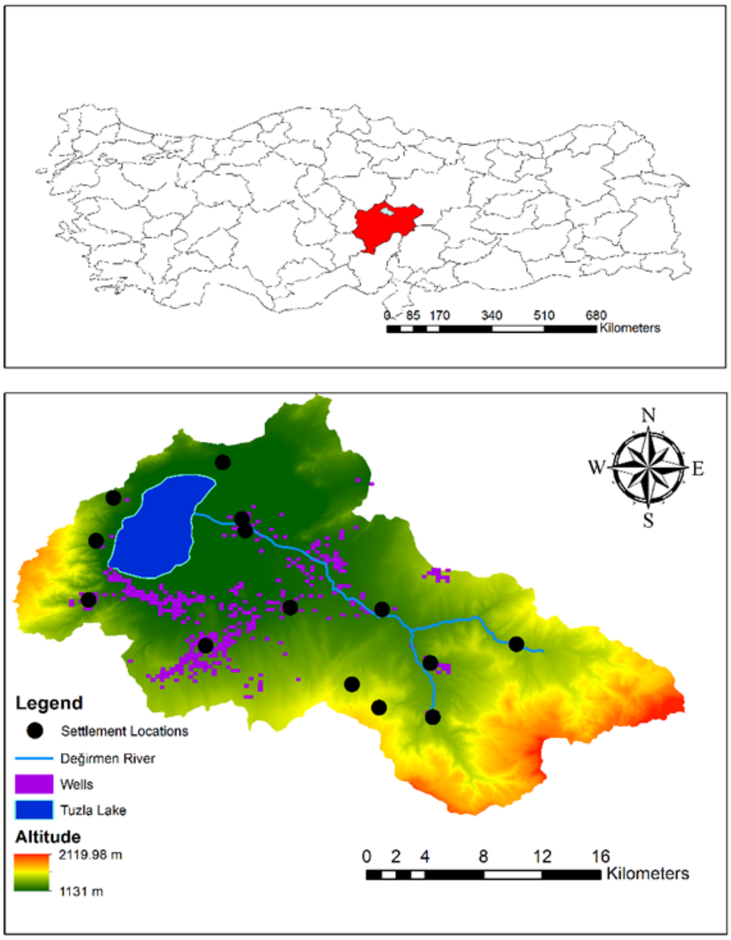


*Figure 1: Study area representation*

Groundwater in the Palas Basin can be vulnerable to pollution due to intensive agricultural activities taking place in the basin. Nitrate concentrations in groundwater are already high in some parts of the basin. Groundwater levels are also decreasing as a result of intensive use of groundwater. The change in groundwater salinity can be a problem due to the interaction of the saline Tuzla Lake with groundwater in the region [10].

The DRASTIC method basically uses seven hydrogeological factors to assess the susceptibility of groundwater to contamination. The DRASTIC parameters' weights, defined according to Aller et al. [8], range from 1 to 5 (Table 2). The most important parameter is given weight 5 and the least important parameter is given weight 1. The weights are chosen depending on the parameters affecting the spread of the pollutants. In addition, each parameter is divided into degrees according to its pollution potential. The degrees are determined according to rating classes in layers and the impact rating values of that layer are determined. Later, these layers were combined according to their weight values and the DRASTIC index layer is created. Mathematical equation for the DRASTIC index is given in Eq. 1.

$$\mathrm{DI} = \sum_{i=1}^{7}(W_i * R_i) \quad (1)$$

In Equation 1, the variable "$i$" denote the layers such as Depth to Water (D), Net Recharge (R), Aquifer Media (A), Soil Media (S), Topography (T), Impact of Vadose Zone (I), Hydraulic Conductivity (C). "W" variable is weighted number for each layer, "R" variable is rating number for each by "i" layer class. Finally, "DI" is the DRASTIC Index. The summary of the raw data sources and the operations applied for the "i" layers obtained are given in Table 1. Also, the weighted values and rating values selected according to the literature are given in Table 2.

*Table 1: Summary of the raw data sources and the operations applied for the DRASTIC layers*

| Layers | Raw Data Source | Data Adjustments |
|---|---|---|
| Depth to Water | Log Data for Different Location at Basin | * Coordinate transformation<br>* GRID installation (100mx100m)<br>*Classification |
| Net Recharge | SWAT Model | * Coordinate transformation<br>* GRID installation (100mx100m)<br>*Classification |
| Aquifer Media | State Hydraulic Works | * Coordinate transformation<br>* GRID installation (100mx100m)<br>*Classification |
| Soil Media | FAO World Soil Map | * Image Clip Process<br>* Coordinate transformation<br>* GRID installation (100mx100m)<br>*Classification |
| Topography | Using DEM image by SRTM Satellite | * Image Clip Process<br>* Coordinate transformation<br>* GRID installation (100mx100m)<br>*Slope Analysis<br>*Classification |
| Impact of Vadose Zone | FAO World Soil Map | * Image Clip Process<br>* Coordinate transformation<br>* GRID installation (100mx100m)<br>*Classification |
| Hyraulic Conductivity | SPAW Hydrology Programme | *Hydraulic Conductivity Values Search and Input for Soil Types<br>* Coordinate transformation<br>* GRID installation (100mx100m)<br>*Classification |

