GROUNDWATER VULNERABILITY ASSESSMENT WITH DRASTIC METHOD: A CASE-STUDY ON KIRIKKALE PLAIN, TURKEY

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

AHMET HAKAN BÜYÜKDEMİRCİ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

MAY 2012

Approval of the thesis:

GROUNDWATER VULNERABILITY ASSESSMENT WITH DRASTIC METHOD: A CASE-STUDY ON KIRIKKALE PLAIN, TURKEY

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ABSTRACT

GROUNDWATER VULNERABILITY ASSESSMENT WITH DRASTIC METHOD: A CASE-STUDY ON KIRIKKALE PLAIN, TURKEY

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May 2012, 70 pages

The objective of this study is to achieve vulnerability assessment of the groundwater by using DRASTIC Method which is developed by United States Environmental Protection Agency (USEPA). It is most commonly used overlay and index method all over the world. Evaluation of groundwater vulnerability would be performed by using computer programs which are based on Geographical Information System (GIS) in order to facilitate data management and spatial analysis. The term vulnerability, that is used in this study, could be defined as a degree of capacity of the geological settings which are above water table, cause as joining of contaminants to groundwater where imposed by environmental factors. All the groundwater has some degree of protection under natural condition. It is an important initial step to identify degree of vulnerability by an index which is provided by superimposition of the environmental and geological properties that are explained in DRASTIC Method.

At the end of the study by using a computer program together with DRASTIC Method a vulnerability map will be obtained. The vulnerability map is an informative tool from different aspects such as it is an initial step for taking an attention of risk of groundwater could be getting polluted in some areas. In addition, surface activities could be limited by focusing on groundwater protection strategies which are considering degree of vulnerability of areas that are delineated by DRASTIC vulnerability index.

With the purpose of groundwater vulnerability assessment Kırıkkale Plain is selected for a study area. Because of inappropriate management of the industrial and domestic wastes, lack of waste water treatment plants and uncontrolled agricultural activities cause this region proned to groundwater pollution. At the end of this study a groundwater vulnerability map of the Kırıkkale Plain is obtained and attention is drawn to the places which are more vulnerable are pointed out.

Keywords: DRASTIC, GIS, Vulnerability, Groundwater, Kırıkkale Plain

ÖZ

DRASTIC YÖNTEMİ İLE YERALTISUYU ZAFİYETİNİN

DEĞERLENDİRİLMESİ: ÖRNEK ÇALIŞMA KIRIKKALE OVASI, TÜRKİYE

Büyükdemirci, Ahmet Hakan

Yüksek Lisans, İnşaat Mühendisliği Bölümü

Tez Yöneticisi: Prof. Dr. Halil Önder

Mayıs 2012, 70 sayfa

Bu çalışmada yeraltı suyu zafiyetinin Birleşik Devletler Çevre Koruma Dairesi (USEPA) tarafından geliştirilen DRASTIC Metodu kullanılarak değerlendirilmesi amaçlanmıştır. Bu dünya çapında en yaygın olarak kullanılan katman ve sıralama metodudur. Yeraltı suyu zafiyeti değerlendirmesinde Coğrafi Bilgi Sistemi (CBS) tabanlı bilgisayar programlarının kullanımı, bilgi yönetimi ve coğrafi analizlerde kolaylık sağlamaktadır. Bu çalışmada geçen zafiyet terimi yeraltı su seviyesinin üstündeki jeolojik yapının, çevresel etkenlerin baskısı altında, kirletenleri yeraltı suyu tablasına ulaştırma kapasitesinin göstergesi olarak tanımlanabilir. Tüm yer altı suları belli derecede doğal olarak koruma altındadır. DRASTIC Metodunda anlatıldığı gibi çevresel ve jeolojik özelliklerin üst üste birleştirilmesiyle elde edilmiş sıralamanın kullanılmasıyla zafiyet derecesinin tespiti önemli bir ilk adımdır. Bu çalışma sonunda bilgisayar programı yardımı ve DRASTIC Metodu ile zafiyet haritası elde edilecektir. Bu zafiyet haritaları her açıdan bilgilendiren bir araçtır mesela ilk adım olarak yeraltı suyunun bazı alanlarda kirlenebilirlik riskine dikkat çekmektedir. Bununla beraber DRASTIC zafiyet sıralaması kullanılarak belirlenen alanların zafiyet derecesi göz önünde bulundurulup, yeraltı suyu koruma stratejilerine odaklanarak arazi üzerindeki faaliyetler kısıtlanabilir.

Zafiyet değerlendirmesi amacıyla çalışma alanı olarak Kırıkkale Ovası seçilmiştir. Çünkü evsel ve sanayi katı atıklarının bertaraf edilmesinde işletme eksiklikleri, atık su arıtma tesislerinin bulunmaması ve denetimsiz tarımsal faaliyetler bu bölgeyi yeraltı suyu kirlenebilirliğiyle karşı savunmasız bırakıyor. Bu çalışmanın sonunda Kırıkkale Ovasının yeraltı suyu zafiyeti haritası elde edilmiş ve zafiyeti fazla olan yerler belirlenerek dikkat çekilmiştir.

Anahtar Kelimeler: DRASTIC, CBS, Zafiyet, Yeraltı suyu, Kırıkkale Ovası

To my grandmother and my daughter Güzide and my wife, my mom

ACKNOWLEDGEMENTS

I would like to express my hearth full thanks to my supervisor Prof. Dr. Halil Önder for motivating me from the beginning of graduate lessons to the end of thesis writing. Also introducing me with this subject and the suggestions during this study is very valuable for me.

I would like to present my thanks to Assoc. Prof. Dr. Elçin Kentel for giving me a point of view while searching solution. This study could not be completed without the valuable opinions of Assoc. Prof. Dr. Ayşegül Aksoy, Assoc. Prof. Dr. Zuhal Akyürek and Assist. Prof. Dr. Şahnaz Tiğrek. I really appreciate for their support.

Turning back to university after a long period it was really hard times for me. Adaptation to school and working in the job at the same time are the difficulties that I faced. Luckily the people around me are so helpful. Lastly I wish to express all my thanks to all lecturers, classmates, friends and colleagues for their support.

I would like to express my special thanks to my wife, my colleague Rukiye for endless support and looking after our daughter Güzide while I was away. Finally my special thanks to my mother Mualla for devoting life to her children.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVATIONS

AHP: Analytic Hierarchy Process

ADNKS: Population Record System Based on Address

MKEK: Machine Chemistry Institute Establishment

DEM: Digital Elevation Model

DMI: State Meteorology Works

DRASTIC: Depth, Recharge, Aquifer media, Soil Media, Topography, Impact of Vadose Zone, Hydraulic Conductivity

DSI: State Hydraulic Works

ED50: European Datum 1950

EPA: Environmental Protection Agency

IDW: Inverse Distance Weighting

NASA: National Aero Space Assembly

SRTM: Shuttle Radar Topography Mission

VM: Vertical Mapper

US: United States

UTM: Universal Transverse Mercator

CHAPTER 1

INTRODUCTION

1.1 Introductory Remarks

Definitely water is described as the origin of life. For example, space journeys aim to search for water in other worlds to find out living organisms. In this manner if water could be found, then there should be a life near there. As a result, starting point of the life is water which is one of the vital substances that all living things need from birth till to end of their life.

The problems that are faced depending on water could be examined in the aspects of quality and quantity. If it is necessary to give an example of water quantity sourced problem, the answer is the people who are suffering from water in arid zones. Quality of water could be determined by measuring the amounts of substances, which are dissolved in water. These harmful materials should be under limits in order to preserve humans' health. It is much more important to know how to reach water in required quantity and quality. The key that will open the door of reaching water sources is hidden in the management of water stocks of our world. In this study the passage of water from surface to underground will be assessed through the window of quality.

Before starting to tell the adventures of water, it should be reminded that, water could be found in different forms related to the pressure and temperature conditions. Liquid form is generally located in oceans, seas, lakes, rivers, and groundwater. Solid form of the water is snow, ice and glaciers. In addition gas form is vapor.

All of the world's water which is like an eye drop of our planet can be seen in the picture in Figure 1.1. In fact all of water including oceans and saline water is in that blue point in the picture. If all worlds' water (liquid, ice, freshwater, saline) was put into a drop it would be about 1,385 kilometers in diameter (USGS, 2010). As a conclusion of the picture, it can be stated that the amount of our planet's water is limited and in the future one drop of water could be more important than imagined.

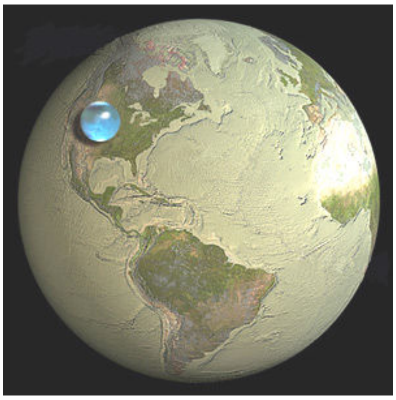


Figure 1.1: Water in Earth (USGS, 2010)

Illustration by Jack Cook, Woods Hole Oceanographic Institution; USGS.

The initial step for management of the water supply is to define the distribution of Earth's water. As far as water basins are delineated, a proper water usage strategy can be developed. As it seen from the bar chart in Figure 1.2, left bar shows that nearly 97 percent of the total global water is gathered in the oceans. Also just 2.5 percent is fresh water. The next bar in the middle is the distribution of the freshwater. The biggest part of the freshwater which is about 69 percent is occupied in glaciers and icecaps. The second greatest storage area of water is groundwater such as 30.1 percent which is the vital water reserves for the sustainability of life. Surprisingly, only about 0.27 percent of all freshwater is contained in rivers and lakes.

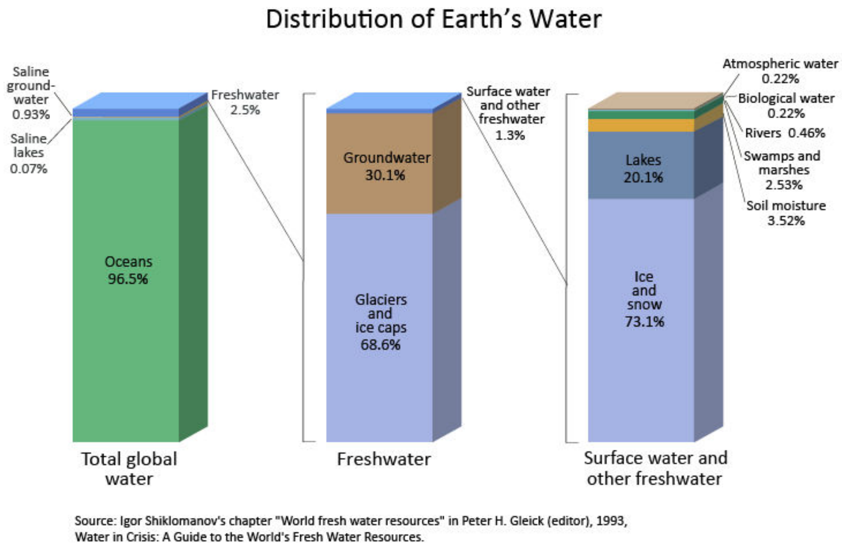


Figure 1.2: Water stock distributions (Gleick, 1993)

The biggest reserve of the fresh water is ice and glaciers which are located near the pole. Actually the transportation of glaciers to any other places is not so easy. Also, the other disadvantage of the glaciers is they are on oceans and freshwater could mix up with the ocean's saline water easily. In addition, saline water treatment to obtain drinkable water requires high technology and also it is a costly procedure. To sum up all, glaciers are water sources but the difficulties made them inappropriate.

