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GIS-BASED DRINKING WATER WATERSHED MANAGEMENT: A CASE STUDY OF THE GALYAN WATERSHED IN TURKEY

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Abstract

Water is one of the most important resources for sustainable development and human life. To meet future water needs, water resources and drinking water watersheds (DWWs) should be placed under protection using efficient methods. The spatial planning and spatial data has an important role in sustainable DWW management. Geographical Information Systems (GIS) is extensively used for spatial data production effectively based on spatial planning. The use of large-extended data, the analyzing of the maps which have no standard with data layered and the prevention of separation between administrative jurisdictions depending on administrative boundaries are possible with using GIS. In this paper since emphasized on the effectiveness of GIS in DWW management in the Galyan Drinking Water Watershed (GDWW), a sub-watershed of the Degirmendere Watershed, which supplies drinking water to Trabzon City, Turkey, is used as a case to study. The results of the study show that the agricultural chemicals and fertilizers used for hazelnut and cultivated farming to threaten the quality of drinking water in a significant part of the watershed (30%). Approximately 72% of the GDWW area is at risk of landslides, and the region as a whole is under threat because of widespread mining activities. The distances between the mining areas and the streams feeding the watershed were investigated. It was found that all the active ore beds are within 1,000 m of the rivers. Moreover, while the average distance of the ore beds to the streams is 253 m, the distance of the active ore beds is 357 m. According to the analysis results of the study, with GIS-based DWW management, decision makers can see where and what type of change has occurred in the area in use; therefore, it can provide requirements for the environmental and economical sustainability of the area in the future.

Key words: GIS, Water Resources Planning, Watershed Management

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Abstract
Water is one of the most important resources for sustainable development and human life. Recently, problems caused by the increasing population, urbanization, industrialization, unconscious fertilization and environmental pollution have become serious threats for Drinking Water Watersheds (DWW). To meet future water needs, water resources and DWW should be placed under protection with efficient methods. Unfortunately, preserving, planning and sustaining the maintenance of the wide-reaching DWW under the responsibilities of different administrative units are particularly difficult. In this study, the projected advantages of using a Geographical Information System (GIS) to improve the administration of the DWW that supply drinking water to settlement areas were investigated. The Galyan Drinking Water Watershed (GDWW), a sub-watershed of the Degirmendere Watershed, which provides drinking water to Trabzon City of Turkey, was selected as the field of application. The results of the study showed that GIS technology allowed for rapid assessment, analysis and visualization opportunities to assist with watershed management.

Keywords
GIS; Water Resources Planning; Watershed Management

INTRODUCTION

Recently, the rapid increase in urbanization and industrialization and the unconscious usage of current water resources or water basins has led to negative sociological, ecological and economical results (UN Report, 2009). These bad consequences have been exacerbated by incorrect decisions and applications of various administrative units. Preserving, planning and sustaining the maintenance of the wide-reaching watersheds are difficult under the responsibilities of different administration units (Frank, 2003; Moss, 2004; Karadag, 2007) Mismatches between the administrative borders and the natural borders of the DWW have prevented administrative activities from reaching the desired level. On the other hand, the management decisions that the administrative unit in the DWW area undertakes might create risks for the other administrative units that have borders of responsibility that also include some portion of the watershed.

The potential of drinkable water per capita in Turkey is about 1600 m^3/year, which, compared with the world average and values from other countries, places Turkey among the less water-rich countries. If it is true that the population of Turkey will reach 80 million by 2025, then the estimated amount of available water per capita will be reduced to 1375 m^3/year by 2025. Given the current growth rate, with the effects of factors, such as changes in water usage habits, it is easy to estimate the possible pressure on water resources. All these estimates predict that plenty of water would be available if the current resources can be left to the future without any damage. Therefore, to leave sufficient and healthy water to the future generations, Turkey should preserve and use its water resources in an efficient way (Akkaya et al., 2006). However, the water quality in Turkey cannot be kept at the required level, and the necessary data banks cannot be established. Except for in some big cities in Turkey, DWW management rules do not exist. Furthermore, even in those big cities, water resources cannot be preserved as they should be.

