GROUNDWATER VULNERABILITY AND RISK ASSESSMENT USING DRASTIC MODEL IN A GIS ENVIRONMENT. A CASE STUDY FROM THE GALLIKOS RIVER BASIN, NORTHERN GREECE

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Abstract

The aim of this paper is to estimate the groundwater vulnerability in the Gallikos river basin using the DRASTIC methodology in a GIS environment. The DRASTIC method is based on the calculation of the vulnerability index of an aquifer against pollution from external surface sources. The complex geological structure and the intense anthropogenic pressures in the basin, make the DRASTIC methodology a useful tool for the stakeholders and the decision makers, regarding the groundwater resources management. The DRASTIC methodology requires geological and hydrogeological data. The combination of the vulnerability index and the land use of the area, allows the estimation of the groundwater risk. The illustration of the spatial distribution of the vulnerability and risk assessment values, contributes to the effective design and the implementation of specific measures towards protection, restoration and integrated management of groundwater resources.

1. Introduction

In Greece, the groundwater resources are under strong human pressures, such as urbanization, land uses changes and increase of water demands for domestic and agriculture use. The inversion of the groundwater quality and quantity gradation depends on the rational management and the determination of the aquifers protection zones (UNESCO 1998; Voudouris *et al.* 2010). Groundwater vulnerability maps constitute a useful tool for the groundwater management and protection (Patrikaki *et al.* 2011) and can be combined with decision support systems (DSS), in order to change and rearrange the land uses (Voudouris *et al.* 2010). There are several methods to estimate groundwater vulnerability, such as the GOD (Foster 1987), the AVI (Van Stempvoort *et al.* 1993), the SINTACS (Civita & De Maio 1997) and the RISKE (Petelte-Giraude *et al.* 2000) methods. The most established worldwide applied method is the DRASTIC (Aller *1987*). The identification of the most appropriate and reliable method has been examined by many researchers (Gogu *et al.* 2000; Kazakis & Voudouris 2011). It was concluded that the selection of the most suitable method depends on the available data and the specific hydrogeological conditions (Kazakis and Voudouris 2011).The DRASTIC method has been applied in several regions in Greece (Kazakis *et al.* 2008; Patrikaki *et al.* 2011; Panagopoulos *et al.* 2005; Antonakos & Lambrakis 2007) and worldwide (Babiker *et al.* 2005; Hamza *et al.* 2007). The groundwater risk map is the outcome of the combination of the vulnerability map (DRASTIC method) and the Hazard map (land uses) (Voudouris 2009). The work described in this paper aimed at estimating the groundwater vulnerability and risk in Gallikos River basin in North Greece.

2. Study area

The Gallikos River is located in northern Greece and flows through the Prefectures of Kilkis and Thessaloniki before it is discharged into Thermaikos Gulf, northern Aegean Sea (Figure 1). The hydrological basin covers an area of approximately 868 Km^2, extending from Krussia Mountain to the area of Nea Philadelfia village, near the administrative border of Kilkis and Thessaloniki Prefecture. The elevations that are lower than 340 m cover 50% of the basin area. The watershed boundary reaches an altitude of 1180 m to the northeast part of the basin. The mean altitude was calculated to 357.7 m. The total length of the river is about 73 km (Meladiotis 1984). The river flow characteristics resemble both a river and a torrent and the maximum discharges occur during summer. The high density of the basin's hydrologic network indicates high runoff percentage compared to infiltration, which in fact suggests that the geological formations of the basin are impervious. The mean annual precipitation over the basin is approximately 480 mm. Geotectonically, the Gallikos basin belongs to the Serbomacedonian massif, Circum Rhodope belt and the zone of Peonia (Mercier 1966; Kockel *et al.* 1965; Kockel *et al.* 1971; Kockel and Ioannides 1979; Ioannides *et al.* 1990). The area is filled with Quaternary and Tertiary sediments. The Quaternary sediments consist of fluviolacustrine deposits, whereas the Tertiary sediments comprise of Neogene marls. They thin out progressively towards the upstream (northern) part of the basin, which is bounded by the bedrock alpine formations. The bedrock of the basin is formed of argillaceous schists, limestones to dolimites, quartzites, amphibolites and gneisses (Figure 1).