It is obvious that groundwater is the second largest freshwater reserve for our world. Meanwhile, groundwater sources are our today and future reservoirs for water demand and they differ from the other water sources it plays an important role, which cannot replaced, in different aspects such as it is clean and easily accessible.

Due to the development of the civilization water consumption is increasing highly. As a consequence of the human activities, wastes exist. Pollution producing actions are mainly agricultural activities, in situ sanitation, gas stations and garages, solid waste disposal, metal industries, painting and enamel works, timber industry, dry cleaning, pesticide manufacture, sewage sludge disposal, leather tanneries, oil and gas exploration extraction and metalliferous coal mining (Foster et al., 2002). Polluters are shown in Figure 1.3.

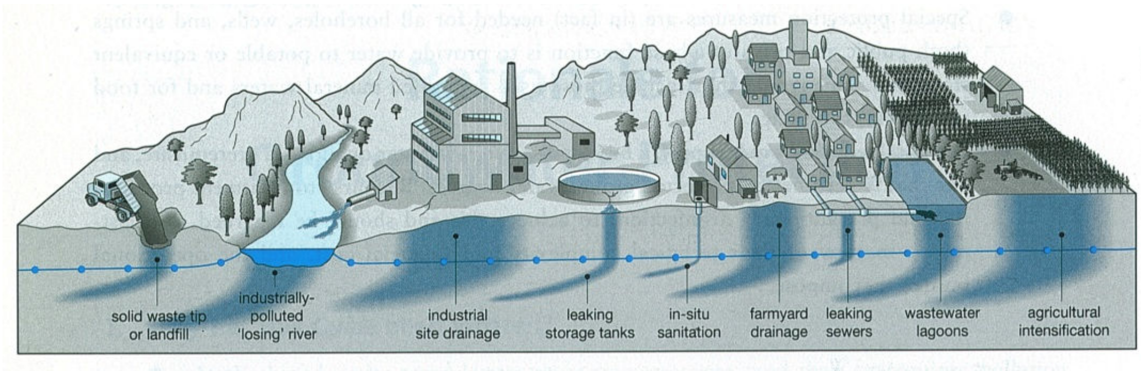


Figure 1.3: Groundwater Pollutant Factors (Foster et al., 2002)

In the nature, there is a continuous movement of water which is called hydrologic cycle. It is important to understand this mechanism in order to manage water sources and to protect it against to the environmental effects caused by people. Water is always in motion between the basins which are defined as water collection regions. For the subsurface part of hydrologic cycle, travelling of water could be explained as input such as infiltration to groundwater and output such as discharge of groundwater to the surface. In other words groundwater is mainly fed by surface water which is mostly sourced from precipitation. After rainfall, some amount of water infiltrates, where it is controlled by physical factors such as land cover, soil type, slope, geological structure and land use then reaches to the groundwater. Water movement after infiltration through underground phase fallows the paths of the geological formations named as aquifers which are defined as the geological settings that contain and convey useable groundwater.

Any activity on the surface could be a possible pollutant factor to the groundwater by infiltration. Fortunately, soil and the unsaturated zone have a capacity to assimilate these contaminants. But depending on the geological settings, the assimilation capacity varies widely. In order to identify the disposal capacity of nature, which depends on the geological formations and the environmental effects, should be helpful for developing a strategy to preserve water sources.

1.2 Objective of the Thesis

Population growth results as an increase in water demand and this situation creates a pressure on human beings in order to discover new sources. Unfortunately these sources are limited and water is in continuous circulation. In this cycle surface water has the advantage of being easily accessible, at the same time, any contaminants that mix with surface water could be observed by public. After this point the activities such as searching for the pollutant source or the cleaning efforts are started. Of course this is a late action because it has already been started after water was polluted. Hopefully cleaning of surface water process is supported by public societies. Possibility of the contaminants to reach to the groundwater is generally ignored because of the fact that groundwater is not in the sight of eye. Once groundwater becomes contaminated, it is very difficult to remediate: groundwater moves slowly, so flushing out an aquifer can take a very long time (Liggett and Talwar, 2009). Treatment of the groundwater is not as easy as surface water because of the movement ability of water underground. So that preventive actions for groundwater is much more important than surface water. In this study it is aimed to evaluate the groundwater vulnerability and to prepare a map which is showing the zones of basin that are sensitive to contamination with using a standard method. Consequently it is important to place an opinion in people's mind that groundwater could be contaminated from any action on surface. Fallowing this, location of surface activities can control the degree of pollution depending on geological and environmental settings.

A variety of methods are developed by researchers and scientists during the studies on the groundwater vulnerability map concept. According to the different approaches, a usage of standardized method is needed. After the works on this subject are accomplished by United States Environmental Protection Agency (USEPA) a method named as DRASTIC is proposed by Aller et al., in 1987. Every letter in the name symbolizes a parameter that has to be considered. This method will be explained in the Chapter 2.

The main objective of this thesis is to prepare a groundwater vulnerability map for Kırıkkale Plain by using DRASTIC Method. The reasons of investigating this place are coming from the aspects of groundwater hazardous surface activities such as petroleum based industry and agricultural activities. The agricultural fields, which chemicals are used in order the increase crops, are the important income for the public. In addition, Kırıkkale City does not have a sewage water treatment plant yet. So that solid and liquid wastes are the threats for water sources. Finally, a lot of hazardous activities are taking place in this area and at the same time groundwater is an important source for irrigation and domestic demand of the people.

Delineating the border of the study is an important concern while creating a model to evaluate groundwater pollution capacity in order to determine the required data and to describe the sensitivity of the outcome. In this manner groundwater protection subject should be classified in to two categories. According to Foster et al. (2002) these are supply and the source protection which should be distinguished from each other. The whole aquifer can be mentioned as groundwater sources and on the other side; groundwater supply can be defined as boreholes, wells, and springs. Briefly, the main difference between supply and source protection is the study scales. To illustrate this subject, the survey of source protection zone could be long termed and costly. Fortunately computer technologies give opportunity to create models of ground by interpolation of limited data. Also for the protection of water supply area there should be general view about the surrounding. Groundwater sources zoning maps, which are first step, would be the guide to protect water supplies. As a conclusion source protection based assessments which are large scaled help to prioritize areas for further investigation, protection, and monitoring with limited data. In this study protection of source is selected in order to evaluate groundwater pollution potential of Kırıkkale Plain. The fact behind the decision can be revealed as the data availability and easy presentation of an assessment of whole basin with a map.

Generally, the importance of groundwater is not understood by all people especially by decision makers and public. Because of this, groundwater sources do not get the attention that is needed. However, in the future groundwater sources will be extremely required reserves. To properly manage and protect the resource, it is therefore important to determine areas where groundwater may be more vulnerable to contamination (Liggett and Talwar, 2009). One of the benefits of the vulnerability map, which will be obtained in this study, is expected as to inform public and government while preparing land use plans with considering groundwater protection zones. In addition, the corresponding preventive actions for the aquifer basin can be applied against pollution sources such as recreation on land use, restriction on industrial plants placements, limitations on pesticides usage in agricultural lands. As a result of this thesis, the prepared vulnerability map could be an informative tool for the education of public.

Maps are the common language for all people. Developments in computer technologies are great facility for data analyzing and creating thematic map. Especially, during geospatial data analyzing, Geographical Information Systems (GIS) based programs make the data processing easier. While in the presentation stage, maps are the forceful images for transferring the scientific results to the public. Therefore, in this study, GIS based zone mapping groundwater vulnerability assessment method is used for informing the authorities and the public about result of evaluation. This subject is selected to learn the assessment methodology with using GIS technique and to prepare maps for presenting the results easily.

Moreover, selecting a commonly used method of DRASTIC gives the opportunity of comparing the results of other areas and creating a platform for the discussion of protection strategies. Because of the difficulties that are faced while working with underground urge the user to search for experiences that are gained by the people who are involved with the groundwater subject. In this manner, the application of this method may provoke the new researches. So, this study aims to be a pioneer in the vulnerability map preparation for Kırıkkale Plain.

1.3 Description of the Thesis

This thesis is composed of four chapters.

In chapter 2, the methodology is described. First of all, the general term “pollution vulnerability” that has been used nearly 50 years in the literature is explained. Methods, which are used for creation of vulnerability maps, are described briefly. Literature reviews for the methods are mentioned in this chapter. Finally, DRASTIC Method assumptions and the application procedure are explained by giving data tables of original and modified parameters. Also potential uses of the DRASTIC Method are narrated in the end of the chapter. Finally computer program of Map-Info and its application Vertical Mapper (VM) which are used in data analyzing are introduced.

In the beginning of the third chapter, Kırıkkale Plain is introduced with different point of views such as geography and economy. The properties of the major city which gives the name to the plain are mentioned. Next, data collection stages as well as explanation of the sources are described. Steps in data processing are shown with a flowchart. In the subsections, which correspond to layers used in DRASTIC Method; descriptions showing the preparation of maps are given. The approaches for the determination of the required data from relevant studies are provided. Finally, obtained maps are presented in the end of each subsection of this chapter.

In the forth chapter, conclusions and recommendations which are obtained from this study are placed. Finally, difficulties that are faced while using this method and the suggestions regarding the application of this method to a case study area are added in the recommendations part.

CHAPTER 2

METHODOLOGY

2.1 Pollution Vulnerability Concept

The subject of groundwater pollution potential to contamination from the surface was introduced in the 1960s in France by Margat (1968). Than the term “aquifer pollution vulnerability” was developed for finding the assimilation capacity of the area to the pollution from surface. In addition The National Research Council (1993) defines it as “the tendency or likelihood for contaminants to reach a specified position in the ground water system after introduction at some location above the uppermost aquifer.” (Liggett and Talwar, 2009). In other words vulnerability is the sensitivity of an aquifer to contaminants and the capacity of becoming polluted during time.

Everything in nature is attached to each other with cause-effect relation. So, the effect of the polluting activities over the surface to groundwater could not be studied individually. All aquifers have weakness to the pollution in different levels depending on geological and environmental characteristics. Vulnerability could be described as a degree of contamination transferring capacity of the geological zones from surface to aquifer under the effect of environmental settings.

As vulnerability has not a common explanation accepted by all countries, the divisions of vulnerability are not meaning same things to every people. To overcome this mind mixing situation it is important to define a standard index of aquifer pollution vulnerability which is more helpful to people who are involved with this subject. So that, vulnerability class definition is prepared by groundwater management advisory team as shown in Table 2.1 (Foster et al., 2002).