With the recent developments in this decade, the world has begun to understand the importance of "Integrated Water Management" as a solution for the worldwide water crisis. To this end, the European Union (EU) shaped its water policies and declared that it accepted the watershed based management approach with the "Water Framework Directive" (WFD), which was put into effect in December of 2000. The directive aims to protect and control both the quality and the quantity of the water sources. As a result, Europe has begun implementing an efficient policy to protect its water sources (Orhon et al., 2002).

Contrary to the EU water policies, Turkey still follows the hydraulic mission, which is majorly about supply augmentation. Nevertheless, Turkey has also experienced the negative impacts of wide spread water resources development. Hence, Turkey has adopted methods like demand management and assessments of environmental impacts. Kibaroglu et al (2007), stated that, within the context of "integrated basin management," WFD gives a priority to completion of "river basins management plans" until 2009 together with identifying detailed negative "impacts" on ground and surface water in related river basins, and "measures" and "sanctions" that will be put into practice for those impacts. However, among the crucial factors in making the river basin management plans, the 'impacts of "existing situation" and mitigation are the most important ones; while "economic analysis", remained in the last row. Moreover, whereas EU defines "future uses" of water as "risks," Turkey does not regard building of new infrastructures (dams and irrigation systems) as "risks" for water resources development. Conversely, in Turkey building of new infrastructure is regarded to have positive effects on socioeconomic development. Conducting river basin management plans in such a vacuum, that is; in isolation from the macroeconomic analysis is not an appropriate policy in the IWRM framework. Hence, the WFD has a "narrow" approach concerned solely with "impacts" and "measures". The Turkish case reveals the deficiencies or the gaps in the general principles of the WFD, indeed. Nonetheless, Turkey has to handle water resources development painstakingly by taking into consideration the environmental, social and economic impacts. This understanding might also be used in formulating a possible future framework national law in the country.

It is seen that the WFD has been supporting a DWW management amendment on the issue of DWW management. The European Parliament and Commission suggest that all member states should determine their surface watersheds and establish administrative arrangements and administrative units to apply the directives, in addition to determining the specialties of the watersheds, performing an analysis of the water usage, and preparing a management plan for each and every DWW (Nisanci et al., 2007). The approach of developing an administration in the governmental border is usually not accepted on the grounds that system treatments and relations cannot be put forward if the hydraulic system is managed separately. Therefore, institutions who have the authority to decide the governmental borders should establish a healthy and efficient water source management to provide the most appropriate operation of water resources in the area by involving applications in the DWW (Meric, 2004).

The development and application of a management model is necessary for meeting all these requirements. A Geographical Information System (GIS) is an efficient tool that could be used to develop such models (Vieux, 2006; Cesur, 2007; Wienand et al., 2009). GIS is used to process geographical data in a digital form. A GIS is a suite of computer-based tools that can efficiently generate, store, analyze, retrieve, manipulate, manage, and graphically display complex spatial data (Kyu et al., 2002; Grayson et al., 2008). Among its facilities are the ability to prepare data for analysis or direct modeling and displaying the results after the process. A GIS can be used to convert a DWW management database that was prepared by traditional methods into spatial data that can be displayed through an integrated layout of the earth. This can be achieved through investigating and including various social, economical and environmental factors depending on the ways in which the water source problems are expressed. The visualization capacity of a GIS on water source models provides the user with much more facilities than traditional methods. With GIS-based DWW management, decision makers can see where and what kind of change has occurred in the area in use; therefore, it can provide requirements for the environmental and economical sustainability of the area in the future. That is, it provides rapid and quick responses to the following questions: What should be done during the process of planning and deciding the field usage in the GIS-based watershed management? And how should we do it? (Rao and Kumar, 2004).

METHODS and RESULTS

Needs Analysis and Model Requirements

The main objective of watershed planning strategies should be to preserve natural resources, revive nature and manage sensitive resources in a sustainable way (Erturk et al., 2007). For such a planning perception, it is necessary to store data and the primary resources for planning in a shared database to complete the necessary analysis efficiently.