The majority of the population resides at the southwestern part of the basin. Agricultural activities and livestock are the main occupation of the inhabitants, especially at the areas along the river. The industrial zone, at the south part of the basin, consists of small and medium size enterprises. The river water quality is affected by agricultural and industrial effluents. A domestic effluent treatment plant operates in the area of Kilkis town. Despite the existence of the aforementioned treatment plant, the Gallikos River still remains receptor of untreated sewages from small size settlements that are located along the riverbed.

3. Materials and methods

3.1 The DRASTIC method

The model of DRASTIC estimates groundwater vulnerability and uses seven (7) parameters: **D**epth of groundwater, net **R**echarge, **A**quifer media, **S**oil media, **T**opography, **I**mpact of the vadose zone media, hydraulic **C**onductivity of the aquifer. The weight (w) of each parameter describes its significance, while the rating of the parameters indicates their participation and degree in the final vulnerability value for each point. The Equation 1 is the DRASTIC index (DI), where **r** is the rating for the study area and **w** is the importance weight for the parameter (Table 1). A numeric value assigned between 1 and 10 should have each parameter of the index, while the weight ranges from 1 to 5.

$$DI = \sum_{j=1}^{7} r_j . w_j \quad \text{or } DI=DrDw+RrRw+ArAw+SrSw+TrTw+IrIw+CrCw \tag{1}$$

Table 1 The parameters of DRASTIC and their weight (Aller et al. 1987).

DRASTIC parameters	weight
Depth of groundwater	5
net **R**echarge	4
Aquifer media	3
Soil media	2
Topography	1
Impact of the vadose zone media	5
hydraulic **C**onductivity of the aquifer	3

The estimation of risk assessment was based on the land use map (Hazard map) and the vulnerability map (Voudouris 2009). The land uses was weighted with 5 and added as a separated parameter (Equation 2) in the risk index (RI).

$$RI = \sum_{j=1}^{7} r_j . w_j \text{ or RI=DrDw+RrRw+ArAw+SrSw+TrTw+IrIw+CrCw+LrLw} \quad \textbf{(2)}$$

Where: **D**, **R**, **A**, **S**, **T**, **I**, **C**, **r** and **w** were defined earlier, and **L** is the land uses with weigh 5. The calculation and distribution of each parameter was based on GIS, the use of Digital Elevation Model, the tool of raster calculator and the geostatistical method of kriging.