Table 2.1: Vulnerability Class Definition (Foster et al., 2002)

Vulnerability class	Corresponding definition
Extreme	Vulnerable to most water pollutants with rapid impact in many pollution scenarios
High	Vulnerable to many pollutants (except those strongly absorbed or readily transformed) in many pollution scenarios
Moderate	Vulnerable to some pollutants but only when continuously discharged or leached
Low	Only vulnerable to conservative pollutants in the long term when continuously and widely discharged or leached
Negligible	Confining beds present with no significant vertical groundwater flow leakage

2.2 Mapping of Groundwater Pollution Vulnerability

In searching for the groundwater pollution assessment, initial step is to prepare a vulnerability map of the area. These vulnerability maps are supportive tools to get the attention of the municipal or provincial authorities.

The development of vulnerability maps is useful for many aspects of water management, including: prioritizing areas for monitoring, protection, and further investigation; and the development of risk assessments, resource characterization, and education (Liggett and Talwar, 2009).

Aquifer pollution vulnerability maps are the most effective media for informing authorities about the possible pollution activities in future. In this manner before starting the groundwater basin protection strategy, the vulnerability map of the region should be presented to public and civil society since the maps, which are the common language between the scientists and non-scientists, have the power of image.

For the areas that are not investigated, groundwater vulnerability assessment map gives an idea about protection levels to be considered. Then, it could be used for land use planning and selecting the location of waste disposal area by the guide of scientific works.

The developments of GIS techniques facilitate data management and increase the capability of updating and operating data. Groundwater vulnerability assessment maps are the simple and easily understandable tools for presenting the results.

2.3 Methods

The important subject is the selection of the method to evaluate vulnerability of groundwater to contamination. There are several methods that are proposed by researchers. Mainly these methods could be classified into three categories. These are overlay and index methods which "are very popular because they are easy to implement, inexpensive to produce, use readily available data, and often produce categorical results (Liggett and Talwar, 2009)". Secondly statistical methods are coming. These methods are typically used in places with diffuse sources of contamination, such as to detect nitrates over agricultural areas (Liggett and Talwar, 2009). Lastly process based methods are used. The difficulty in the examination of process based method is required much more detailed data such as contaminant concentration, time of travel and etc.

In the evaluation of groundwater vulnerability, due to the nature of this subject it is faced with uncertainty, ambiguity and variability. Another problem, that is generally seen, is the limited access to the information. So it is a hard situation to give a decision under the condition that is containing many unknowns.

As mentioned in the first chapter the study scale of this study is source protection. In this thesis when considering the availability of data, overlay and index-based methods are reviewed because of many advantages such as presenting the vulnerability assessment maps and allowing the estimation of required data based on personnel experiences. Index-based methods are best suited to produce regional-scale screening tools for use in decision making, and for prioritizing focus areas and level of site assessments (Liggett and Talwar, 2009).

In the category of overlay and index-based methods several approaches have been proposed for developing aquifer vulnerability assessment maps such as DRASTIC (Aller et al., 1987), GOD (Foster et al., 2002), AVI (Van Stempvoort et al., 1993), and SINTACS (Civita, 1994).

These methods have been mainly applied to groundwater protection in porous aquifers, except the EPIK (Doerfliger et al., 1999), PI (Goldscheider et al., 2000), and COP (Perles et al., 2006) methods which were specifically developed for the assessment of vulnerability in karstic areas.

The DRASTIC Method is developed by United States Environmental Protection Agency (USEPA) by Aller et al. (1987) and this method has been used in several areas by different researchers (Chitsazan and Akhtari, 2009; Sener et al., 2009; Pathak et al., 2009; Ormeci and Davraz, 2010). Software which is developed by Thirumalaivasan et al., (2003) named as AHP-DRASTIC (Analytic Hierarchy Process) in order to modify ratings and weights of DRASTIC Method.

Generally the methods' names are the combinations of the letters that symbolize the layer which is processed. Acronyms mentioned in the methods are listed below.

DRASTIC (**D**epth to water table, net **R**echarge, **A**quifer media, **S**oil media, **T**opography, **I**mpact of vadose zone, and hydraulic **C**onductivity).
GOD (**G**roundwater occurrence, **O**verlying lithology and **D**epth to water table).
SINTACS (**S**-water table depth; **I**-effective infiltration; **N**-unsaturated conditions; **T**-soil media; **A**-aquifer hydrogeologic characteristics; **C**-hydraulic conductivity; **S**-topographic slope).
EPIK (**E**pikarst, **P**rotective cover, **I**nfiltration conditions and **K**arst network).
PI (**P**rotective cover, **I**nfiltration condition).
ISIS (Infiltration, **S**oil type, l**I**thology, **S**oil thickness, thickness of the unsaturated zone, aquifer medium, aquifer thickness).
AVI (**A**quifer **V**ulnerability **I**ndex).

2.4 DRASTIC Method

DRASTIC Method was designed in United States in order to define the pollution potential of any area in country within a standard. Also, this method is preferred in the North America countries.

The method is consisting of two major portions. (1) The designation of mappable units, termed hydrogeologic settings; and (2) the application of a scheme for relative ranking of hydrogeologic parameters (Aller et al., 1987). The description of the layers can be found in Table 2.2. Depending on the data accessibility this method is very useful in the concept of defining the pollution vulnerability assessment.

Hydrogeologic settings are the combination of the geological and hydrologic factors that affect and drive the movement of the water in all directions. This is the mappable part of the method. The second part of the method is vulnerability index of the region prepared by using relative ranking. So the result of this method gives idea to the operators for making generalization of the groundwater pollution potential.

The DRASTIC Method assumes that:

(1) The contaminant is introduced at the ground surface;

(2) The contaminant is flushed into the groundwater by precipitation;

(3) The contaminant has the mobility of water;

(4) The area evaluated using DRASTIC is 0.4 km^2 or larger (Aller et al, 1987).

Table 2.2: DRASTIC Model Parameters Description (Aller et al., 1987)

Factor	Description	Relative weight
Depth to water	Represents the depth from the ground surface to the water table, deeper water table levels imply lesser chance for contamination to occur.	5
Net recharge	Represents the amount of water that penetrates the ground surface and reaches the water table, recharge water represents the vehicle for transporting pollutants.	4
Aquifer media	Refers to the saturated zone material properties, it controls the pollutant attenuation processes.	3
Soil media	Represents the uppermost weathered portion of the unsaturated zone and controls the amount of recharge that can infiltrate downward.	2
Topography	Refers to the slope of the land surface, it dictates whether the runoff will remain on the surface to allow contaminant percolation to the saturated zone.	1
Impact of vadose zone	Is defined as the unsaturated zone material, it controls the passage and attenuation of the contaminated material to the saturated zone.	5
Hydraulic conductivity	Indicates the ability of the aquifer to transmit water, hence determines the rate of flow of contaminant material within the groundwater system.	3

A numerical ranking system to assess ground-water pollution potential in hydrogeologic settings has been devised using the DRASTIC factors. The system contains three significant parts: weights, ranges and ratings (Aller et al., 1987).

2.4.1 DRASTIC Vulnerability Index (DVI)

The name DRASTIC is taken from the initial letters of the seven parameters used to evaluate the intrinsic vulnerability of aquifer systems. The fallowing symbols are used in the computation of DRASTIC vulnerability index.

Dr = ratings to the depth to water table,
Dw = weights assigned to the depth to water table,
Rr = ratings for ranges of aquifer recharge,
Rw = weights for aquifer recharge,
Ar = ratings assigned to aquifer media,
Aw = weights assigned to aquifer media,
Sr = ratings for the soil media,
Sw = weights for the soil media,
Tr = ratings for topography (slope),
Tw = weights assigned to topography,
Ir = ratings assigned to vadose zone,
Iw = weights assigned to vadose zone,
Cr = ratings for rates of hydraulic conductivity, and
Cw = weights given to hydraulic conductivity.

The DRASTIC Index is then computed applying a linear combination of all factors according to the following equation:

$$DRASTIC\ Index = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W \qquad (1)$$

Where D, R, A, S, T, I, and C are the seven parameters and the subscripts R and W are corresponding ratings and weights, respectively. The DRASTIC parameters are weighted from 1 to 5 as seen in Table 2.2 according to their relative importance in contributing to the contamination potential (Aller et al., 1987).

Determination of the DRASTIC index number is done by multiplying each parameter rating by its weight and adding together. Each parameter is rated on a scale from 1 to 10, a rating of 10 indicating a high pollution potential of the parameter.

A picture is given in Figure 2.1 to visualize the superimposition of the layers those are involved in DRASTIC Method.

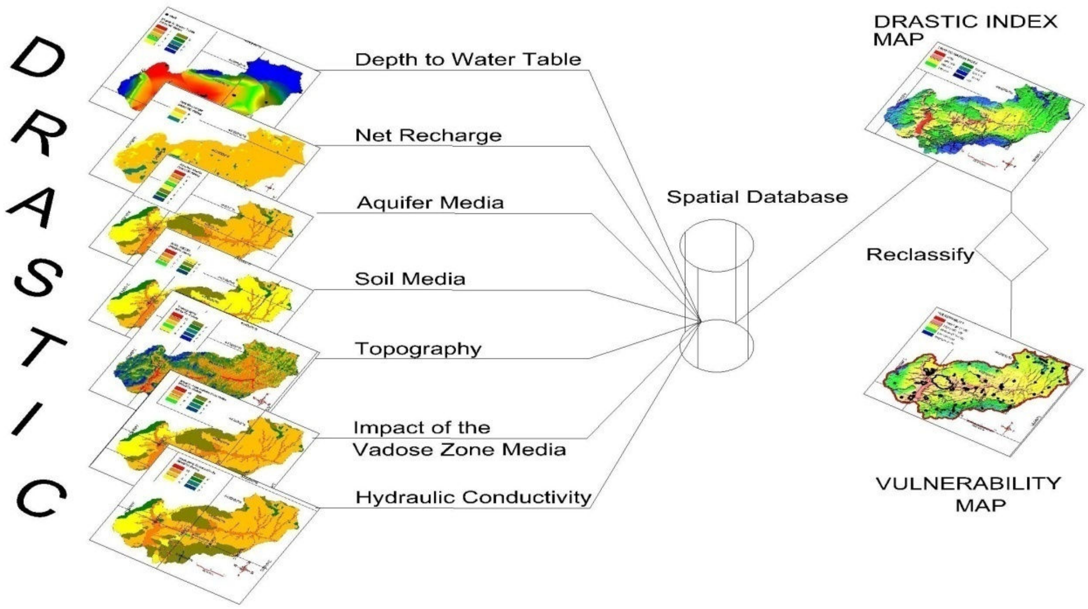


Figure 2.1: Vulnerability Map Flowchart with DRASTIC Method

In Table 2.3 the original DRASTIC parameters which are developed by Aller and friends in 1987 could be seen. Detailed information of data processing will be given in Chapter 3.