Some other important issues include unplanned urbanization in the DWW thought to be used for drinking water supplies in cities, opening indoor or outdoor mining areas, and ongoing agricultural activities in which damaging fertilizers are used. However, in a DWW system, the first course of action is to decide what kind of operations to perform by planning around the primary concerns. To do such planning, it is necessary to store the data in a spatial database and to complete the necessary analysis for planning.

A survey study conducted on 235 knowledgeable and equipped specialists about DWW management revealed that GIS methods and the spatial data should be used efficiently (Table 1).

Table 1. The Necessity of Using Spatial Data and GIS Methods.

Ministry	*Institutions*	*Specialists*	*Spatial Data Needs*		*GIS Needs*	
			Yes	*No*	*Yes*	*No*
Ministry of Interior	*Metropolitian Municipality*	29	%95	%4	%92	%7
	Province Municipality	36	%98	%2	%91	%9
	Town Municipality	67	%90	%9	%90	%9
	Special Provincial Administration	14	%94	%6	%89	%8
Ministry of Agriculture and Rural Affairs	*Directorate of the Ministry of Agriculture*	10	%95	%5	%90	%9
Ministry of Environment and Forestry	*General Directorate of State Hydraulic*	23	%99	%1	%91	%7
	Regional Directorate of Forestry	56	%99	%1	%92	%6
	Total	**235**				

Spatial Data in DWW Management

One of the most important components of GIS-based DWW management models is spatial data (Qi et al., 2000; Wienand et al., 2009; Wu et al, 2010). But, in Turkey, spatial data cannot be used and managed efficiently (Karadag, 2007) because the desired spatial data for DWW planning are produced by many institutions. Due to the lack of an authorized institution in Turkey to the production of spatial data, in some cases the same map is produced and used by different organizations at the same time. In addition, the lack of specific standards for production of spatial data and the use of spatial data across many public institutions are among the factors that negatively affect the use of spatial data.

The most important characteristic of a GIS is that it allows for the organization of local data in a data management system. GIS also contributes to gathering the spatial data on a shared platform, o a GIS can be used for the investigation, analysis and presentation of the data. This contribution not only includes graphical or non-graphical data but also supports data sharing among different institutions and administrations. GIS is particularly useful for keeping and processing verbal and spatial data in different scales and accuracies under the responsibilities of different institutions, such as DWW.

The rapid change in technology in the last decade has also positively affected GIS. During this process GIS has been marked by new developments in terms of data gathering, presentation and databases. In today's technology, along with 3D video records, it has become possible to get a lot of data and to monitor the changes in the area quickly without physically being there. Since the introduction of GIS, database applications have also developed and its classical coverage structure has changed into geo-database structure. And object-based studies has come to fore. This progress has been continuing by the development of cloud technologies[1] that enable us to reach the data from anywhere quickly and independently from the platform. While these innovations provide a significant contribution to GIS development, it also lead to both a reduction in the expenditures and will shorten the time consuming.

Study Area

The Galyan Drinking Water Watershed (GDWW), which meets the water needs of the Trabzon city and it's vicinty, was selected as the study area. The GDWW is located in the southwest of Trabzon between 39° 39' and 39° 45' east longitude and 40° 45' and 40° 52' north latitude, 17 km west of the Trabzon-Erzurum highway (Figure 1).

The city of Trabzon is 4.938 km^2 and GDWW, 191,4 km^2, which constitutes 3.8% of the area of the city. The supply basin begins at 210 meters wide in the north-south direction and it reaches 2706 meters in width through the Gumushane City borders.

[1] Cloud computing furnishes technological capabilities - commonly maintained off-premise - that are delivered on demand as a service via the Internet. Since a third party owns and manages public cloud services, consumers of these services do not own assets in the cloud model but pay for them on a per-use basis. In essence, they are renting the physical infrastructure and applications within a shared architecture. Cloud offerings can range from data storage to end-user Web applications to other focused computing services. One critical difference between traditional and cloud computing is the scalable and elastic nature cloud computing provides. Instead of a static system architecture, cloud computing supports the ability to dynamically scale up and quickly scale down, offering cloud consumers high reliability, quick response times, and the flexibility to handle traffic fluctuations and demand. Cloud computing also supports multi tenancy, providing systems configured in such a way that they can be pooled to be shared by many organizations or individuals. Virtualization technology allows cloud vendors to convert one server into many virtual machines, thereby eliminating client-server computing with single-purpose systems. This maximizes hardware capacity and allows customers to leverage economies of scale (Kouyoumjian, 2010).