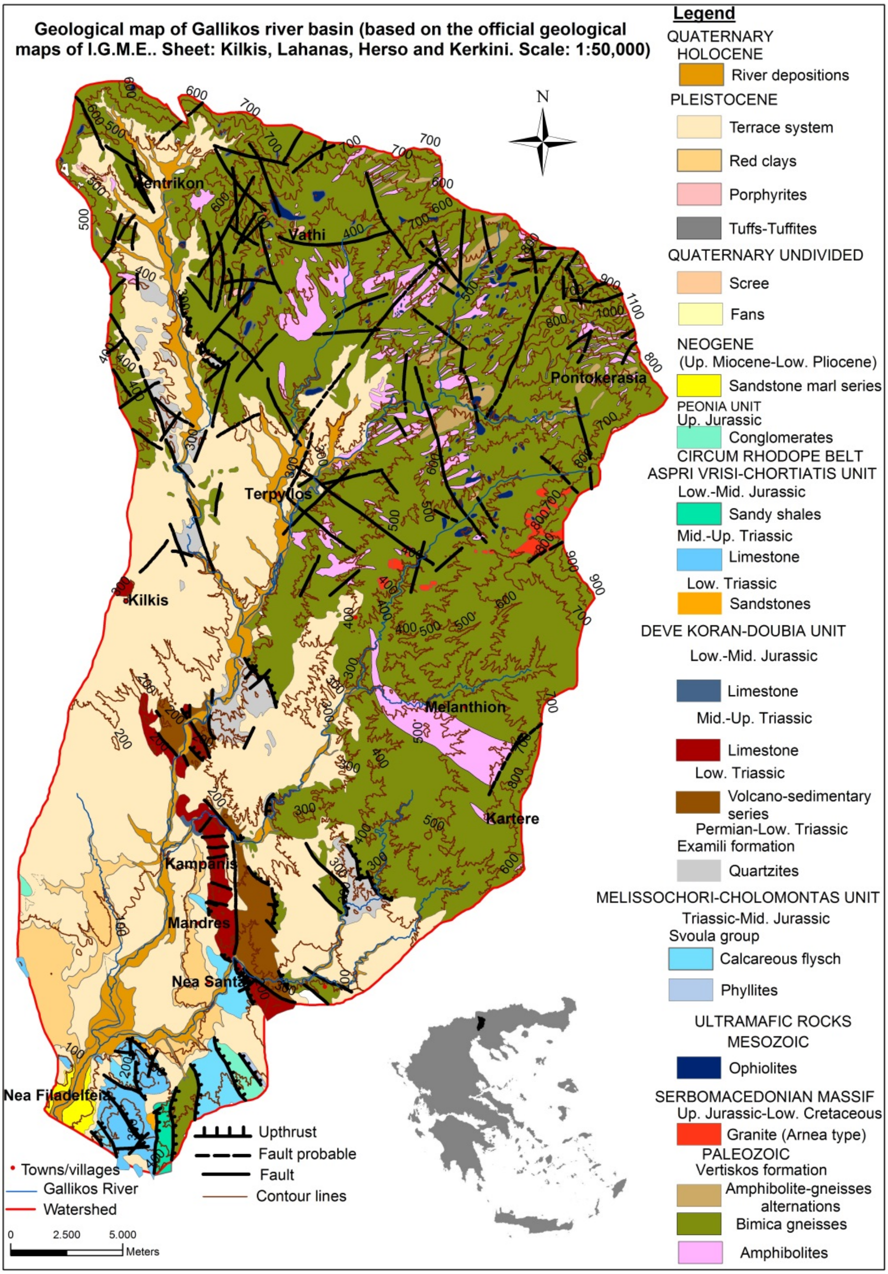

Figure 1. Geological map of the study area.

4. Results and discussion

4.1 *Depth of groundwater (D)*

The water level depth measurements were conducted during the wet period (April) of 2004 in 67 wells and boreholes (Mattas 2009). The water level depth ranged from 1.15 to 121.75 m below ground surface. The water level depth in the majority of the boreholes (approximately 76%) was smaller than 20m. The deeper water level occurs in boreholes drilled in the crystalline rocks area at the east part of the basin. On the contrary, the water level in the boreholes drilled in the sediments across the main river flow axis is shallow. The depth of the groundwater (D) is a parameter with important weight (weight value: 5). The greater depth of the water level indicates higher protection against pollution and, therefore, smaller vulnerability risk. The depth was classified into 10 classes; each class was rated in a continuous scale from one to ten (Figure 2).

