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HYDROGEOLOGY

DRASTIC-based methodology for assessing groundwater vulnerability in the Gümüşhacıköy and Merzifon basin (Amasya, Turkey)

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ABSTRACT

Preparing aquifer vulnerability maps has become crucial during recent years for preventing adding new ones to aquifers which have been contaminated due to environmental effects and been out of use. GIS techniques and DRASTIC method were used when preparing vulnerability maps for the basin in which the Gümüşhacıköy and Merzifon aquifers are located. Groundwater flow is approximately directed west-east and many villages are located across the aquifer in the basin which contains two sub-provinces and is characterised by intensive agricultural activity. DRASTIC layers were created when preparing vulnerability map, using parameters such as groundwater level, recharge, aquifer environment, topography and hydraulic conductivity. The aquifer vulnerability map was prepared by overlapping the layers by means of GIS. , three different vulnerability zones were determined in the Gümüşhacıköy basin according to DRASTIC scores low (<100), medium (100-140) and high (>140). Based on the vulnerability map, it was found that the Gümüşhacıköy Basin had a low contamination potential. It was established that 16% of the basin had high vulnerability and 47% low vulnerability. Areas having high vulnerability generally overlapped areas where the slope was gentle soil above the aquifer was permeable.

Key words: Vulnerability Mapping, DRASTIC, Geographic Information System (GIS), Turkey

RESUMEN

La preparación de mapas de vulnerabilidad acuífera se ha convertido en una actividad crucial en los últimos años para prevenir la contaminación por efectos ambientales de un afluente y su posterior inutilización. Técnicas GIS y el método DRASTIC fueron utilizados en la preparación de mapas de vulnerabilidad en la cuenca donde están localizados los acuíferos Gümüşhacıköy y Merzifon, en Turquía. El flujo de las aguas subterráneas corre aproximadamente Oeste-Este y varias poblaciones están ubicadas al paso del acuífero por dos subprovincias que se caracterizan por la actividad agrícola. Se crearon capas en el método DRASTIC cuando se preparó el mapa de vulnerabilidad con parámetros como nivel, recarga, ambiente del acuífero, topografía y conductividad hidráulica. La representación de vulnerabilidad se logró al sobreponer estas capas a través de técnicas GIS, lo que permitió determinar tres zonas diferentes de vulnerabilidad en la cuenca de Gümüşhacıköy basado en los puntajes del método DRASTIC: baja (<100), medio (100-140) y alta (>140). Con base en este mapa, se concluye que la cuenca de Gümüşhacıköy tiene un bajo potencial de contaminación. Se estableció que el 16 % de la cuenca es altamente vulnerable y el 47 % de baja vulnerabilidad. En aquellos lugares identificados con alto potencial de contaminación se suelen sobreponer áreas donde la inclinación de tierra sobre el acuífero es permeable.

Palabras claves: Mapa de vulnerabilidad, DRASTIC, Sistema de información Geográfica (GIS), Turquía.

Record

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Introduction

Groundwater has been considered as an important source of water supply due to its relatively low susceptibility to pollution compare to surface water. Groundwater quality is usually subject to contamination especially in agriculture-dominated areas having intensive activity involving the use of fertilisers and pesticides. Vulnerability assessment has been recognised for its ability to delineate areas which are more easily contaminated than others as a result of anthropogenic activity on/or near the earth's surface. Vulnerability studies can thus provide valuable information for stakeholders working on preventing further deterioration of the environment (Mendoza and Barmen 2006).