Figure 1. Study Area

GDWW Land Cover and the Land Use Capability Classification

One of the important data resources in DWW planning is the Land Cover and the Land Use Capability Classification (LUCC) data set. The digital data gathered from the Ministry of Agriculture and Rural Affairs (MARA) was combined with the watershed layer by classifying the LUCC data-layer in a GIS environment (Table 2). In Turkey, The General Directorate of Rural Services within the MARA is responsible for the production of these soil maps and related information. These maps on the whole of Turkey were produced from 1966 to 1971 by MARA.

Table 2. The Rates of the LUCC

LUCC*	Area (km^2)	Rate (%)
II (Excellent Agriculture)	0.3	0.2
III	0.8	0.4
IV	1.1	0.5
VI	82.3	41.2
VII (Non Agriculture)	115.3	57.7
Total	**199.8**	**100.0**

*LUCC indicates the degree of soil suitability for agriculture

Today, Remote Sensing (RS) techniques have efficiently been used to determine land cover (Wu et al, 2010). The study carried out by Reis (2003) was adapted while determining the land cover. In this study, a Landsat ETM+ satellite view taken on Sept. 19, 2000 was used. Using the supervised classification method, overall accuracy was determined to be 84.7%. The land cover of the watershed was determined by overlaying the land cover of Trabzon City obtained by supervised classification with the watershed border (Table 3). The types of land covers in the watershed are provided in Table 3. In addition, the relationship between the watershed based on the LUCC and the land cover was investigated by superposing the LUCC layer with the field layer vegetation.

Table 3. The Rates of Land Cover

Type	Pixel Count	Area (km^2)	Rate (%)
Tea	438	0.3	0.2
Hazelnut	34796	27.3	13.7
Broad Leaved Forest	76231	59.8	29.9
Coniferous Forest	3231	2.5	1.3
Mixed Forest	17651	13.8	6.9
Rocky Areas	3961	3.1	1.6
Pasture Areas	53097	41.6	20.8
Agricultural Areas	40063	31.4	15.7
Settlement Areas	1530	1.2	0.6
Others	23842	18.7	9.4
Total	254840	199.8	100.0

Drainage Density of the GDWW

The drainage capacity of a watershed is the evacuation capacity of the rain water that falls into the watershed through the main streams, rivers and various different branches of rills that constitute the drainage canals in the watershed. Rivers were obtained by digitizing 1:25000 scaled National Topographic maps which were produced in 1984 with aerial photogrammetry by General Command of Mapping (GCM).

The drainage density is an important criterion for determining the drainage capacity of the watershed. The drainage density is calculated by dividing the total length of all streams in the watershed by the total area of the watershed.

$$\boldsymbol{D_d = \Sigma\ L / A}$$

(D_d: drainage density, L: stream length (km), A: watershed area (km^2))

$D_d = 209.6 / 199.8 = 1.04$

The drainage density of a river is directly proportional to its surface flow. Small drainage densities are often seen in densely vegetated watersheds and in areas with hard or permeable soil. High drainage densities are often seen in the mountainous places with little vegetation and in areas with weak soil or soil with a low permeability. As a result, according to the calculated value with respect to equation given above, the drainage density of a river is moderate.

Stream Frequency of the GDWW

The stream frequency expresses the number of rivers per unit area of a watershed. Greater stream frequencies indicate more convenient drainage of the watershed.

$$\boldsymbol{S_f = Nr / A}$$

(S_f: stream frequency, Nr: total number of rivers from various classes, A: watershed area (km^2))

$S_f = 128 / 199.8 = 0.64$

Depending on the result obtained from the formula for stream frequency, it is said that the stream frequency of river is poor.