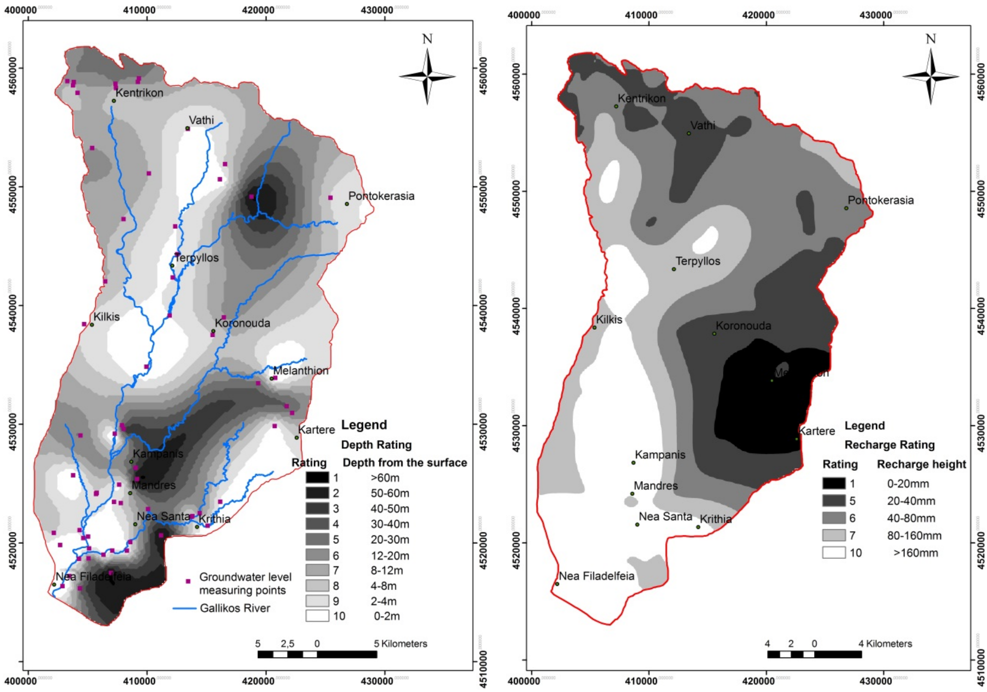

Figure 2. Thematic map of the parameters D (left) and R (right).

4.2 *Net Recharge (R)*

The Recharge (R) is the amount of the meteoric or surface water that infiltrates the ground and reaches the aquifers, transferring, in some cases, pollutants from the surface. Precipitation was calculated from the equation $y = 0.2609x+380.36$ (Mattas 2009). Recharge rate was calculated as height (mm) according to precipitation spatial distribution, geological formations infiltration coefficient and slope of the topography. The parameter weight value is 4. The recharge rate was classified into 5 classes and was rated according to the aforementioned characteristics (Figure 2). The highest values were estimated in the areas with permeable sediments and carbonate rocks.

4.3 *Aquifer media (A)*

The granulometry of the permeable sediments is a determining factor, as regards the ability of the aquifer for the pollutants attenuation, with coarse grained materials having small ability

(Kazakis *et al*. 2008). According to the data available from borehole lithological columns, the aquifer media was classified into 4 classes. The weight of the parameter was estimated equal to 3 (Figure 3).

4.4 Soil media (S)

The soil zone is very important for the attenuation of the pollutant load, especially for pollutants such as nitrates. The attenuation below the root system of the plants is negligible. The flow of nitrate pollutants towards the aquifers ranges from 0.3 to 3 m/y, depending on the soil type, the climate and the type of crop (Juergens-Gschwind 1989).The soil media was classified into 4 classes and the weight of the parameter was set equal to 2 (Figure 3).