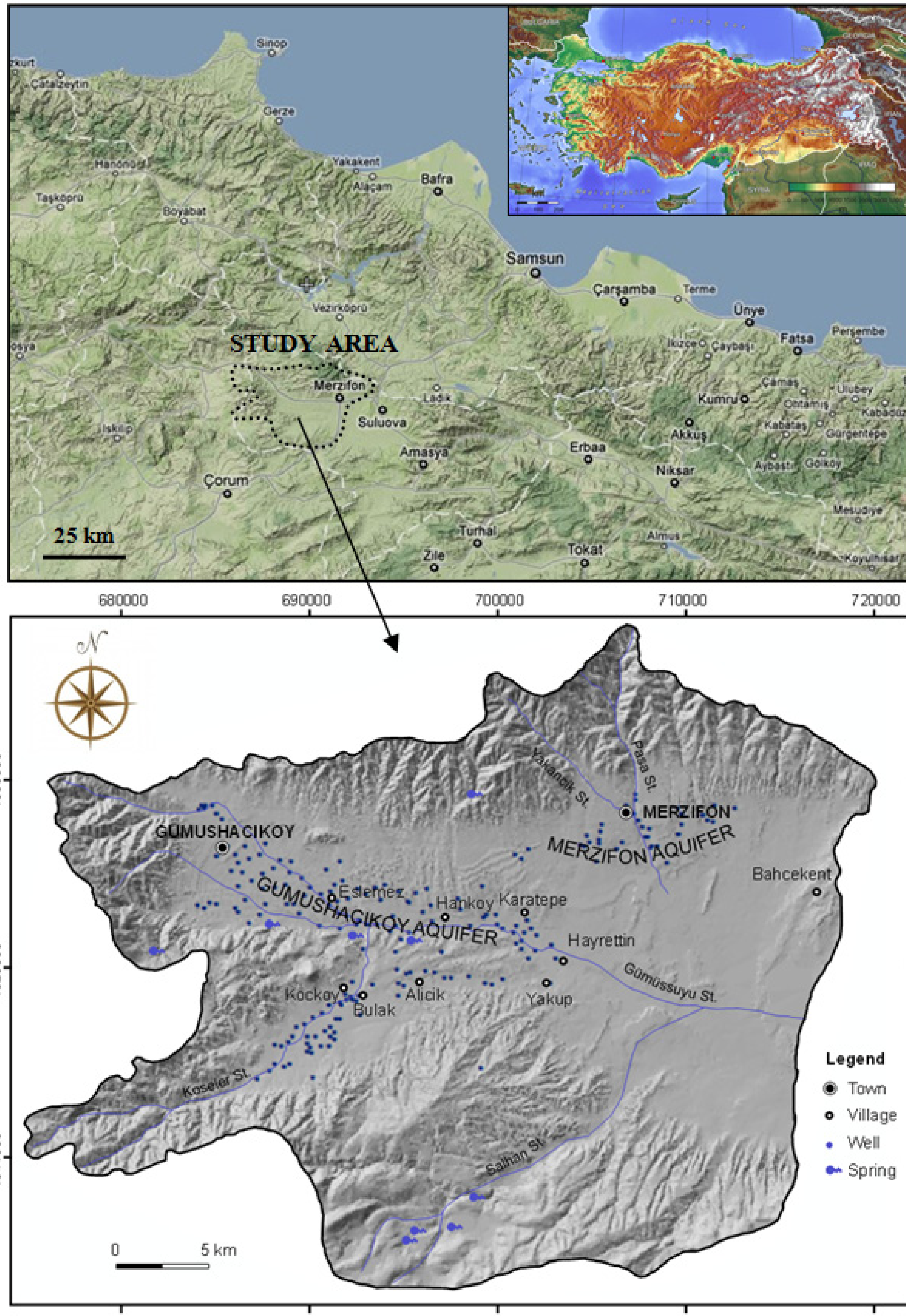

Figure 1. Location map of the Gümüşhacıköy-Merzifon basin (GMB)

The concept of groundwater vulnerability to contamination was introduced in the 1960s in France by Margat (1968). Several approaches for developing aquifer vulnerability assessment maps were adopted such as DRASTIC (Aller et al. 1987), GOD (Foster 1987), AVI (Van Stempvoort et al 1993), and SINTACS (Civita 1994). Conventional methods (i.e. DRASTIC, AVI, GOD, SINTACS) can distinguish degrees of vulnerability on a regional scale involving different lithology (Vias et al 2005). DRASTIC is a familiar method developed for the US Environmental Protection Agency (EPA) by Aller et al (1987) it has been used in several regions (Merchant 1994; Melloul and Collin 1998; Cameron and Peloso 2001; Al-Adamat et al 2003; Baalousha 2006; Jamrah et al 2007; Sener et al 2009; Massone et al 2010).

The area studied in this research is located in Amasya (mid Black Sea region), namely the Gümüşhacıköy-Merzifon Basin (GMB) (Figure 1). Groundwater is the major source of irrigation in the Amasya District in Turkey. Surface water has been the main source of water supply for irrigation during the last few decades (Fırat Ersoy and Gültekin 2008). However, water demand has increased and groundwater is now used as a secondary source. Annual groundwater exploitation yield was only 3.5x10^{6}m^3 during the 1970s, and rose to 5.5x10^6 m^3 in 2005 (Fırat Ersoy, 2007). Due to the excessive exploitation of groundwater, water levels have significantly decreased. Groundwater quality has also been affected by over exploitation. The town of, Gümüşhacıköy is located in this basin. Some well water's nitrate concentration has reached 15.6 mg/l in the Gümüşhacıköy Basin. Nitrite and ammonium concentration have reached 0.03 and 0.3 mg/l respectively, around the town (Fırat Ersoy et al, 2006).

This paper was aimed at assessing groundwater vulnerability to pollution in a shallow aquifer using the DRASTIC model and geographical information system (GIS) techniques combined with hydro-geological data layers, i.e. depth of water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity. A vulnerability map, showing high, medium and low vulnerability areas was produced for the mentioned basin.