Topography of the GDWW

The GDWW is 35 km long in the north-south direction. The widest part of the watershed is 10 km long in the east-west direction. The lowest height of the watershed is 100 m, and the highest elevation is 2560 m in the southern part, on the border of the city of Gumushane. A three-dimensional (3D) model of the watershed was created based on a digital topographic map, with a scale of 1:25000 which was produced by GCM in 1984. The slope layer and aspect layer were also produced. Additionally, the current border was verified by reevaluating the watershed border based on the model. A general overview of the slope and aspect groups calculated in the analysis is provided in Table 4. The table shows that the overall aspect is in the northeast and westerly direction. It is also seen that only 4% of the watershed is flat. When it was examined in terms of slope, the flat areas were determined to be quite limited, and the watershed was found to have a particularly rugged structure.

Table 4. The Rates of Watershed Aspect

Aspect	Pixel Count	Rate %)
Flat	9091	4
North	63659	25
East	55615	22
South	40939	16
West	85536	34
Total	**254840**	**100**

Conservation Areas of the GDWW

General Directorate of state hydraulic Works (DSI) together with its Regional Directorates continues to develop and manage water resources in the basins in the integrated manner. This means that a Regional Directorate may work on several river basins or several Regional Directorates may work on one river basin. Water Pollution Control Legislation, (Dec 31,2004, no: 25687) states that various conservation areas should be established around the reservoir from which potable and drinkable water are provided to keep them safe from polluting elements. Accordingly, three types of conservation areas are defined for the reservoir from which potable and drinkable water is provided (Figure 2).

*Absolute conservation area***:** a 100-meter-wide area around the reservoir from the maximum reservoir water level.
Short-range conservation area: a 900-meter-wide area extending from the absolute conservation area
Long-range conservation area: All of the areas excluded from the conservation areas defined above are considered to be long-range conservation areas. If the area boundaries reach beyond the water-gathering watershed, they terminate in the short-range conservation area.

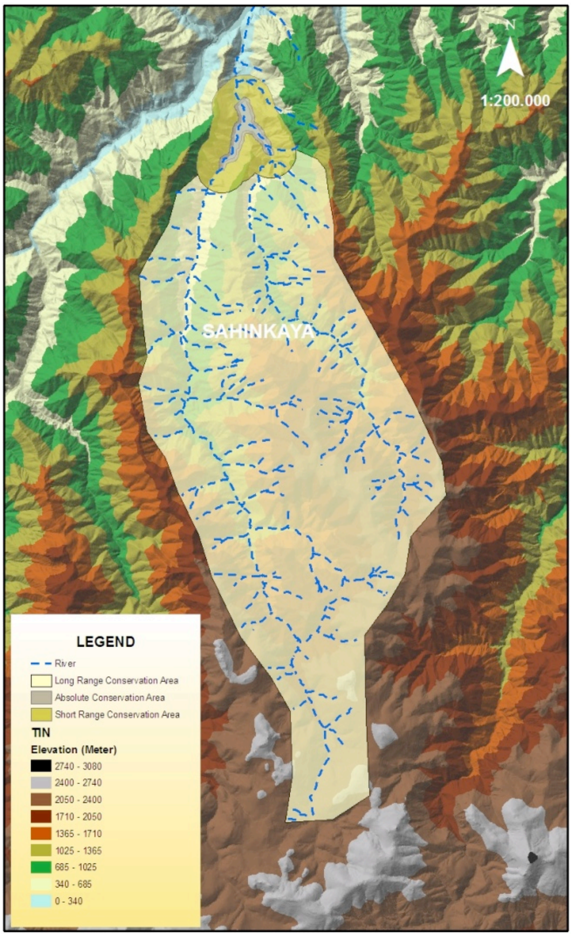

Figure 2. Reservoir Conservation Areas

Different protection precautions for each of the conservation areas exist. All of the cadastral parcels in the reservoir area and the absolute conservation areas are expropriated (Official Gazette, 2004). With the help of a GIS, the parcel of the whole study area and how much of the area will be expropriated can easily and quickly be calculated. All of the limitations and usage characteristics as well as the excavations to be done on the parcels can easily be determined by correlating the conservation areas with the cadastral areas. These correlated data sets also provide an important database for DWW planning. The absolute conservation area of the reservoir is 25 km^2, the short-range conservation area is 6.5 km^2, and the long-range conservation area is 147.5 km^2.