*Table 2: Weights and ratings assigned to seven parameters used in the DRASTIC vulnerability index modelling*

| Parameter | Classes | Rating | Weight |
|---|---|---|---|
| Depth to Water (m) | 0-1.5 | 10 | 5 |
| | 1.5-4.6 | 9 | |
| | 4.6-9.1 | 7 | |
| | 9.1-15.2 | 5 | |
| | 15.2-22.9 | 3 | |
| | 22.9-30.5 | 2 | |
| | >30.5 | 1 | |
| Net Recharge (m/year) | 0-0.141 | 1 | 4 |
| | 0.141-0.282 | 3 | |
| | 0.282-0.494 | 6 | |
| | 0.494-0.705 | 8 | |
| | >0.705 | 9 | |
| Aquifer Media | Silty Clay, Sand, Gravel | 4 | 3 |
| | Sandstone | 6 | |
| | Siltstone, sandstone, clay limestone | 6 | |
| | Silty clay | 7 | |
| | Broken cracked rock | 3 | |
| | Impervious tuffs | 9 | |
| Soil Media | Sandy clay loam | 2 | 2 |
| | Clay silty | 3 | |
| | Silty clay loam, sandy clay loam, clay loam | 4 | |
| | Sandy clayey gravelly | 6 | |
| | Fine sandy loam - sandy loam | 8 | |
| | Clay - silty clay - sandy clay | 2 | |
| Topography (percent) | 0-2 | 10 | 1 |
| | 2-6 | 9 | |
| | 6-12 | 5 | |
| | 12-18 | 3 | |
| | >18 | 1 | |
| Impact of Vadose Zone | Sandy clay loam | 2 | 5 |
| | Clay silty | 3 | |
| | Silty clay loam, sandy clay loam, clay loam | 4 | |
| | Sandy clayey gravelly | 6 | |
| | Fine sandy loam - sandy loam | 8 | |
| | Clay - silty clay - sandy clay | 2 | |
| Hyraulic Conductivity (m/day) | 0.19 | 1 | 3 |
| | 0.21 | 1 | |
| | 0.18 | 1 | |
| | 0.23 | 1 | |
| | 0.24 | 1 | |
| | 0.27 | 1 | |

## 3. RESULTS

Seven hydrogeological parameters were combined to create the drastic index map for the Palas Basin. Figure 2 presents each layer and their categories. Here, the depth to water layer is the distance of the groundwater aquifer from the surface. As this distance decreases, groundwater becomes more vulnerable to pollutants. Depth to water layer values were divided into seven categories according to Aller et. al. [8]. Another layer is the net recharge layer. The increase in the net recharge value in this layer means that the groundwater is more vulnerable for potential contamination. Net recharge values were obtained from a previously developed SWAT model and classified into three [11]. In this study, aquifer media is divided into 6 classes. In the aquifer media variable, contamination potentials may increase or decrease depending on the permeability of aquifer materials. A similar situation is valid for the soil media and impact of vadose zone. In the topography layer, the contamination potential changes depending on the slope. As the slope value increases, the leakage into the groundwater will decrease, so a low pollution rating value is stated. As the slope value decreases, the contamination potential degree increases as the water flow will go towards leakage. Finally, in the hydraulic conductivity layer, the increase in conductivity value is the effect that increases the potential for groundwater contamination. When the hydraulic conductivity value increases, the rating value of the variable class also increases.