Study area

The GMB covers a 1,060 km^2 area elevation ranging from 550- 1,873 m (Figure 1). Average annual rainfall is 458 mm average annual temperature is 13.6°C (URL-1) and the average annual potential evaporation is 680 mm (Fırat Ersoy, 2007). The most important body of surface water flowing through the basin is the Gümüşsuyu River, which discharges 8.5x10^{6}m^3/year (Fırat Ersoy, 2007). Groundwater in the basin draws from both alluvium aquifers, one being confined, (the Gümüşhacıköy aquifer) and the other unconfined (Merzifon). Agriculture is widespread in the basin, and fertiliser and pesticide application have caused groundwater contamination through leaching. 193 wells had been drilled in the GMB up to 2006, 173 wells were aimed at irrigation, and 20 well for domestic purposes.

Geology

The Paleozoic metamorphic rocks in the study area, represent the oldest formation. These rocks consist of clayey schist, chlorite schist and green schist, marble and re-crystallised limestone. Upper Jurassic-Lower Cretaceous limestone, in the area has fossils which are generally compact, thick-bedded, very hard and fissured lower Cretaceous limestone is pink, very hard, thick bedded and micritic, overlying Jurassic limestone. Cretaceous limestone outcrops on the plain. The flysch series having mixed volcanic material composed of conglomerate, green and black sandstone, shale, marl, limestone, andesite, tuff and tuffite are deposited in the Upper Cretaceous limestone. Cenozoic beds started with the Middle Eocene age flysch series in the study area. Flysch consists of sandstone, shale, sandy limestone, marl, local conglomerate, tuff and agglomerate. The Miocene series consist of thick blue claystone and marl and the Pliocene beds of micro conglomerate, sandstone, sand, clay, gravel and a mixture of these layer thickness ranges from 10 to 50 cm in these series. The very loose layers are not continuous and change their lithology over short distances. This unit gradually become harder as one goes deeper and turns out to be conglomerate. Some blocks of the gravels are 50 cm thick and about 5-10 cm-in diameter 95% of such gravel and blocks are usually rounded and are composed of volcanic material. The Quaternary is characterised by alluvium and an alluvium cone consisting of detrical material that comes from north and south with the flood waters. Alluvium and cone (10-60 m thick) take the form of gravel, sand, clay and a mixture of these, along the Gümüşsuyu, Köseler and Salhan Rivers.

Hydrogeology

The GMB's hydrogeological setting has been outlined by Fırat Ersoy (2007). The most impotant geological units for groundwater transport in the basin are Quaternary alluvium and Pliocene clay, sand, gravel and a mixture of these. Unconsolidated Quaternary and Pliocene sediments are around 350 m thick. The other units underlying the alluvium do not bear significant amounts of groundwater. The GMB can be divided into discrete hydrogeological units, including permeable (alluvium), semi-permeable (weak cemented pebble and sandstone, silty clay and volcanic rocks) and impermeable (massive marble and limestone, silty clay and schist).

Alluvial materials and the Pliocene units consisting loosely cemented pebbles, sand and clayey-silt materials outcrop in most parts of the basin. Known as the Gümüşhacıköy aquifer, this part is crucial to groundwater storage and transfer since it is characterised by high conductivity and storage capacity. Deposits have a heterogeneous structure, being formed as alluvial cones at the end of tributary rivers. The alluvial cone formed by the alluvial unit of the Paşa and Yakacık river is called the Merzifon aquifer. Well logs show that the cone's middle sections consist of clayey levels between pebble and sand layers and that level becomes thin along the eastern edge, dominated by clay and silt. Since the section between the east of the Gümüşhacıköy aquifer and the south of the Merzifon aquifer consists of Miocene clay and marl, it is not important in terms of groundwater.

The Late Eocene volcanic rocks outcropping across the north, northwest and northeast of the basin form a catchment area with their fractured and fissured structure. Natural discharge in the basin is provided by a stream flowing through it from west to east. The Gümüşhacıköy aquifer naturally discharges into the Gümüşsuyu river, located in the east of basin.

The basin contains numerous springs discharging from geological units, faults and fractures. Some are exploited as potable for drinking water and others are used for irrigation, consequently recharging the groundwater. The springs' total flow rate is 720 l/sec.

Three ponds in the basin are used for irrigation. Infiltration into the groundwater from these ponds has been estimated as being 41.5 m3/year on average (Fırat Ersoy, 2007).

The basin contains 193 wells, 167 in the Gümüşhacıköy aquifer and 26 in the Merzifon aquifer (DSİ, 2006). Well depth varies from 39 to 290 m and pump flow-rates from 5 to 60 l/sec (DSİ, 2006). As most of these wells are used for irrigation, pumps operate from May to October. The increased number of wells drilled in the aquifer during recent years and accordingly, the increased amount of water pumped from the aquifer has resulted in a decrease in groundwater level by 15 to 20 m (DSI, 2006).