RESULTS

In this study it is emphasized that some mineral deposits in the basin and the basin area where some of approximately 16% were found to be in danger of land slide. The use of approximately 30% of basin areas for agricultural activities and also the use of chemical pesticides effects drinking water quality and adversely affect the health of society. Depending on the management of the current administrative boundaries, watershed-based governments are inadequate.

Determination of the Areas Susceptible to Landslide in the GDWW

The East Black Sea region is composed of potential landslide risk areas. Excessive rainfall and the topographic structure in the region increase the landslide risk. Limitations on land use because of the topographic structure of the region give rise to the destruction of the forests by the residents. This is another important reason for the increased landslide risk in the region. To diminish the landslide risk, determining the landslide susceptible areas and keeping them under control is vital (Reis, 2003). Therefore, an analysis was conducted to determine the landslide-susceptible areas in the watershed. In this study, topography, geology, land use, streams and roads were utilized as factors. The same matrix method and scoring system that were used in the study conducted by Yalcin et al. (2002) were adapted in determining the weights. The pixel size of data layers in the factors was fixed to 100 meters and the layers in the vector format were changed to a grid format. The pixel size was decided according to the purpose of the study and the spatial data scale. Scores for the data sets belonging to the factors were calculated out of one hundred. In the scoring system, the high scores represent low-landslide-risk areas, whereas low scores represent high-landslide-risk areas. Next, weights according to each factor were determined out of a possible maximum one hundred. Table 5 shows the scores and weights of the factors used in determining the landslide areas. Thanks to its effective value, the slope layer is the factor that determines the high-landslide-risk areas. Therefore, the slope weight was kept highest. e

Table 5. Scores and Weights of the Factors Used in Determining Susceptible Landslide Areas (Yalcin et al., 2002)

Factor	Score	Weight	Factor	Score	Weight
Slope(%)		**100**	**Land Cover**		**40**
0 – 20	100		Rocky	100	
21 – 30	70		Forest	80	
31 – 40	40		Settlement	50	
41 – 50	20		Agriculture, Pasture	40	
> 51	10				
Geology		**60**	**Stream and Road**		**20**
Alv, pl	30		Stream *	10	
Kru5a, kru5b	60		Road*	10	
Ev, jkr, jlh,	70		Other Areas	100	
Kru1, 2, 3, 4,	80				
Gama2, 3	100				

* 100 meter proximity area was formed for rivers and roads

After determining the scores and weights of the factors, each factor score was multiplied by its weight using the spatial analysis module of the ArcGIS 9.3 software. By doing so, the scores of the factors were obtained, and by adding the scores of parameter groups, the map representing the total scores to be used in determining the susceptible landslide areas was generated. As a result, five-class landslide susceptibility maps were established by evaluating the total scores obtained. The class intervals were determined based on the standard deviation and factor scores (Table 6).

Table 6. Statistical Data of Landslide Areas

Landslide Risk	Pixel Count	Area (km^2)	Rate (%)
High Risk	3121	31.21	15.6
Risky	10694	106.94	53.5
Medium Risk	2670	26.7	13.4
Low Risk	1354	13.54	6.8
No Risk	2141	21.41	10.7
Total	**19980**	**199.8**	**100.0**

Ore Bed Analysis of the GDWW

The environment analysis conducted in the GDWW showed that the mines that extract ore from the vicinity of the watershed do not pollute the water and that the wastes are removed from the area (Anonymous, 2009). However, although mining activities are forbidden around the absolute and short-range conservation areas because of the rules of water watershed management governing the distance between ore beds and watershed, an inactive copper mine is located in the area. In addition, when the distances of other mining areas to the rivers feeding the watershed were investigated, it was found that all of the active ore beds are within 1000 m of the rivers. Moreover, although the average distance of the ore bed to the rivers is 253 m, distance of the active ore beds is 357 m.