Table 2.3: Original DRASTIC Parameters (Aller et al., 1987)

Layer	Range	Rating	Typical Rating	Weight
Depth to Water (m)	0-1.5	10		5
	1.5-4.5	9		
	4.5-9	7		
	9-15	5		
	15-22.5	3		
	22.5-30	2		
	30<	1		
Recharge (mm/y)	254<	9		4
	178-254	8		
	102-178	6		
	51-102	3		
	0-51	1		
Aquifer Media	Karst Limestone	9-10	10	3
	Basalt	2-10	9	
	Sand and Gravel	4-9	8	
	Massive Limestone	4-9	6	
	Massive Sandstone	4-9	6	
	Bedded Sandstone, Limestone and Shale Sequences	5-9	6	
	Glacial Till	4-6	5	
	Weathered Metamorphic/Igneus	3-5	4	
	Metamorphic/Igneus	2-5	3	
	Massive shale	1-3	2	
Soil Media	Thin or Absent	10		2
	Gravel	10		
	Sand	9		
	Peat	8		
	Shrinking and/or Aggregated Clay	7		
	Sandy Loam	6		
	Loam	5		
	Silty Loam	4		
	Clay Loam	3		
	Muck	2		
	Nonshrinking and Nonaggregated Clay	1		
Topography (%)	0-2	10		1
	2-6	9		
	6-12	5		
	12-18	3		
	18<	1		

Table 2.3: Original DRASTIC Parameters (Aller et al., 1987) (Cont'd)

Layer	Range	Rating	Typical Rating	Weight
Impact of the Vadose Zone Media	Karst Limestone	8-10	10	5
	Basalt	2-10	9	
	Sand and Gravel	6-9	8	
	Metamorphic/Igneus	2-8	4	
	Sand and Gravel with significant Silt and	4-8	6	
	Bedded Sandstone, Limestone and Shale	4-8	6	
	Sandstone	4-8	6	
	Limestone	2-7	6	
	Shale	2-5	3	
	Silt/Clay	2-6	3	
	Confining Layer	1	1	
Hydraulic Conductivity (m/d)	82<	10		3
	41-82	8		
	29-41	6		
	12-29	4		
	4-12	2		
	0-4	1		

In order to evaluate vulnerability index, ratings that belong the case study area are given in Table 2.4. It is named as Modified DRASTIC parameters because of the limited accessibility of data; some assumptions which will be explained briefly in the next chapter are made within the approaches that are described by Aller et al. (1987) in DRASTIC Method.

Table 2.4: Modified DRASTIC Parameters

Layer	Range	Rating	Weight
Depth to Water (m)	0-1.5	10	5
	1.5-4.5	9	
	4.5-9	7	
	9-15	5	
	15-22.5	3	
	22.5-30	2	
	30<	1	

Table 2.4: Modified DRASTIC Parameters (Cont'd)

Layer	Range	Rating	Weight
Recharge (mm/y)	181	8	4
	126	6	
	66	3	
Aquifer Media	Terrace (k1)	10	3
	Gravel-Sand-Clay (k2)	9	
	Gravel-Sand-Clay (n2)	8	
	Basalt (β)	7	
	Conglomarate-Sandstone-Limestone-	6	
	Granit (γ)	5	
	Serpantin-Radiolorit-Limestone (of)	4	
	Marble(j)	2	
Soil Media	Terrace (k1)	10	2
	Gravel-Sand-Clay (k2)	9	
	Gravel-Sand-Clay (n2)	8	
	Basalt (β)	7	
	Conglomarate-Sandstone-Limestone-	6	
	Granit (γ)	5	
	Serpantin-Radiolorit-Limestone (of)	4	
	Marble(j)	2	
Topograpy (%)	0-2	10	1
	2-6	9	
	6-12	5	
	12-18	3	
	18<	1	
Impact of the Vadose Zone Med.	Terrace (k1)	10	5
	Gravel-Sand-Clay (k2)	9	
	Gravel-Sand-Clay (n2)	8	
	Basalt (β)	7	
	Conglomarate-Sandstone-Limestone-	6	
	Granit (γ)	5	
	Serpantin-Radiolorit-Limestone (of)	4	
	Marble(j)	2	
Hydraulic Conductivity	Terrace (k1)	10	3
	Gravel-Sand-Clay (k2)	9	
	Gravel-Sand-Clay (n2)	8	
	Basalt (β)	7	
	Conglomarate-Sandstone-Limestone-	6	
	Granit (γ)	5	
	Serpantin-Radiolorit-Limestone (of)	4	
	Marble(j)	2	

2.5 Benefits of DRASTIC Method

DRASTIC Method is developed to be a proactive tool to illustrate the protection guide of groundwater against contamination. According to Aller and friends the system must: 1) function as a management tool, 2) be simple and easy-to-use, 3) utilize avaible information and 4) be able to be used by individuals with diverse backgrounds and levels of expertise (Aller et al., 1987). For describing briefly, first of all if this method is used with the combination of GIS then its resulting map has the capability to facilitate the basin management in order to find out the right placement of surface activities over the land with considering groundwater protection. Secondly it is an easy applicable method such that the application is done by reading instructions and the previous studies are more helpful for the data utilization. Meanwhile the main complaint that is done by researchers is the blocking of groundwater vulnerability assessment due to unavailable data. However this method allows user to add experiences and estimations for completing lack of data in order to finish assessment. As a conclusion, this method has developed to decrease the difficulties which are faced while the evaluation of groundwater and also it is expected that the care that is shown to environment will increase by the application of this method in widespread.

DRASTIC Method is a screening tool to identify the groundwater pollution potential relative to the surrounding while faced with land use activities. Initial step is defining the more vulnerable places. In this manner, result of DRASTIC method index facilitates the evaluation. For example high index value warns that the geologic setting of the area is highly sensitive to the pollutants. Next, to identify a preventive or protective strategy highly vulnerable places are needed to be examined by monitoring and site investigations. Places that need monitoring activities are selected from the vulnerability map. The placements of the monitoring and sampling equipments are arranged according to the high pollution potential areas. As a result, the application of the DRASTIC Method gains time and money for the selection of the places require any action of controlling groundwater quality.

2.6 Computer Programs for Data Analyzing in DRASTIC Method

In recent years, advancements in computer technologies provide user friendly package programs such as Map-Info, Vertical Mapper. With these programs, spatial data analyzing and updating is not a time consuming process for the researchers.

Nowadays, there is an incredible progress in technological platform. Developments on computer software bring more ability to the users for data analysis. As mentioned earlier, a GIS based package program Map-Info Professional v.10.0 which is a product of the Pitney Bowes Business Insight, is used in this study. Also Vertical Mapper v.3.0 application that is developed by the same company preferred for the analysis of Digital Elevation Model (DEM).

To visualize the data of DRASTIC parameters creating thematic menu tool ranges of region are used except depth to water table and the topography subjects. There are several types of thematic maps such as ranges, bar charts, pie charts, granulated, dot density, individual, and grid. Ranges are the suitable thematic mapping method for this study. Custom ranges are entered as described in DRASTIC Method ratings.

In this study, IDW (Inverse Distance Weighting) method which is described as the interpolation of point data is used. Continuous data variations between the grids could be obtained by IDW technique which is very useful to observe the general trend of the area and the estimation of absent data. The principle of this method is the nearby data of points have the greater effect than farther points. The average value of the points is calculated in the given distance. The user should enter the search radius which means the data point is in center and calculation continue within the data that defined in circle area. So that by increasing the radius, more data involve in the interpolation. Also, in the settings it is easy to select different data merge methods such as summation, count, max, min and average. For example average method is preferred in this work.

For the data estimations while preparing the Depth to Water Table map IDW is used for getting the uncorrupted index transition which means interpolation and extrapolation are done between nodes in continuously. The obtained data is a point on the surface. But the purpose of this study is getting the index of the zones. So that it should be necessary to produce more points values from the known point data by making interpolations and extrapolations.

The supplied DEM data which is formed as a basis of slope map has a distance of 90 m between points. This means; the lower limit for the points distance is the 90m. In order to superimpose all the layers by using the points in same locations it is necessary to determine an interval which will reflect the interval of result map. Also in the literature commonly used interval is 100 m such as Elçi (2009). As a conclusion in the preparation of vulnerability map by using IDW method the grid data of the layers are resized to 100 m intervals

CHAPTER 3

APPLICATION OF DRASTIC METHOD

3.1 Description of the Study Site

3.1.1 Location

Study area is located in the Middle Anatolia of Turkey. It includes the City of Kırıkkale which is 80 km east of the capital Ankara and it is in the borders of Kızılırmak Basin, between the coordinates of 4390000-4450000 north latitudes and 520000- 580000 of east longitudes of Universal Transverse Mercator projection. Kızılırmak River is running from south to north and Çoruhözü Creek which is directing from east to west is discharging in to Kızılırmak River are the major surface water sources. In the inspected area, considering Çoruhözü and Kızılırmak valleys, there are two lowlands that total plain area is 115 km^2 and the total drainage area is 1127 km^2. Elevation of the valley varies between the 650 m and 900 m and the surrounding mountains rise to highest altitude of 1700 m in the southeastern part.

Major districts of study watershed are Yahşihan, Bahşili and Balışeyh. The yellow colored area in Figure 3.1 is the location of the case study in Turkey.

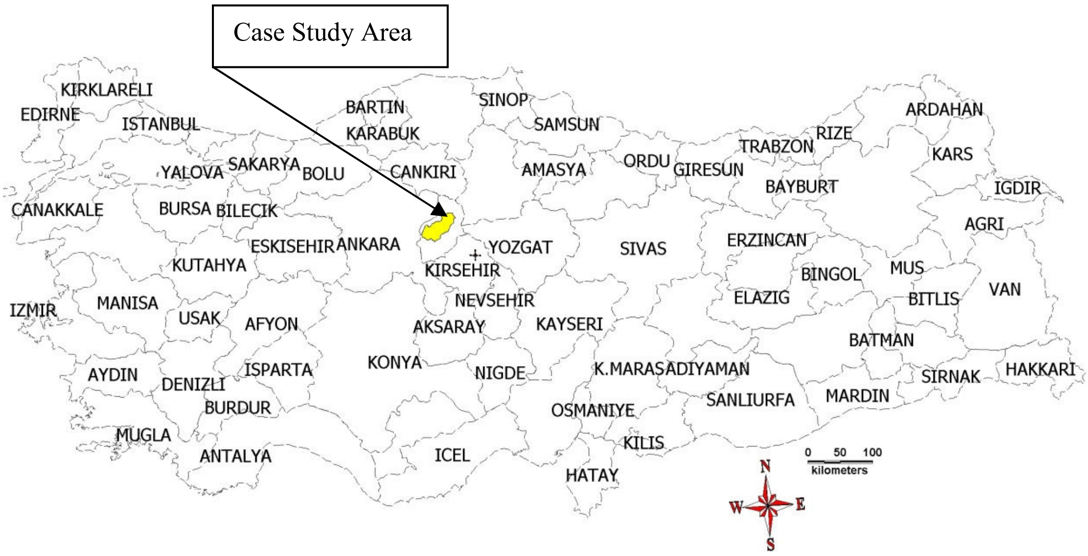


Figure 3.1: Map of Turkey

Detailed map of the placement which shows the neighbor provinces of the study area could be followed in Figure 3.2.The important point is that, this area is in front of the east door of capital city Ankara that connects the west and east sides of Turkey to each other.