Several pumping tests have been performed at existing wells in the Gümüşhacıköy and Merzifon aquifers. Data interpretation has indicated 89.7-1727 m^2/day transmissivity, 0.76- 19.17 m/day hydraulic conductivity and 1.5x10-^{5}- 7.9x10-^{3} storage coefficient for the basin (Fırat Ersoy, 2007).

Materials and Methods

DRASTIC, proposed by the US Environmental Protection Agency (Aller *et al.,* 1987) and its modification termed SINTACS (Civita, 1994),

Table 1 DRASTIC Weighting factors (Aller et al. 1987)

Parameter	Range	Rating	Description	Relative weighting
Depth to water (D) (feet)	0-5 5-15 15-30 30-50 50-75 75-100 >100	10 9 7 5 3 2 1	Refers to the depth to the water surface in an unconfined aquifer. Deeper water table levels imply lesser chance for contamination to occur. Depth to water is used to delineate the depth to the top of a confined aquifer.	5
Net recharge (R) (in)	0-2 2-4 4-7 7-10 >10	1 3 6 8 9	Indicates the amount of water per unit area of land which penetrates the ground surface and reaches the water table. Recharge water is available to transport a contaminant vertically to the water table, horizontal with in an aquifer.	4
Aquifer media (A)	Massive shale Metamorphic/igneous Weathered met./igneous Bedded sandstone, Limestone, Shale sequences Massive sandstone Massive limestone Sand and gravel Basalt Karst limestone	2 3 4 6 6 6 8 9 10	Refers to the consolidated or unconsolidated medium which serves as an aquifer. The larger the grain size and more fractures or openings with in an aquifer, leads to higher permeability and lower attenuation capacity, hence greater the pollution potential.	3
Soil media (S)	Soil thin or absent Gravel Sand Peat Shrinking and/or aggregated clay Sandy loam LoamSilty loam Clay loam Muck Non-shrinking and non-aggregated clay	10 10 9 8 7 4 5 4 3 2 1	Refers to the uppermost weathered portion of the vadose zone characterised by significant biological activity. Soil has a significant impact on the amount of recharge which can infiltrate into the ground.	2
Topography (T) (slope%)	0-2 2-6 6-12 12-18 >18	10 9 5 3 1	Refers to the slope of the land surface. It helps a pollutant to runoff or remain on the surface in an area long enough to infiltrate it.	1
Impact of vadose zone (I)	Silt/clay Shale Limestone Sandstone Bedded limestone, Sandstone, shale Sand and gravel with significant silt and clay Metamorphic/igneous sand and gravel Basalt Karst limestone	1 3 6 6 6 6 4 8 9 10	Is defined as unsaturated zone material. The significantly restrictive zone above an aquifer forming the confining layers is used in a confined aquifer, as the type of media having the most significant impact.	5
Hydraulic conductivity (C) (GPD/ft2)	1-100 100-300 300-700 700-1,000 1000-2,000 >2,000	1 2 4 6 8 10	Refers to the ability of an aquifer to transmit water, controlling the rate at which groundwater will flow under a given hydraulic gradient. material within the groundwater system	3

are two methods for evaluating vertical vulnerability based on the following seven parameters: depth to water (D), net recharge (R), aquifer media (A), soil media (S), topography (T), vadose zone impact (I), and hydraulic conductivity (C) Figure 2). Each mapped factor is classified into ranges (continuous variables) or significant media types (thematic data) having an impact on pollution potential. Weighting multipliers are then used for each factor to balance and enhance their importance, the typical rating ranging from 1 to 10 (Table 1). The final vulnerability index is a weighted sum of the seven factors.

The DRASTIC index (Di) can be computed using expression (1):

$$Di = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw \quad (1)$$

Di DRASTIC index for a mapping unit
w weighting factor for each parameter
r rating for each parameter
D, R, A, S, T, I, and C the seven parameters