Farming Areas Need to be Protected according to LUCC

The soil data is divided into eight classes based on the LUCC. These classes range from I to VIII according to soil damage and classification. The first four classes are considered to have good land management prosperities; they have the capacity to grow forest plants, grassland and pasture plants and culture plants adapted to the region. Classes V, VI and VII are convenient for local plants. If the necessary precautions for land and water preservation are taken into account, some special plants can also be raised on the land with classes V and VI soils. Although growing crops is possible on land with class VIII soil by using efficient and expensive improvement methods, in the current market conditions, the products will not meet the investment expenditures (Reis, 2003). The analysis conducted based on the scope and soil data showed that land areas with LUCC values in the GDWW that are I, II, III, and IV is about 2.2 km^2, and according to the analysis, other areas were found to be 197.6 km^2. That is, 99% of the total area proved to be non-agricultural area. The results of the analysis revealed that there are no priority agricultural preservation areas.

Use of Agricultural Chemicals in the GDWW and Slope Analysis

In the GDWW watershed, 14% of the area has been used for hazelnut farming, and 16% has been used for cultivated farming. Because of the agricultural chemicals and fertilizers used for hazelnut and cultivated farming, the quality of drinking water in a significant part of the watershed (30%) is estimated to be under threat. The agricultural chemicals used for these crops have been diffused into the GDWW through underground or above-ground water resources. With the help of the results of the analysis conducted on the established database, unsuitable areas for chemical use were determined. These areas include various specialties such as the following: (1) rocky areas and (2) agricultural lands consisting of tea and hazelnut and (3) lands with a slope higher than 20% and (4) lands close to a stream, i.e., closer than 300 m (Figure 3). According to this calculation, 4.14 km^2 of the area were found to be under threat.