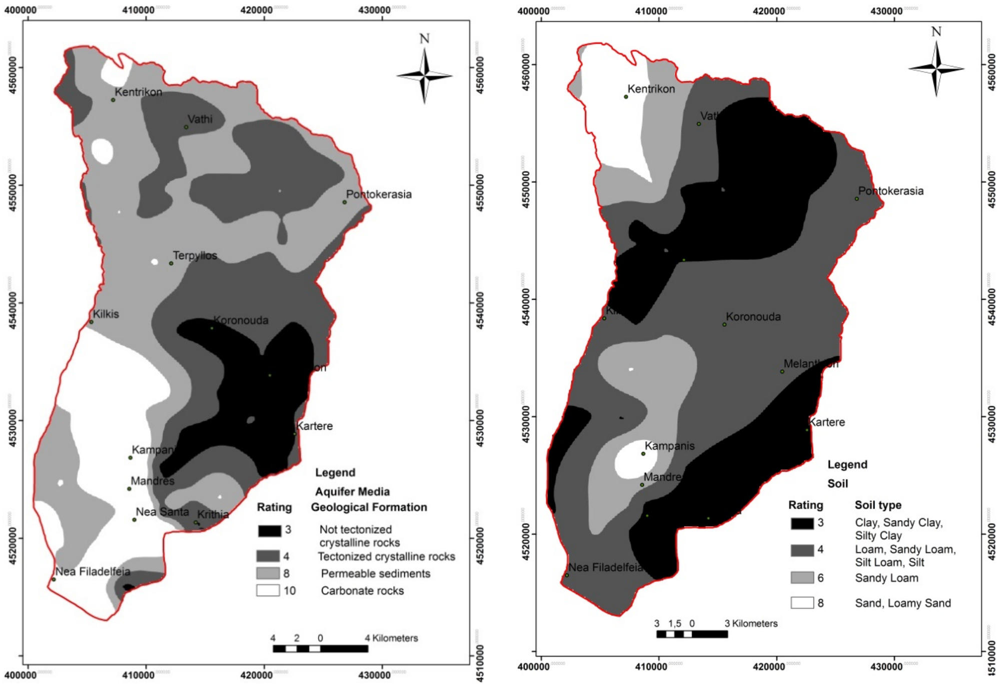

Figure 3. Thematic map of the parameters A (left) and S (right).

4.5 Topography (T)

The slope of the ground surface plays an important role in the vulnerability of an aquifer, since it forms favorable conditions either for infiltration or for surface run off. High slopes are in favor of surface runoff and, thus, of small vulnerability risk. The spatial distribution of the slope rating is depicted in Figure 4. The weight of the parameter is 1.

4.6 Impact of the vadose zone media (I)

Several chemical (i.e. adsorption, cation-exchange) and biological reactions take place in the vadose zone, resulting in the attenuation of the pollutants, the degradation of pathogenic microorganisms e.t.c. (Kazakis 2008). Therefore, the thickness and the composition of the vadose zone are very important. The big thickness in combination with the presence of clay, reduces the degree of an aquifer vulnerability. The weight of the parameter is 5. The data used for the estimation of the parameter were derived from the available borehole lithological columns (Figure 4).