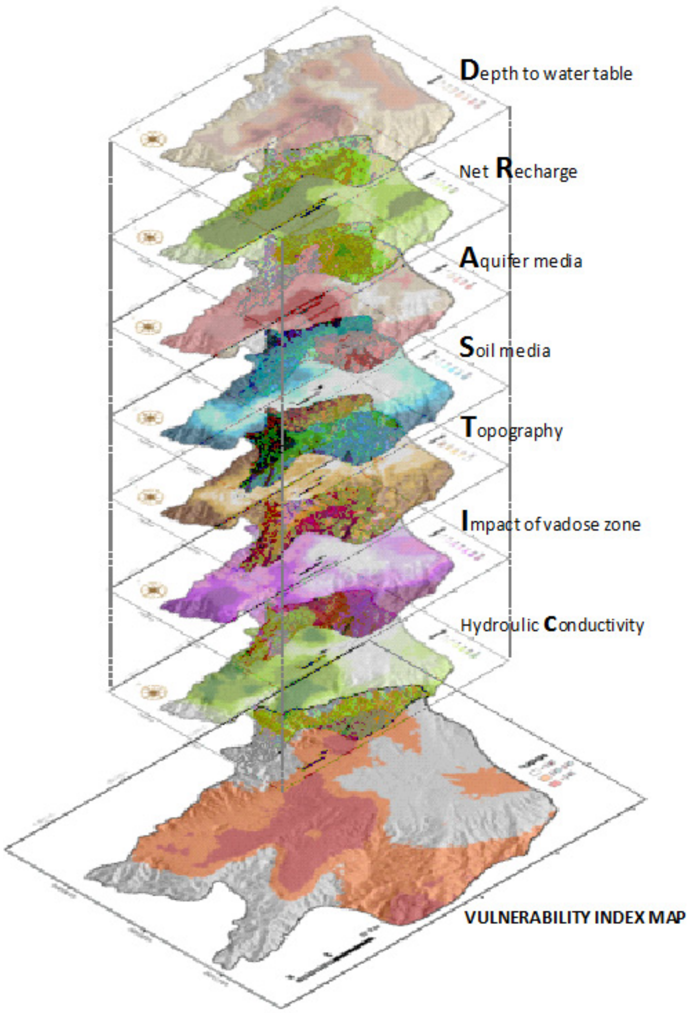

Figure 2. DRASTIC Method flowchart

Results

Depth to water (D)

Depth to water is defined as the distance (in meters) from the ground surface to the water table. Groundwater table depth in the GMB has been measured since 1976. This present study, has used the 2005 values for groundwater table depth. The 167 wells' location was digitised from the accompanying digital elevation model (DEM).Groundwater table depth changed between 9-40 m in the GMB the Merzifon aquifer has the lowest groundwater depth in the GMB. The deepest groundwater occurred at the end of the impermeable layer over the aquifer media in the mostly confined Gümüşhacıköy aquifer. The depth to water table map was then classified into ranges defined by the DRASTIC model and assigned rates ranging from 1 (minimum impact on vulnerability) to 10 (maximum impact on vulnerability) (Figure 3).

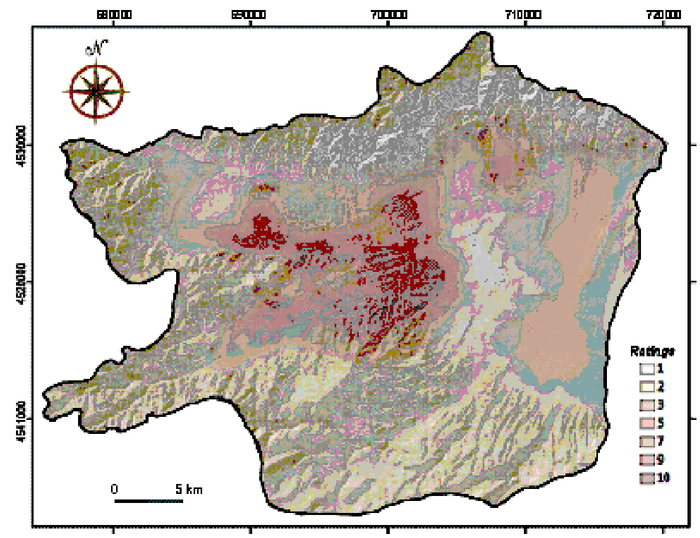

Figure 3. Depth to water table map of the study area

Net recharge (R)

Net recharge is the total quantity of water infiltrating from ground surface to an aquifer on an annual basis. Local recharge in the study area comes from inflow by the Gümüşsuyu river and its branches, irrigation return flow and direct recharge. The main groundwater recharge source are the Gümüşsuyu River, springs, located high in the basin, and irrigation leakage. The average direct annual volume of recharge into the aquifer from the surface of the basin and from the springs is about 11334316 m^3 (Fırat Ersoy, 2007). Irrigation pond canals contribute 41.5 m^3 recharge in the area (Fırat Ersoy, 2007) the recharge map was then classified into ranges and assigned ratings from 1 to 8 (Figure 4).

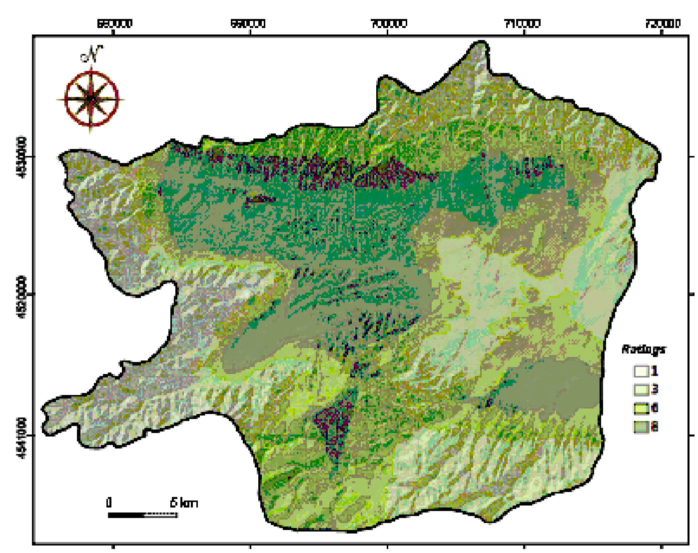

Figure 4. Net recharge map of the study area

Aquifer media (A)