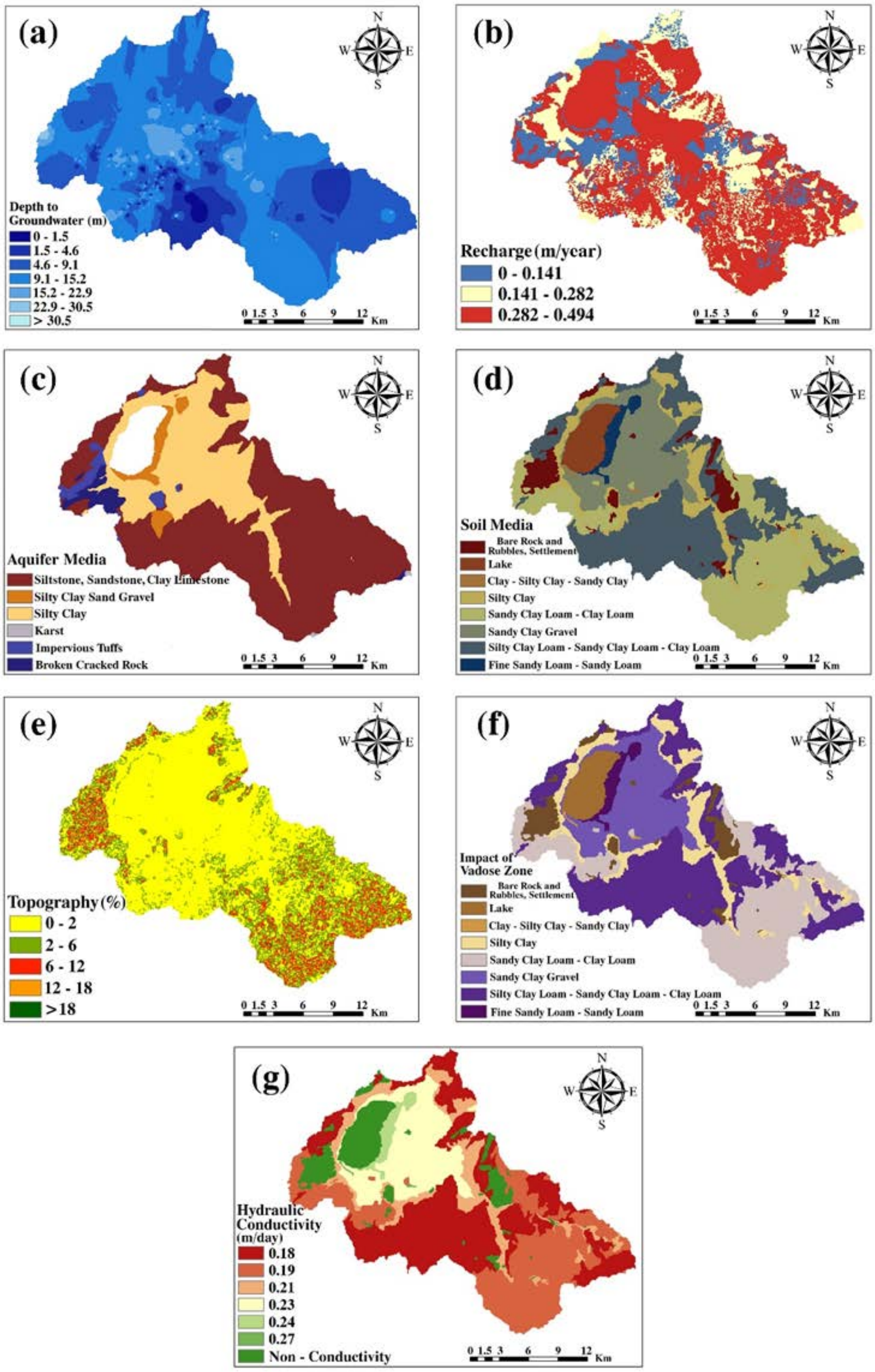


*Figure 2: DRASTIC layers and classes of each layer*

DRASTIC Index map was created by combining seven separate layers (Figure 3). In this map, a numerical output value was created for each grid value and these values were divided into three classes as low, moderate, and high vulnerability zones.

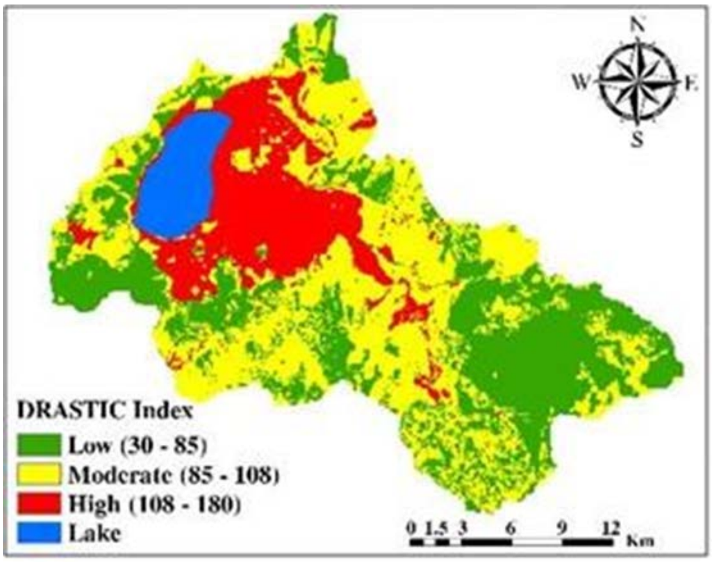


*Figure 3: Drastic index map for Palas Basin*

According to Figure 3, majority of the basin is covered by moderate vulnerability class (66%). Low vulnerability zone covers 17% and high vulnerability zone covers 23%. However, the areas with high vulnerability are located in the region where agricultural activities are intense and settlements are located. This situation creates a potential risk for groundwater quality. Therefore, the use of chemicals such as fertilizers and pesticides in the region should be strictly controlled.

## 4. CONCLUSION

This study was conducted for groundwater vulnerable assessment in the Palas Basin. DRASTIC model with inputs for depth to water (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I), and hydraulic conductivity (C) were used to estimate spatial vulnerability of Palas Basin. Vulnerability studies reflect the potential for contamination of the region's groundwater. As a result of the study, approximately 23% of the groundwater in the basin was determined to be highly vulnerable to pollution. The data obtained in this study can be used for comparison with actual pollution values or to determine the effects of land use changes on the basin.

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