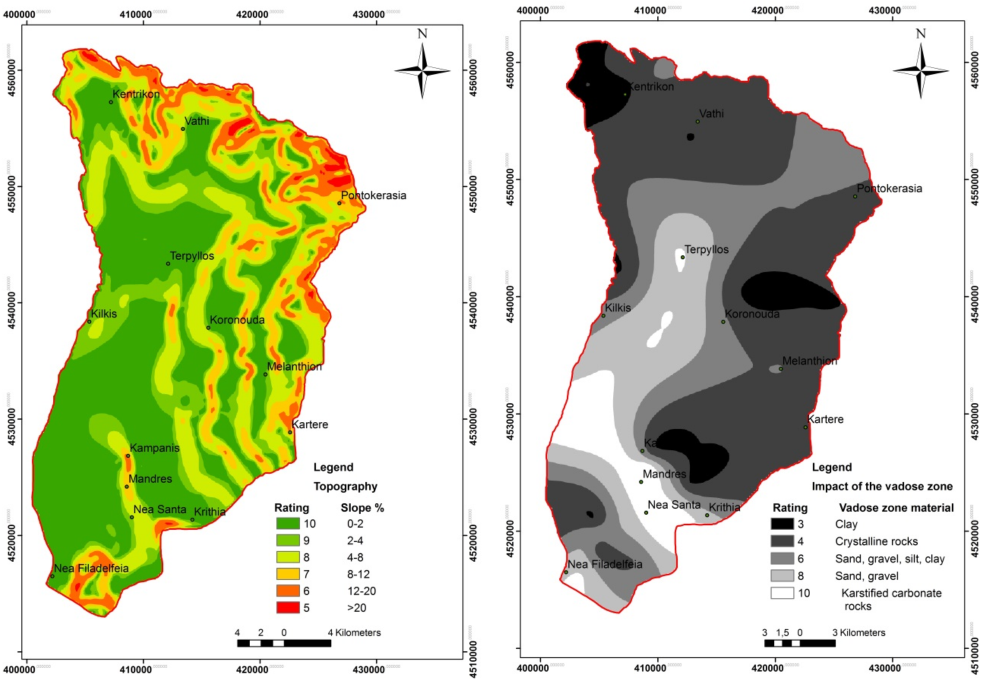

Figure 4. Thematic map of the parameters T (left) and I (right).

4.7 Hydraulic Conductivity of the aquifer (C)

The hydraulic conductivity of the geological formations was derived from literature (Morris & Johnson 1967; Soulios 2010; Mattas 2009) and available pumping test that had been conducted in the basin. Hydraulic conductivity is a measure of the ease with which the water can move through a porous material or fractures. The value of the hydraulic conductivity determines the velocity of the groundwater flow of an aquifer. The higher hydraulic conductivity values indicate higher vulnerability (Figure 5). The weight of the parameter was set equal to 3.

4.8 Groundwater vulnerability and risk assessment map

The DRASTIC vulnerability index is indicative for the ease of which a pollutant can reach an aquifer from the surface. The spatial distribution of the vulnerability index is depicted in Figure 5. The highest values are estimated for the west part of the basin, where permeable coarse grained sediments mainly outcrop. Towards the eastern part of the basin, the vulnerability index becomes progressive smaller given that the crystalline impervious rocks prevail at this area. The variation of the index values in the crystalline rocks are attributed to the different tectonic conditions. The crystalline formations at the north part have undergone a stronger tectonization than the eastern part, where the smallest values of vulnerability have been estimated. It should be mentioned that the pollution risk does not only depend on the vulnerability but also on the existence of pollution sources on surface, which is related to the land use. For the risk assessment of the groundwater resources in Gallikos basin, the CORINE Land Cover Map (Hazard Map) was used (Figure 6). The land use was used as an extra parameter to the applied DRASTIC methodology, with weight equal to 5. The Risk map of Figure 6 illustrates the areas that are the most probable to have groundwater quality degradation problems in the future.

The nitrates are the most common pollutant in agricultural areas. Being also, in many cases, a superficial pollutant, it can be considered as the most appropriate indicator to check the reliability of the Risk Assessment. High concentrations of sodium and chlorides had been recorded in the area during the field survey conducted in the period 2004-2006 (Mattas *et al*. 2005; Mattas 2009). These values are attributed to the operation of textile dyeing industries. The spatial distribution of the sodium and nitrate concentration, from the wet period (April) of 2005, is illustrated in the maps of Figure 7. The risk map was used as a background.