Aquifer media refers to consolidated or unconsolidated rock which serves as an aquifer. The main aquifer being exploited and that most vulnerable to contamination is partially confined, here called the Gümüşhacıköy aquifer the central and northern parts of the Gümüşhacıköy aquifer are confined. The clayey layer over high permeability uncemented sediments is 2- 10 m thick from the drilling data. Clayey layer thickness of gradually changes from the centre to the north of the basin. The Merzifon aquifer is unconfined. The aquifer media was obtained using a subsurface geology map, geological sections, and drilling profiles of the Gümüşhacıköy and Merzifon aquifers. The main aquifer includes Quaternary alluvium and Pliocene gravel, sand and clayey levels. The Merzifon aquifer's alluvial fan is relatively thin, consisting of coarse-grained gravel and sand with silt and clay interbeds. The aquifer media were mapped as shown in Figure 5.

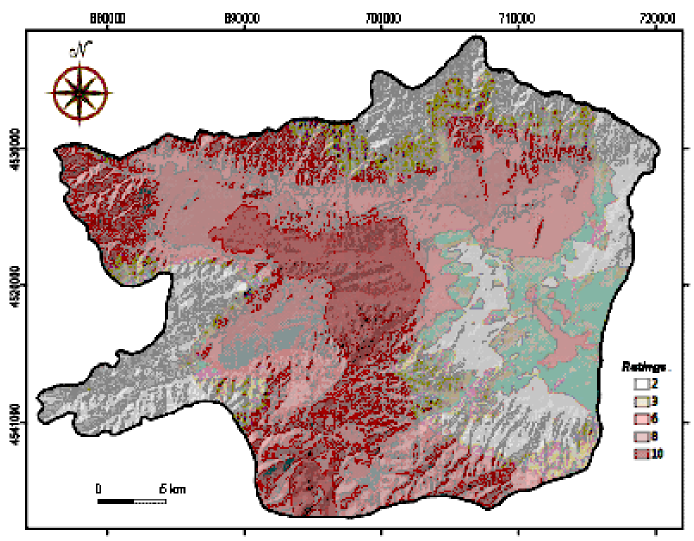

Figure 5. Aquifer media map of the study area

Soil media (S)

Soil media refers to the uppermost portion of the vadose zone characterised by significant biological activity. Soil plays a significant role in the amount of recharge which can infiltrate into the ground and hence on a contaminant's ability to move vertically into the vadose zone. A soil's pollution potential is largely affected by the type of clay present, such clay's shrink/swell potential, and soil grain size. Soil media in the GMB was determined using drilling profiles. The Gümüşhacıköy and Merzifon aquifers are covered by clayey gravel and sand and alluvial plains. Fractured volcanic rocks are located west and south-west of the GMB and limestone outcrops south of the basin. Thickness over the volcanic rock and limestone gradually changes form bottom to top, the hills especially, having little or no soil. The soil media map was then classified into ranges and assigned ratings from 3 to 10 (Figure 6).

Topography (T)

Topography refers to land surface slope variability. Slope degree will determine the extent of pollutant runoff and settling long enough to infiltrate. A digital elevation model (DEM) was used to extract the slope of the study area, while 27% of the GMB has a gentle slope, most of the basin has a steep slope. The areas in the extreme east and south consist of ridges which may reach 1050 m.. The topography has been mapped as shown in Figure 7.