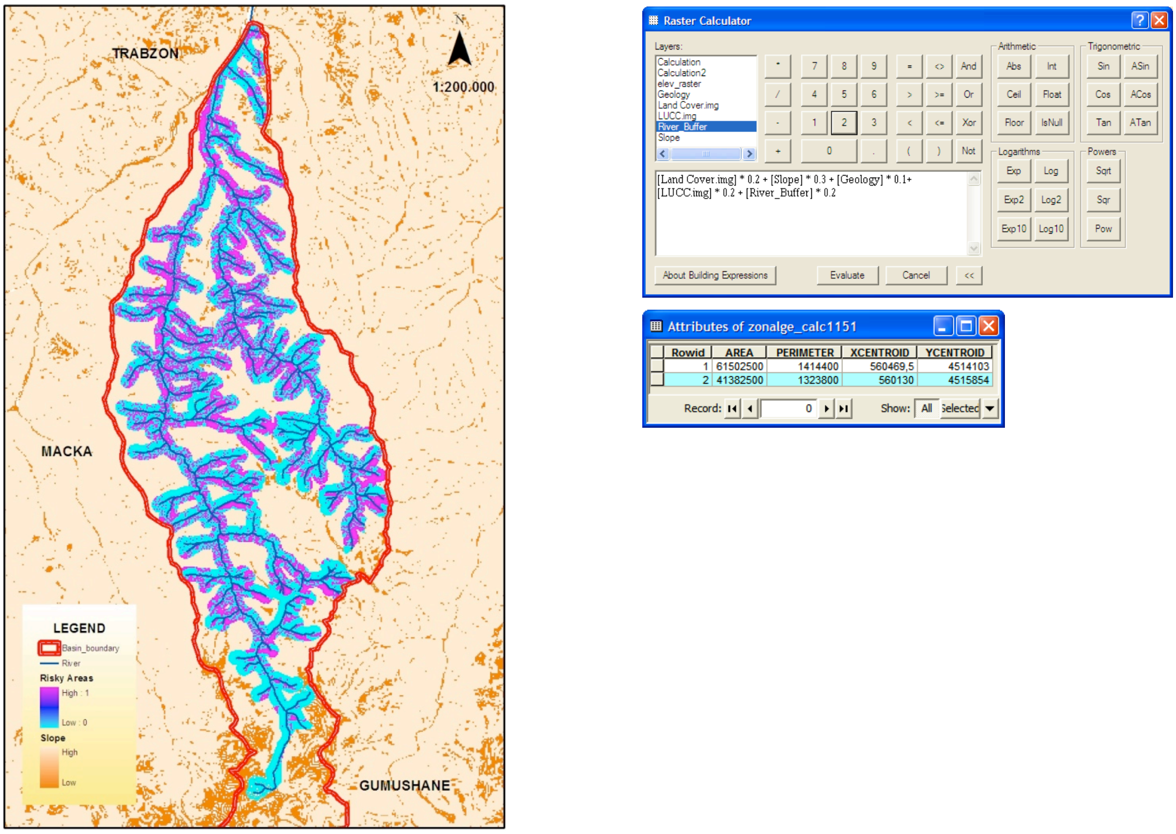

Figure 3. The Effects of Agricultural Chemicals on the Results of the Watershed Analysis

The Impact of the Settlements on the GDWW

There is one town municipality, three district municipalities and 20 local village administrative units within the watershed boundaries. The population within the watershed is approximately 21.000. The analysis, which was conducted through Quickbird Satellite View in 2008, revealed that 2.984 buildings exist in the watershed;18 of these buildings are located in the absolute conservation area, and 525 are located in the short range conservation area.

According to the data gathered in 2008, the amount of discharged waste water per capita through the drainage network was determined to be 173 liters (TUIK, 2008). In this respect, when the population and construction in the watershed were considered, it was found that approximately 1.326.045 tonnes of wastewater had been evacuated. Although 345.725 tones of this wastewater can be regained, 980.320 tonnes have been stored in cesspools. In time, the waste water in these cesspools will integrate with the watershed through underground water resources.

DISCUSSION and CONCLUSIONS

Today, comprehensive spatial data is required for watershed planning and sustainable watershed management. Good decisions about watershed planning are only possible when all of the details about related watershed are fully known. Therefore, all the necessary organizations should be prepared to gather all the necessary data about the watershed, and the data should be stored in a digital form and examined in such a way as to enable spatial analysis. In this respect, GIS is regarded as one of the most efficient technological tools used in this field.

To prove the efficiency of GIS-based watershed management, the results of the study conducted in the GDWW demonstrated that necessary baselines were established, which will assist in making healthy decisions in future management planning and activities.

Based on the determination of the fact that the average distance of the ore beds to the rivers in the watershed is 253 m, and the active ore beds are on average 357 m away from the rivers, it was concluded that these mining areas are contaminating the watershed. The contamination level of these mining areas should be investigated, and depending on the data gathered, they should either be closed or the necessary precautions should be taken to prevent unacceptable levels of contamination of the water sources.

Because of the rugged surface, the majority of the region encompassing the watershed is considered to be a landslide risk area; 15.6% of the watershed (31.21 km^2) is located in high-landslide-risk areas. Particularly for these areas, necessary precautions for preservation should be taken after performing the necessary determination work.

The basic source of income for the people residing in the watershed is agriculture. The study revealed that there is little convenient land for farming according to LUCC; however, it was found that 30% of the area has been used for farming activities. As a result of these farming activities, it was determined that the areas with a threat from pesticide integration occupy 4.14 km^2. In light of these results, it is clear that new farming policies should be developed in the watershed. Particularly, controls on agricultural chemical use should be tightened.

The structural activities in the absolute conservation and short-range conservation areas of the watershed should be controlled. Domestic waste in particular should be disposed away from the cesspools, and the necessary precautions should be applied to accomplish this. Large-, medium- and low-scale zone planning activities should be devised to meet the requirements of future structures such as drainage networks and irrigation systems.

DWW should be controlled by Municipality instead of DSI. It is hard to control of drinking water watershed across many public institutions. For example, while the quality of drinking water is checked by DSI, the Municipality or Special Provincial Administration controls construction inspections. Therefore the municipality that is responsible for managing the drinking water needs to be competent in all current applications in the watershed.

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