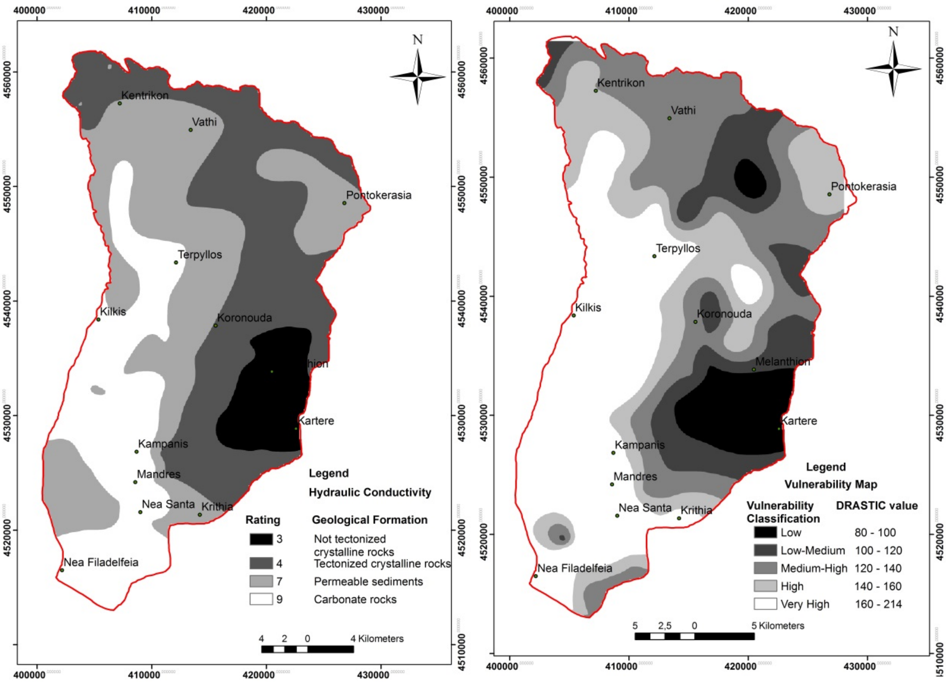

Figure 5. Thematic map of the parameter C (left) and the final vulnerability map (right).

The highest values of both pollutants are recorded in high risk areas that occupy the central-west part of the basin. These areas mainly coincide with those of high vulnerability index (due to the geological conditions), with operating industries, agricultural activities and higher population density. The disadvantage regarding the reliability of the method in this specific area, and for these specific indicators, is that in some cases the high concentrations of nitrates and sodium in the groundwater are attributed to the direct discharge of the effluent in the aquifer from septic tanks and industries (i.e. not from the surface). In any case, the latter is indicative of the bad management practices performed in the area from the inhabitants and the industries. This should motivate the authorities and decision makers to take the required measures. In order to achieve the effective reduction of nitrate groundwater pollution of agricultural origin through reduction and appropriate application of fertilization, the Code for Good Agricultural Practice (COGAP) should be implemented. Instead of simple discharging untreated waste into the local rivers, torrents and septic tanks, the construction of treatment plants for the appropriate waste effluent treatment would contribute greatly to the groundwater quality restoration. Finally, the education and training of the inhabitants on the implementation of European Laws and Directives on environmental protection and water resource management should not be underestimated (Mattas *et al.* 2014).