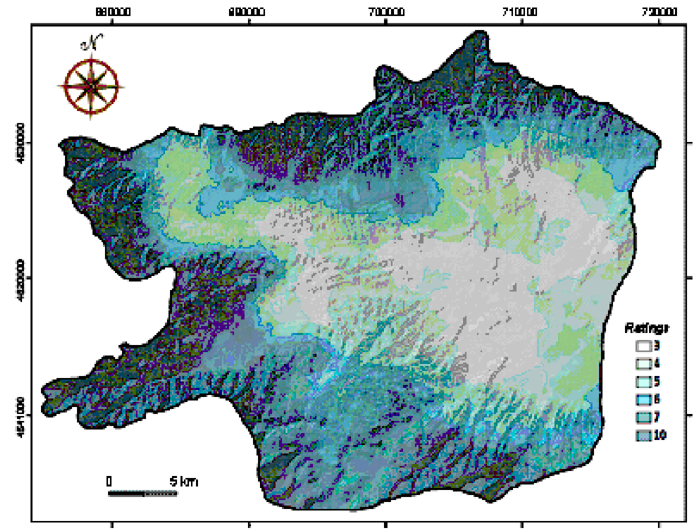

Figure 6. Soil media map of the study area

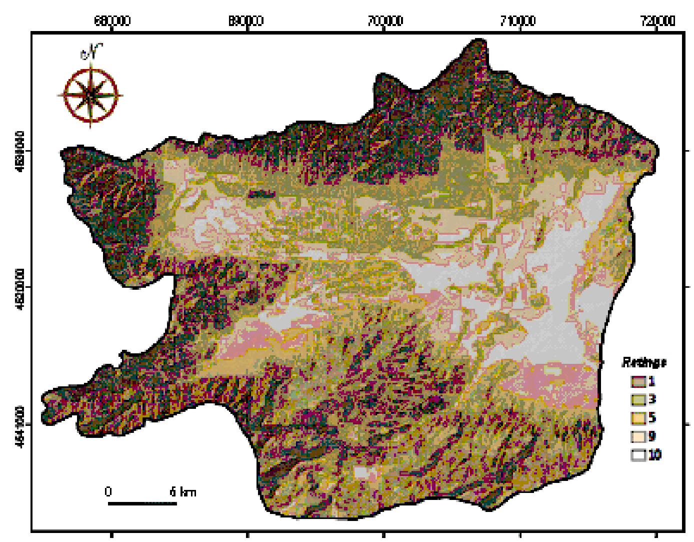

Figure 7. Topography map of the study area

Vadose zone impact (I)

The vadose zone is defined as the zone above the water table which is unsaturated. Unconsolidated clayey gravel and sand represents the vadose zone in the plain, volcanic rocks and limestone is the vadose zone in the mountain areas. The map of vadose zone impact is shown in Figure 8.

The aquifer's hydraulic conductivity (C)

Hydraulic conductivity is important because it controls the rate of groundwater movement in the saturated zone, thereby controlling the degree and fate of contaminants. Hydraulic conductivity values used in this study were derived from pumping test data. Hydraulic conductivity varied from 8.79×10^{-6} to 2.21×10^{-4} m/s in alluvium (Fırat Ersoy, 2007). The hydraulic conductivity of the other rock in the basin was available from the pertinent literature. Hydraulic conductivity values for various rock types have been proposed by Domenico and Schwartz, (1990). The hydraulic conductivity of the limestone and fractured volcanic rocks, located in the west and south part of the basin, were 10^{-3} m/s and $3x10^{-4}$ m/s, respectively. Clayey unit permeability is 10^{-9} to 10^{-10} m/s. Hydraulic conductivity rating distribution is shown in Figure 9.