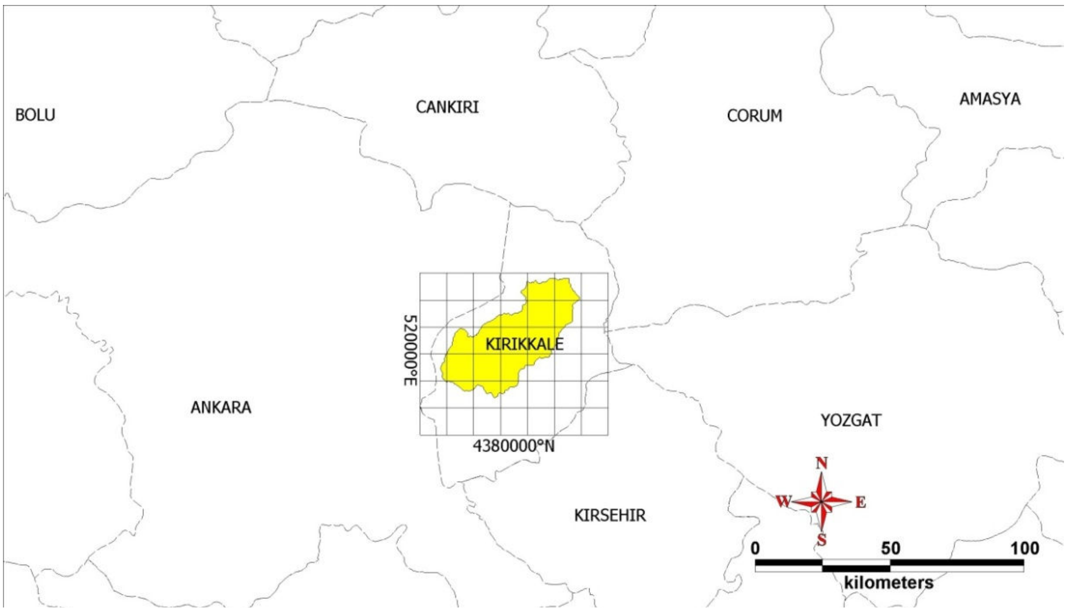


Figure 3.2: General Location of Study Area

3.1.2 Mountains

Koçubaba Mountain which has the height of 1300-1400 m is placed in the north side and the names of the main hills that should be mentioned are Fındık Hill, Vayaman Hill, and Samanlık Hill. In the west, mountains of Kızıldağ and Küredağ which are approximately height of 1100 m and 1300 m are placed and in addition Aktepe Hill, Hacıağıl Hill and Aparca Hill are standing. In the east side of the area there are Sarı Hill, Beşik Hill and Seyran Hill, and in the south Maruf Hill, Mamıkkaya Hill, Yediler Hill, Düzağaaç Hill, Karagüney Hill can be seen. Mean altitude of the plain is 750 (DSI, 1979).

Google Earth satellite image is obtained from the website as seen in Figure 3.3.The light yellow colored lines are the main highways that are passing through the basin, which is located on the junction point of east, west and also north.

Figure 3.3: Google Earth Image

3.1.3 Rivers

The major rivers of the study basin are Kızılırmak River and Çoruhözü Creek which flows from east to west. In addition, there are some creeks that pour from north and south. The important creeks are Acısu Creek and Taşlıtarla Creek, which are both perennial (DSI, 1979).

3.1.4 Climate

Climate is the characteristic of the middle Anatolian climatic properties. Winters are cold and rainy and the summers are hot and semi arid. Mean annual temperature is 12.55 ^{o}. The maximum precipitation is reached in spring season. The precipitation, temperatures and the number of mean wet days are shown in Table 3.1. The annual mean precipitation between the years 1975 and 2010 is measured as 381.1 mm.

Table 3.1: Meteorological Statics of Kırıkkale*

KIRIKKALE	J	F	M	A	M	J	J	A	S	O	N	D
	Mean values in long term (1975 - 2010)											
Mean Temperature (°C)	0.3	2.3	6.9	12.2	16.9	21.2	24.6	24.2	19.5	13.6	6.8	2.1
Mean of the Highest Temp. (°C)	4.0	6.9	12.6	18.1	23.1	27.5	30.8	30.8	26.8	20.6	12.4	5.7
Mean of the Lowest Temp (°C)	-3.0	-1.8	1.4	6.2	10.1	13.9	16.8	16.5	12.2	7.5	2.2	-1.0
Number of mean wet days	11.0	10.5	9.9	12.2	11.3	8.2	3.6	3.0	4.2	7.1	8.7	10.5
Mean Precipitation (kg/m^2)	39.5	29.1	32.3	48.6	49.9	37.5	12.4	10.0	13.8	30.6	33.5	43.9

*http://www.dmi.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=KIRIKKALE

3.1.5 Population

Population of the study area is obtained from the Population Record System Based on Address (Turkish acronym, ADNKS) data. Urban and rural population distribution between the years 2000-2010 are given in Table 3.2. From the analyzis of the results of the region population, it is dramatically decreased from the year 2000 to the year 2007. However, urban population starts to increase in 2007 till 2010.

Table 3.2: Population Statics of Kırıkkale *

Year	Urban pop. (people)	Urban/Total Pop (%)	Rural Pop (people)	Rural/Total Pop (%)	Total pop (people)
2000	285,294	74,39	98,214	25,61	383,508
2007	230,189	82,14	50,045	17,86	280,234
2008	230,354	82,47	48,971	17,53	279,325
2009	232,990	82,96	47,844	17,04	280,834
2010	233,073	84,25	43,574	15,75	276,647

*http://www.kirikkale.gov.tr

According to the results of the Population Record System Based on Address (ADNKS), which was announced on 28 January 2011 for the year 2010, total population is 276,647 people. Also 233,073 people are living in urban areas and 43,574 people are living in rural areas. Finally, 84.25% of the population is located in urban places. The city center is growing by migration from rural areas.

Population has an important effect on the groundwater consumption. The study region is developing in the urbanization so that disposal areas of solid waste should be planned.

3.1.6 Economical Conditions

3.1.6.1 Industry

City center of Kırıkkale is heavily based on the state industrial firms. On the other hand, district centers and the rural economy are based on agriculture. Kırıkkale manufacturing industries mainly depend on the state-owned large enterprises. Also, private-sector consists of small and medium-sized businesses. Machine Chemistry Institute Establishment Factories (MKEK) and Tupras Refinery occupy an important place of the province's economic profile (Kırıkkale Governorship, 2010).

3.1.6.2 Agriculture

Total agricultural field of Kırıkkale province is 463,000 ha. The area of the 306,506 ha (66.2%) is used as agricultural areas. Fields that are nearly 181,998 ha are the major part of the agricultural areas. Cereals that corresponds %53 to the all products are the main group of the crop (Kırıkkale Governorship, 2010).

3.1.7 Infrastructures

3.1.7.1 Drinking Water Supply System

City center of Kırıkkale, Keskin, Bahşili, Yahşihan Distincts and Hasandede, Hacılar and Çerikli towns' drinking water is supplied from Kapulukaya Dam, which is located on Kızılırmak River. Network construction of drinking water is done by Provincial Bank, opened in 2002. It is really important project for the area that concerns 8 municipalities including Çorum-Sungurlu.

Project of drinking water treatment plant, which is also completed by Provincial Bank, working with Reverse Osmosis method, is constructed in August 2008 and since then potable water is supplied to houses (Kırıkkale Governorship, 2010).

The capacity of the system is 90,000 m^3 per day and satisfies the needs of the 300,000 people. Nowadays, drinking water demands of 223,128 people are supplied from this project (Kırıkkale Governorship, 2010).

3.1.7.2 Liquid and Solid Waste System

Sewage network can be found in the city center of Kırıkkale and also neighboring districts and towns around Kızılırmak. However, there is no sewage treatment plant. Therefore, industrial and domestic waste water directly flows into Kızılırmak. As a result, in the future, unrecoverable environmental impacts would be observed in Kızılırmak ecological system.

The planning of solid waste stock places and sewage network are being undertaken by municipalities. Septic tanks are still in service in the small villages.

Solid waste collection and transportation service is provided by Kırıkkale, Ahılı, Aşağımahmutlar, Çullu, Hacılar and Hasandede municipalities. The border area of Ahılı village is used for the waste stocks (Kırıkkale Governorship, 2010).

3.1.8 Geology and Hydrogeology

The oldest formation in the study area is the marble of the Jura period. Following to the upper levels, ofiolit and granite of Mesozoic Era can be observed and after than the time of Eosen conglomerate, sandstone, clay stone can be found and lastly some places which are layers of compounds are seen. Surface includes conglomerate sandstone that is Neogene time with basalt and gravel, sand, clay and alluvial of the era Quaternary as given in Figure 3.4.

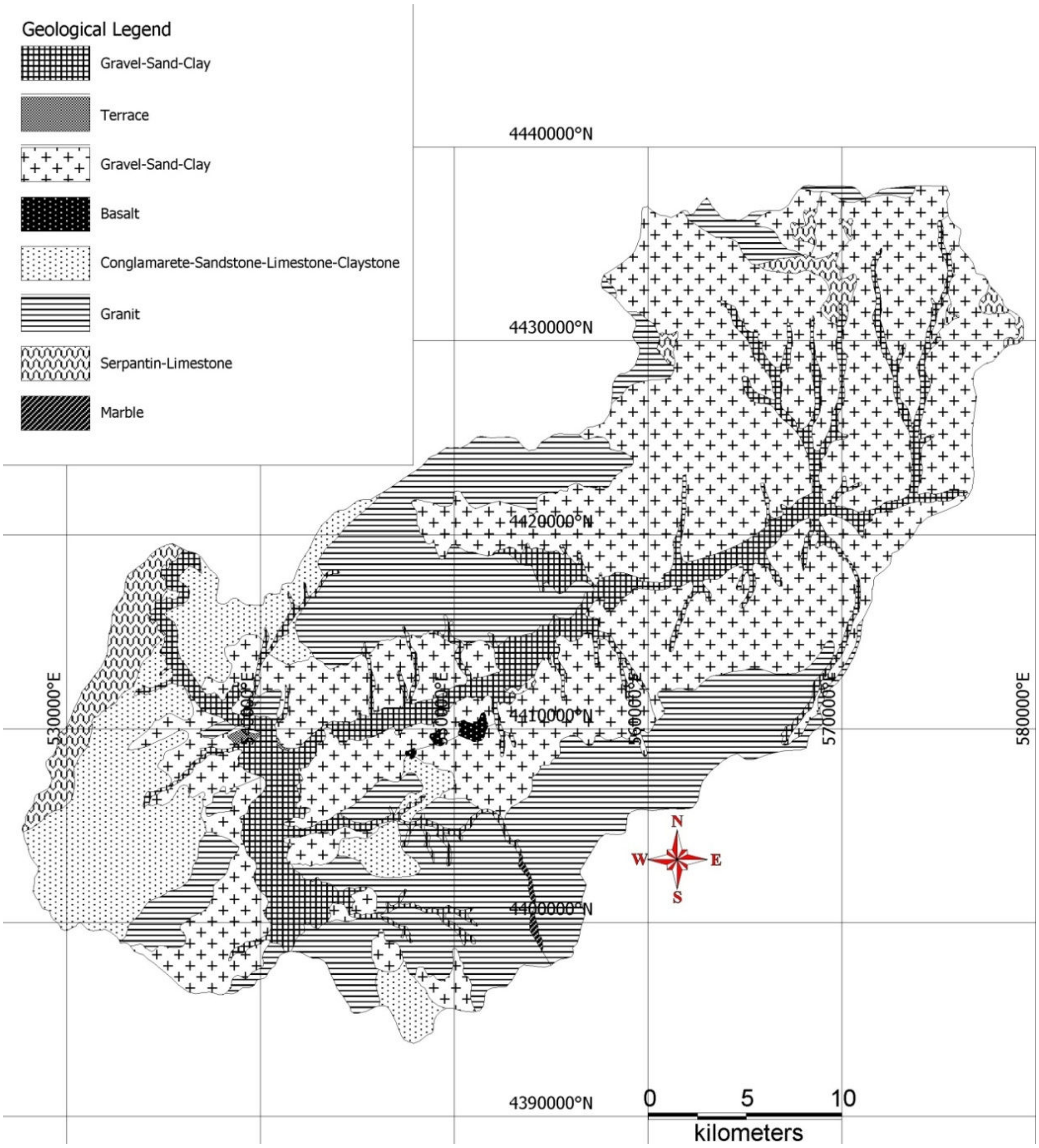


Figure 3.4: Geological Map of Study Area

The Neogene aquifer beside the alluvial formation, which reaches the flow in river bed, exists. Thickness of the aquifer varies such as in the east side that is named as Çoruhözü unit measured from 15 m to 30 m and in west side of Kızılırmak valley differ from 50 m to 60 m (DSI, 1979). Aquifer is fed by infiltration through Neogene and surface runoff. Discharge from the aquifer is through to the rivers and the wells Physical and hydrogeologic properties of the earth layers are given in Table 3.3.