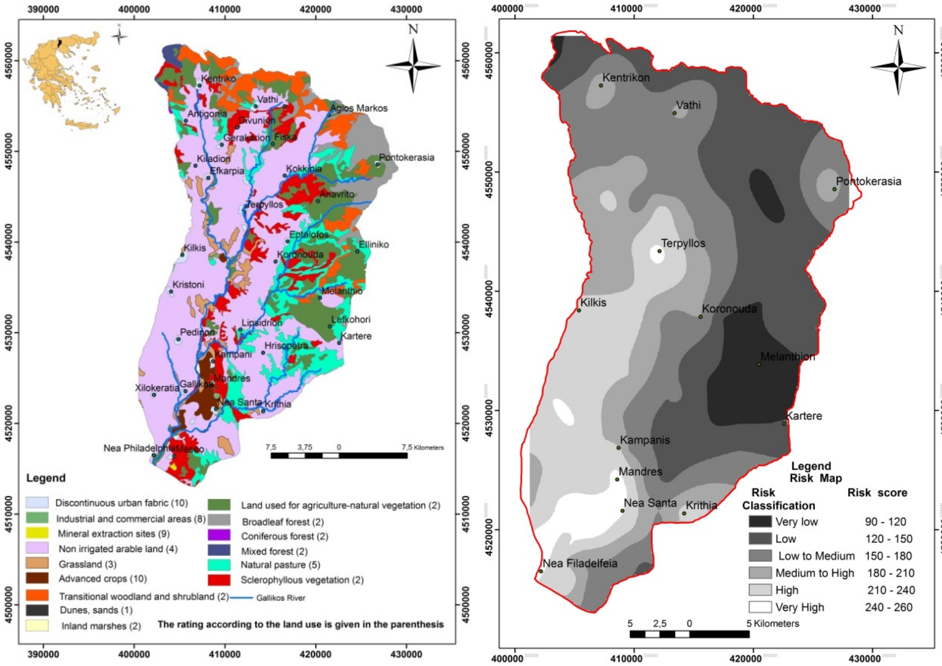

Figure 6. The CORINE (www.geodata.gov.gr) land cover map (left). The Final Risk Assessment Map of the Gallikos River basin (right).

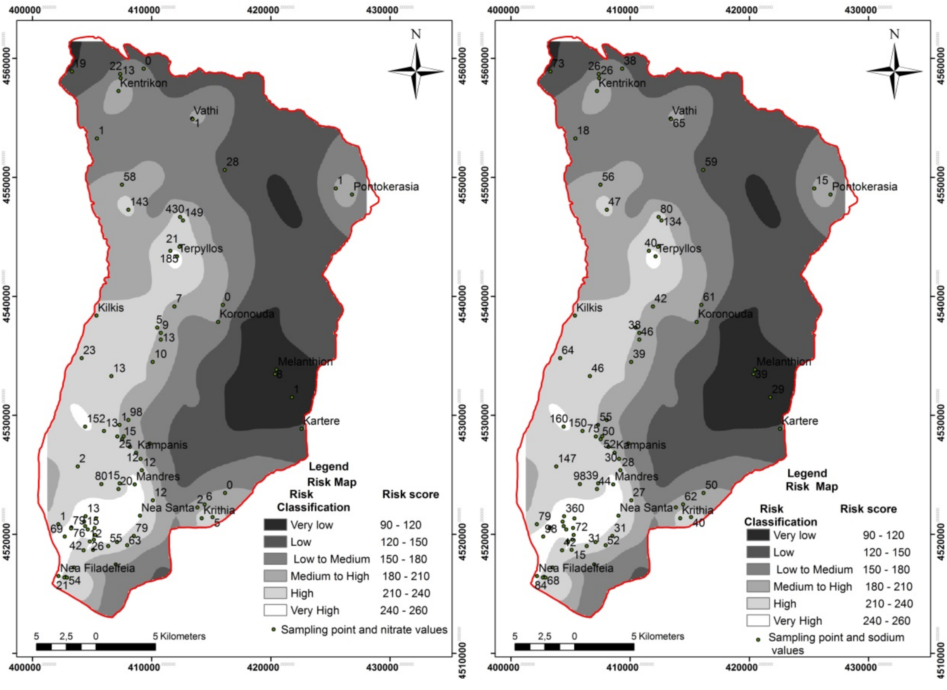

Figure 7. Nitrate values spatial distribution (left) and sodium values spatial distribution (right) in mg/L.

5. Conclusions

In the case of the Gallikos River basin, the application of DRASTIC method enabled the identification of the most vulnerable areas against aquifers pollution from external surface sources according to hydrogeological criteria. The majority of the basin, especially the western part, is classified as a high vulnerability area. This is mostly attributed to the existence of permeable sediments and strong tectonized crystalline rocks. The geologic conditions are different in the eastern part of the basin, resulting to the corresponding reduction of the vulnerability index values. The combination of land use and DRASTIC index, allowed the risk assessment of the basin. The higher risk values were estimated for the central-west part of the basin, where most of the anthropogenic activities occur and the majority of the inhabitants reside. The risk assessment is confirmed from the available data regarding the quality characteristics of the groundwater and the recorded degradation problems. It is imperative that the authorities should take the appropriate measures for the restoration and integrated management of the water resources, before the deterioration of groundwater quality is irreversible.

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