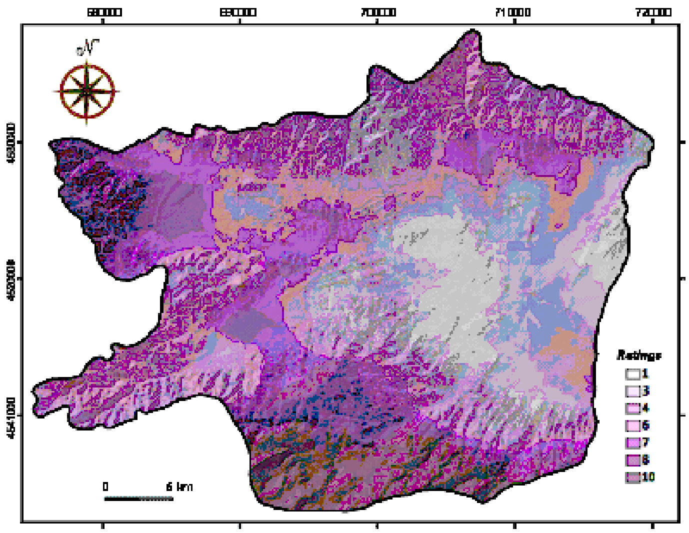

Figure 8. Vadose zone impact map of the study area

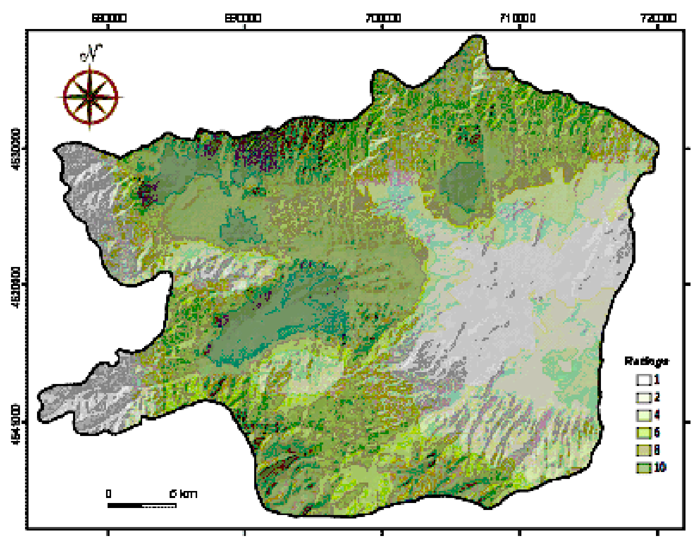

Figure 9. Hydraulic conductivity map of the study area

The aquifer vulnerability map

The vulnerability map was obtained using the seven hydro-geological data layers in the ArcView GIS software environment. DRASTIC scores ranged from 58 to 177, taking into consideration the determined ratings and weightings. These values were reclassified into three classes using the Natural Breaks (Jenks) classification method. The study area's vulnerability was classed as low (<100), medium (100-140) and high (>140) according to data obtained from hydrogeological investigations (Figure 10).

The GMB's high groundwater vulnerability risk zones were mainly located in the centre of the basin where some villages are located and also in the northern and southern parts of the basin. These vulnerable zones covered around 16% of the studied area. Four springs in the southern area had as high vulnerability risk.

The GMB's middle groundwater vulnerability risk zones were mainly located in the groundwater recharge area (Figure 10), these vulnerable zones covered around 37% of the studied area. The GMB's low groundwater vulnerability risk zones were mainly located in the west and south-east of the study area (Figure 10), these vulnerable zones covered 47 % of the studied area.

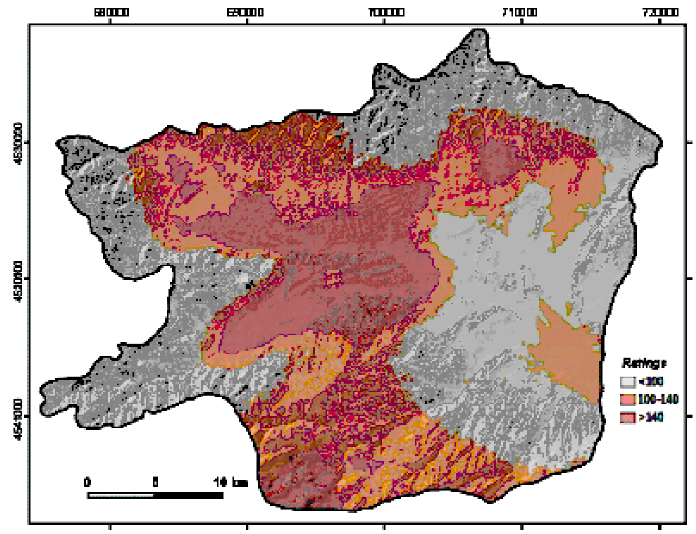

Figure 10. Vulnerability index map of the study area

The resulting vulnerability map indicated that the highest potential areas for contamination were the central part of the basin where the slope is gentle. In the southern area where karstic limestone outcropped, the high DRASTIC index probably represented the effects of aquifer media and hydraulic conductivity. Impermeable volcanic rocks and clay, silty-clay units located in the west and east respectively had low DRASTIC index.

Conclusions

The Merzifon-Gümüşhacıköy (Amasya-Turkey) Basin is an important agricultural centre for the central Black Sea section groundwater is a major water source for such activity. Groundwater quality has deteriorated due to excessive abstraction of groundwater. This study involved using a GIS model and the DRASTIC method for determining the vulnerability of the groundwater in the basin. The aquifer vulnerability map was prepared using depth to water, net recharge, aquifer media, soil media, topography, vadose zone impact, and hydraulic conductivity. The study area was divided into three zones according to groundwater vulnerability assessment results: low (risk index <100); middle (risk index 100–140) and high groundwater vulnerability risk (risk index >140).

The DRASTIC method results should be useful in designing aquifer protection and management strategies. The DRASTIC index map indicated that overall potential for groundwater becoming polluted was low for the GMB. Low sensitivity areas lay outside the agricultural areas in the basin. The alluvium and most Pliocene sediments were used for agriculture in the GMB. The town of Gümüşhacıköy is located on an aquifer recharge area. Areas determined by the DRASTIC method should thus be given priority in research in terms of contamination. High nitrate concentrations were mainly near urban areas according to the the study area's analysis (Fırat Ersoy et al, 2006). High nitrate concentration was likely to be related to wastewater leakage from industrial activities, urbanisation and agricultural practices.

Two towns and many villages were situated in the study area involving agricultural activities many wells were used for springs. The prevention of groundwater pollution caused by waste and wastewater in Gümüşhacıköy's recharge area was significant owing to groundwater flow being west to east in the basin. Regarding urban planning and organisation of agricultural activities in the Merzifon and Gümüşhacıköy districts, the vulnerability risk map prepared in the study could be most important when considering protection off groundwater quality

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