Table 3.3: Hydrogeologic Properties of the Formation (DSI, 1979)

Era	Period	Sub Period	Lithology	Physical Properties	Hydrologic Properties
Cenozoic	Quaternary		Gravel-Sand-Clay (k2)	Generally gravel and sand, low clay, gray colored, contains more void	Highly permeable
	Tertiary	Neogene	Gravel-Sand-Clay (n2)	Uncemented dark yellow brown colored	Permeable
			Basalt (β)	Hard, brittle black color	Low permeable
		Paleogene Eosen	Conglomarate -Sandstone-Limestone-Claystone (e)	Thin layered, cemented brown and dark green	Impermeable
Mesozoic			Granit (γ)	Gray, white, dark gray, black hard and friable	Impermeable
			Serpantin-Radiolorit-Limestone (of)	Dark green, black sometimes red and gray colored	Impermeable
	Jura		Marble(j)	White, hard brittle fissured	Impermeable

3.2 Data Collecting and Processing

Data collection is a great problem in Turkey. Sometimes necessary data is not avaible, sometimes data is avaible but not accessible by public. Problems associated with data may be handled by extending personal experiences. One of the advantages of DRASTIC Method is that it gives the opportunity to the user to select the indexes among a possible range of values. So that errors in the data could be minimized by the experienced users during the rating selection.

To symbolize this process of assessment, DRASTIC method is the vehicle, data should be thought as the road and the target will be the vulnerability map. Also driver is the user. In this manner it is not important that how your vehicle is fast, if the road is not suitable for driving conditions. So that, more data should lead to reach target in shorter time. However, the main difficulty of studying about underground is uncertainty caused by lack of data. The geological layers of earth can change suddenly and to see this variation more surveys should be made which is not a cheap process. So the starting idea of DRASTIC Method could be said as to be a pioneer for leading the field surveys and the groundwater assessment.

In the case study, the data which are necessary for determination of DRASTIC ratings are obtained from the report that is prepared by State Hydraulic Works in 1979 based on long term surveys. From hereafter this report will be referred to as “The Report”. The report can be divided into two parts. First part is composed of text which includes the observations done in field and the assessments of groundwater quality and quantity. Second part includes geological map of the basin and well logs’ data sheets which include groundwater table. Geological layers are given in the appendix of The Report.

In this study first, hydrogeologic map provided in the report is digitized. This digital map forms the basis for the spatial data analysis. Also it is used in the preparation of DRASTIC rating index of the Aquifer Media, Soil Media, Impact of the Vadose

Zone Media and Hydraulic Conductivity. The layer of Depth to Water Table is generated by using well logs. Topography map is created with 90 m resolution Digital Elevation Model which is obtained from the National Aeronautic Space Administration (NASA) Shuttle Radar Topography Mission (SRTM) database.

Before preparing the map of recharge land use is delineated from the map of Turkey, which has scale of 1/100000. Then Soil Conservation Service Curve Number method is used for the determination of net recharge. Turkey map is obtained from State Hydraulic Works (DSI) and the precipitation is taken from the almanacs published by DSI in the year of 1990.

The flowchart of the supplied data and process can be found in Figure 3.5. Brief explanations of the data processing are described in the subsections.

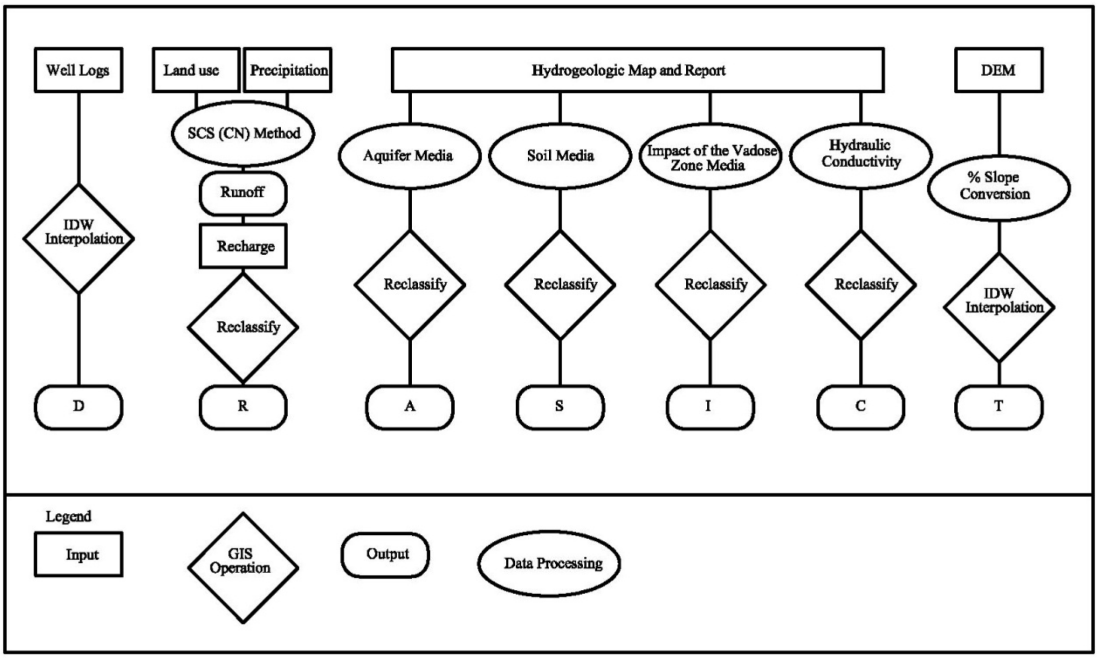


Figure 3.5 Flowchart of Spatial Data Processing

The map projection of the study area is set to Universal Transverse Mercator (UTM) Coordinates as 6 degree 33 Central Meridian of Zone 36. The datum of the projection is European Datum, 1950 (ED50).

Ground surface model which is needed to prepare a topography map is created by using Digital Elevation Model that has a resolution of 90 m which is obtained from the National Aeronautic Space Administration (NASA) Shuttle Radar Topography Mission (SRTM) database. Our project area is in the N39E33 and N40E33 parts of the database.

Overview of the basin colored according to the atlas color range can be found in Figure 3.6. The blue color represents the lower elevations and also Kızılırmak River can be easily distinguished from the picture.

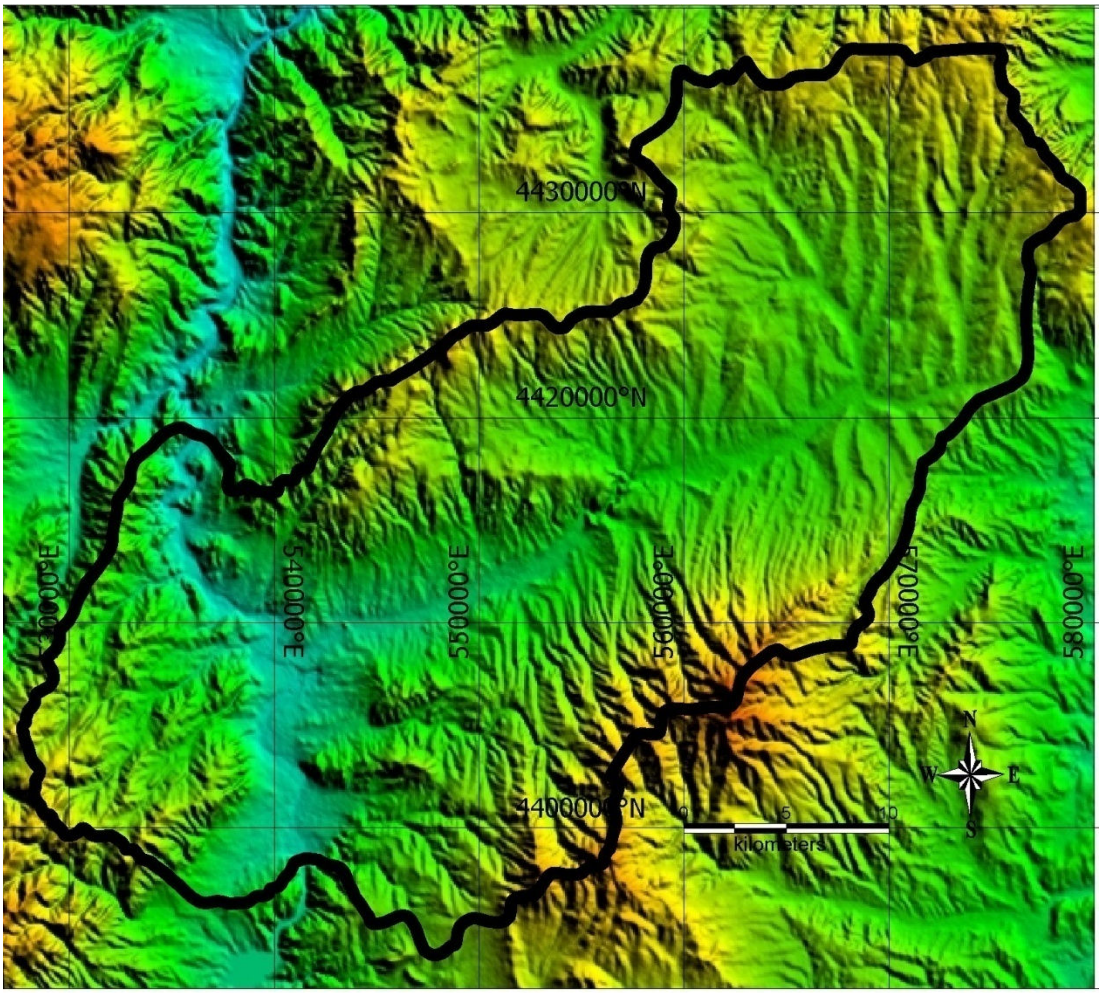


Figure 3.6: 90 mx90 m Resolution Image from NASA SRTM Database

The format of the ground data in SRTM database is “hgt”. However, format conversion to the “DEM” is done by a small application which is supplied via SRTM web site. Converted DEM files are named as grid file in the language of Vertical Mapper menu.

Shaded relief of the study area is obtained by the “3D view” tool in the “grid manager”. In this menu, options could be modified by the user such as direction of the sight, position of the view and the azimuth, inclination. As a result of the process, created view could be seen in Figure 3.7.

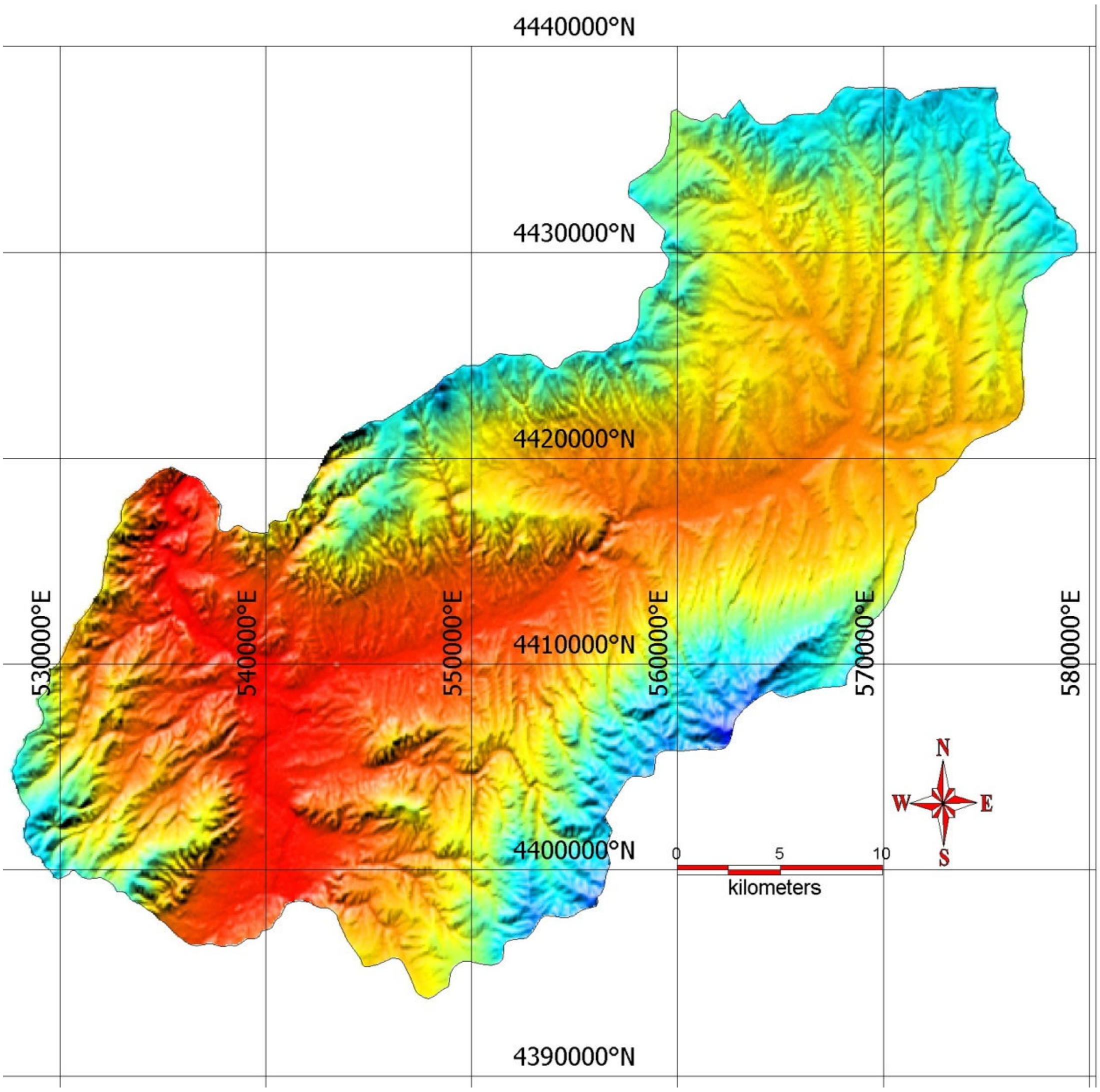


Figure 3.7: Shaded Relief of the Basin

3.2.1 Depth to Water Table

Depth to water is important primarily because it determines the depth of material through which a contaminant must travel before reaching the aquifer and it may help to determine the contact time with surrounding media (Aller et al., 1987). It is the factor that determines the length of the path which contaminants reach to the water table. In other words deeper water table means longer path which provides time for attenuation process. At the same time pathways control the interaction between the contaminants and the layers of earth. As a result of longer pathways, greater interaction causes more disposal action.

Ground water occurs in unconfined, confined and semi-confined conditions (Aller et al., 1987). Confined aquifers are always observed below the unconfined aquifers. The sensitivity of the semi-confined aquifers depends on the hydraulic gradient. On the other hand, unconfined aquifers are observed close to the surface so that they are highly sensitive for the actions on the ground. In this study Kırıkkale Plain aquifer is an unconfined aquifer which is the most vulnerable aquifer type relative to the others.

As mentioned before depth to water table is the distance between the surface and the water table. This distance could be obtained from well logs or hydrogeologic reports. In this study data are obtained from the well logs that are operated by DSI. Also, wells, which are the water supply for irrigation, are drilled by agricultural cooperatives and the municipalities are using wells for the purpose of drinking water. DSI's wells are drilled for the purpose of investigations (DSI, 1979). In the Hydrogeologic Report of Ankara-Kırıkkale Plain, there is a data sheet that shows the list of municipality wells, unfortunately coordinates of the wells are absent. Thus, municipality well logs could not be used in determining the depth to water table map.

In order to generate a realistic model of the study area as much information as possible should be gathered. So that, collected data would allow an accurate and valid selection of the media ratings. For this purpose during the data collection stage, DSI was visited. The aim of this visit was to find out if any updated well logs could be found. The wells that are in operation are stated. As a result, wells' properties such as identity (ID) numbers, coordinates and water depths are obtained as shown in Table 3.4. Wells are given in the ascending order of Easting coordinates.

Table 3.4: Wells in the Basin (DSI, 1979)

ID	Elevation	Easting	Northing	Depth to WT	DRASTIC Ratings
IM1	1 216	528 600	4 402 700	--	1
IM2	667	536 225	4 418 457	--	10
6634/B	680	540 069	4 405 836	0.55	10
IM3	686	541 400	4 399 000	--	10
52773/A	741	542 375	4 404 925	2.50	9
52773/B	735	542 975	4 404 750	1.00	10
52772	750	543 200	4 404 900	2.00	9
43459/B	752	543 800	4 404 875	2.00	9
52774	762	543 980	4 405 575	4.50	9
52771	770	544 375	4 405 050	5.50	7
43459/A	778	545 025	4 404 825	8.00	7
6843	720	546 112	4 409 937	0.62	10
20420	721	546 433	4 410 093	2.00	9
20421	723	546 666	4 410 263	1.00	10
IM4	1 025	548 000	4 394 100	--	1
IM5	1 250	550 010	4 423 971	--	1
20609	760	551 668	4 412 065	0.84	10
20608	762	552 227	4 412 171	0.60	10
20607	767	552 711	4 412 497	0.80	10
6635	774	553 140	4 412 582	0.20	10
20606	771	553 433	4 412 700	1.00	10
20605	775	553 723	4 412 934	0.10	10
20686	779	554 033	4 413 327	0.90	10
IM6	1 540	555 917	4 398 147	--	1
IM7	1 180	558 300	4 432 500	--	1
6636/A	859	561 420	4 418 070	4.33	9
6636/B	859	561 700	4 418 110	7.30	7
IM8	1 700	562 612	4 406 811	--	1
6842	936	572 068	4 420 649	9.77	5
IM9	1 250	571 200	4 437 300	--	1
IM10	1 262	579 100	4 430 000	--	1

While creating the thematic map of the depth to water table, it is necessary to make interpolations between the well locations. The obtained wells are located near Kızılırmak River and Çoruhözü Creek where the groundwater table is not so deep. Pumping groundwater to the surface in this case requires less electric consumption for operating the pumps. As seen in Table 3.4 maximum distance of the water table is 9.77 which correspond to a DRASTIC rating of 5. The DRASTIC Rating index of other wells varies from 7 to 10.

However the wells are concentrated in the middle of the valley and the data does not cover the whole basin. The lack of depth to water data should lead unrealistic results while generating the DRASTIC Index Map. In the surrounding hilly areas of the Valley, the position of ground water table is very deep (>30 m), which is in fact, insignificant for the ground water vulnerability evaluation of shallow aquifer of the study area (Pathak et al., 2009). In addition, parameters such as depth to water and hydraulic conductivity may be extrapolated, based on known points, to areas with limited or no data (Liggett and Talwar, 2009). Imaginary wells are placed on the boundary of the region at an elevation of higher than 1000 m to make extrapolation possible. The code of IM is used for imaginary wells. Depth to water table map is generated using both real and imaginary wells.

Inverse Distance Weighting (IDW) method is selected for creating depth to water table map. In addition, to cover the entire basin, search radius is assumed as 10 km which is the maximum distance between the wells. Also, an aggregate coincident point by average function is enabled while executing data.

An interval of grid surface cells was chosen as 100 m considering spatial resolution of available data such as Digital Elevation Model (DEM) and computational consideration. The obtained grid cell data which is having interval of 100 m are used in Vertical Mapper calculator menu in order to create superimposed map.

As a result depth to water table map is obtained according to the instructions given in DRASTIC method by Aller et al., in 1987 as seen in Figure 3.8. The usage of imaginary wells in the preparation of depth to water table map makes the model more similar to the real life. To make it clear existing depths to water table data do not cover the whole area especially where the IM2 and IM3 named unreal wells on Kızılırmak River rated as 10. The real and imaginary wells are executed together, in order to generate depth to water table map. It is briefly seen that the central parts of the region where water table close to surface have higher DRASTIC Index such as 9, 10 and indicated with color red. As a conclusion, the depth to water table rating in the middle part of study area is high, and gradually decreases to boundaries by are approached, where elevation increases.

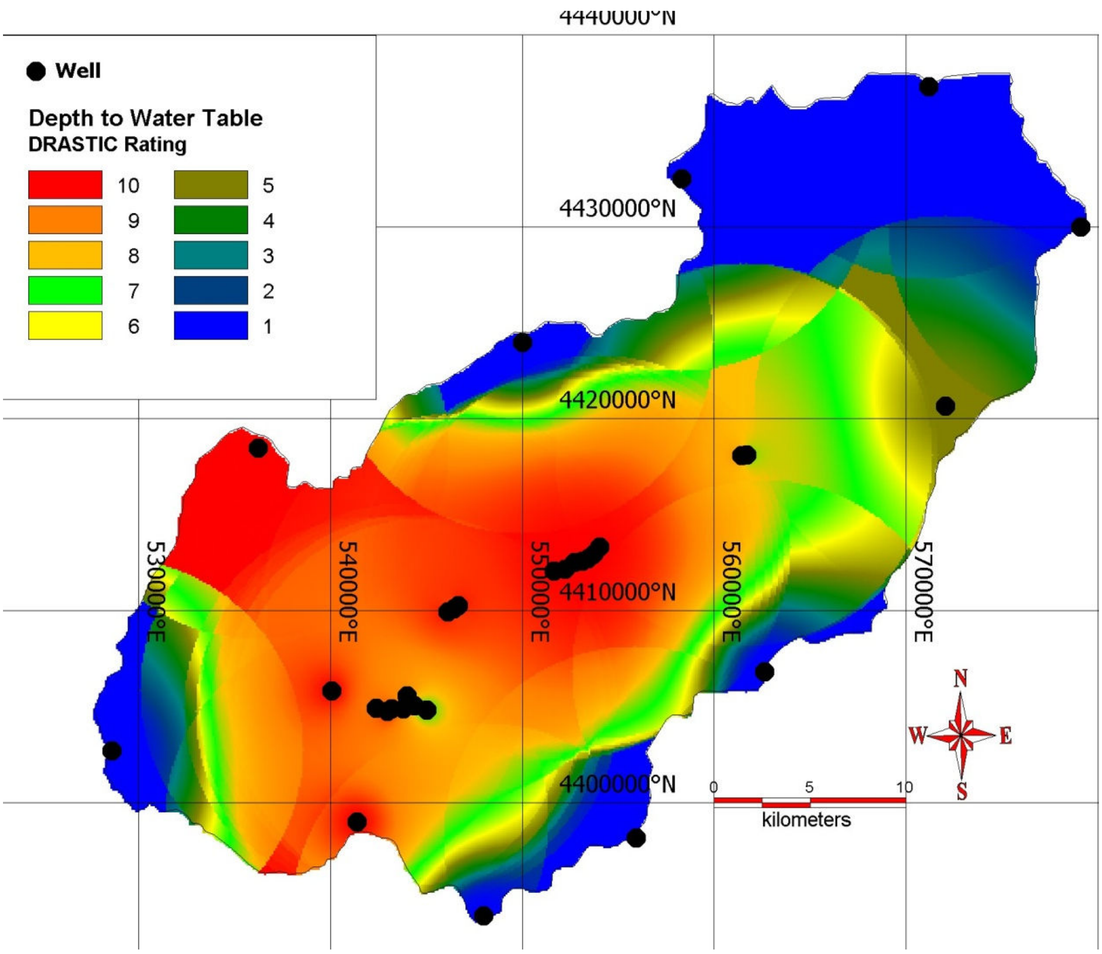


Figure 3.8: Depth to Water Table Rating Map

3.2.2 Net Recharge

Net recharge represents the amount of water per unit area of land which penetrates the ground surface and reaches the water table (Aller et al.,1987). Groundwater is generally fed by the infiltration caused by surface water resulting from precipitation. Infiltration is the entrance of water into soil through the pores and openings at the surface (Usul, 2009). As used in the methodology, net recharge is defined as the total quantity of water which is applied to the ground surface and infiltrates to reach the aquifer (Aller et al.,1987).

Net recharge can be described as the amount of water that meets with groundwater which is the main tool for contaminant transportation. Water is the vehicle that carries contaminants. This transportation is controlled by environmental and geological settings. Much water means many vehicles to carry contaminants. Gravity is the driving force for vertical movement of water. Net recharge is defined in units of mm per year.

Net recharge parameter can be estimated using hydrological precipitation-runoff models, field experiments or simply by multiplying the difference of the spatial distribution of evapotranspiration and the spatial distribution for mean annual rainfall by an infiltration coefficient (Elçi, 2010). In addition to infiltration from precipitation, sources of recharge including irrigation, artificial recharge and wastewater application must be considered (Aller et al., 1987). However the data, which is necessary for recharge calculation, could not be obtained such as evapotranspiration, irrigation and wastewater. On the other hand, this area is not water rich so the vegetation pattern is based on low water demand. Actually, wells are used for irrigation and the pumped water returns to the water table. Also, sewage is discharged directly to Kızılırmak River or other surface water bodies so that sewage discharge is not taken into consideration as a recharge.

In this study, for determining the net recharge, precipitation values of the region are investigated. For this purpose, the map which is published by DSI (2006) shows the Meteorological Stations over the area (Figure 3.9). Stations in the study area are identified; precipitation values of these stations are obtained.

The study area is located in Kızılırmak Basin. The code number of the basin is 15 which is used as a basin identity in DSI. This region is in the boundary of the DSI V. (5th) Region Directory which is located in Ankara.

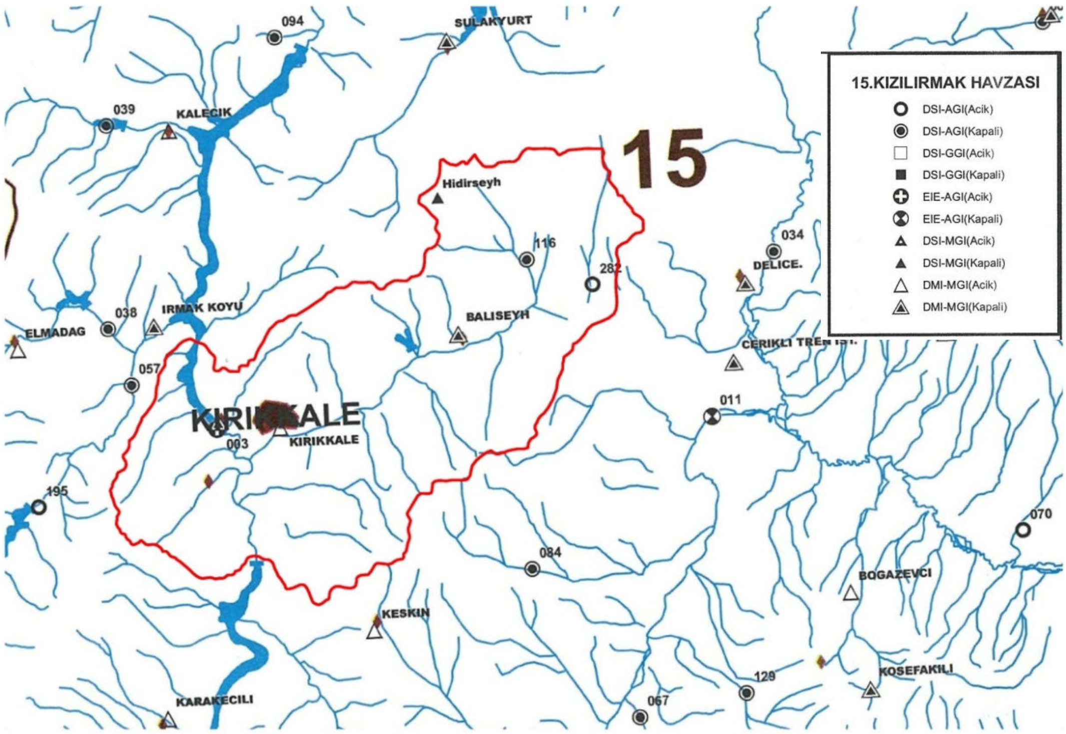


Figure 3.9: Meteorological Stations of Kızılırmak Basin (DSI, 2006)

The annual mean precipitations of the stations are obtained from the book published by DSI (1990). There are three stations in the covered area of the basin. Unfortunately, Hıdırseyh station rainfall data could not be accessed since the station is not in operation. At the station of Kırıkkale, data observations were started in year 1953 and ended in 1987. The years, during which no data is recorded, are noted as 1956, 1957, 1959, 1961 and last 1962. Total numbers of data observations are found as 30. Likewise in the station of Balıseyh observations are started from the year of

1964 and ended in the year 1987. Number of data could be obtained as 24. Updated values can be obtained from the website of General Directory of Meteorology (DMI). Rainfall data which are obtained from book published in 1990 are listed in Table 3.5.

Table 3.5: Meteorological Stations and Annual Mean Precipitation (DSI, 1990)

STATIONS	Elevation (m)	X	Y	P(mm/year)
BALISEYH	860	561389	4419508	395.06
KIRIKKALE	725	543562	4412378	375.73

Kırıkkale is the most populated setting and the excessive human activities commonly take place in this area and also it is the center of the basin. In order to determine the recharge of the basin, annual mean precipitation which is obtained from website including the newer observations done between the years 1970 and 2010 is considered as 381.1 mm/y. Then calculations are continued with this value. There will be an explanation in the end of this section to show the effect of assumption for determining the rating.

The shallow aquifer recharged mainly by direct infiltration from precipitation therefore net recharge was estimated by using formula of Net Recharge equals to the summation of evaporation and runoff are subtracted from rainfall (Pathak et al., 2008). Also topography and the soil media are the effective parameters for runoff determination; however these items are taken into consideration as a separate layer in DRASTIC Method.

In this study for the determination of the runoff a method that developed by The Soil Conservation Service for computing abstractions from storm rainfall, is used as mentioned in the book of Chow in 1988. According to Chow there is some amount of rainfall initial abstraction before ponding for which no runoff will occur, so the potential runoff is equals to subtraction of initial abstraction from total rainfall. According to the Soil Conservation Service (SCS) method, rainfall equals to the summation of the runoff and the amount of water infiltrated and stored by soil.

During the determination of recharge, surface runoff will be subtracted from the precipitation. The assumption, that is done to define net recharge, is the summation of the initial abstraction and continuing abstraction accepted as the amount of water resulting as net recharge.

SCS method uses Curve Number (CN). It is in the range 0-100, and determined as a function of soil classification, given as soil groups, and land cover (Usul, 2009). Definition of soil groups are given in Table 3.6.

Table 3.6 Definition of Soil Groups (Usul, 2009)

Group A	Lowest runoff potential: Deep sand, deep loess, aggregated silts
Group B	Moderately low runoff potential: Shallow loess, sandy loam
Group C	Moderately high runoff potential: Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay
Group D	Highest runoff potential: Soils that swell significantly when wet, heavy plastic clays, and certain saline soils.

The basin is divided into three categories which are forest, urban and rural. These zones are delineated from the 1/100.000 scaled maps of Turkey. In The Report, it is stated that Kızılırmak and Çoruhözü Valley soil is composed of the gravel, sand, clay and silt. Gravel is the major part of Çoruhözü valley however in Kızılırmak valley clay and the silt is the main portion. So that covering the whole area it is assumed that %50 percent is Group B and the rest is Group C. Curve Numbers of the study area is determined according to the assumptions based on The Report prepared by DSI in 1979 can be found in Table 3.7.

Table 3.7 Runoff Curve Numbers (Kızılkaya, 1988)

Land use	Hydraulic Condition for Infiltration	Hydraulic Soil Group	
		Group B	Group C
Forest	Good	55	70
Rural	Good	35	70
Urban	Avarage Impervious %33	74	82

As mentioned before, precipitation of the whole area is taken as 381.1mm/y. Annual rainfall is the x-axis of the graph in Figure 3.10. Then runoff is read on the right side of the graph in Figure 3.10 according to the Curve Numbers crossing point.

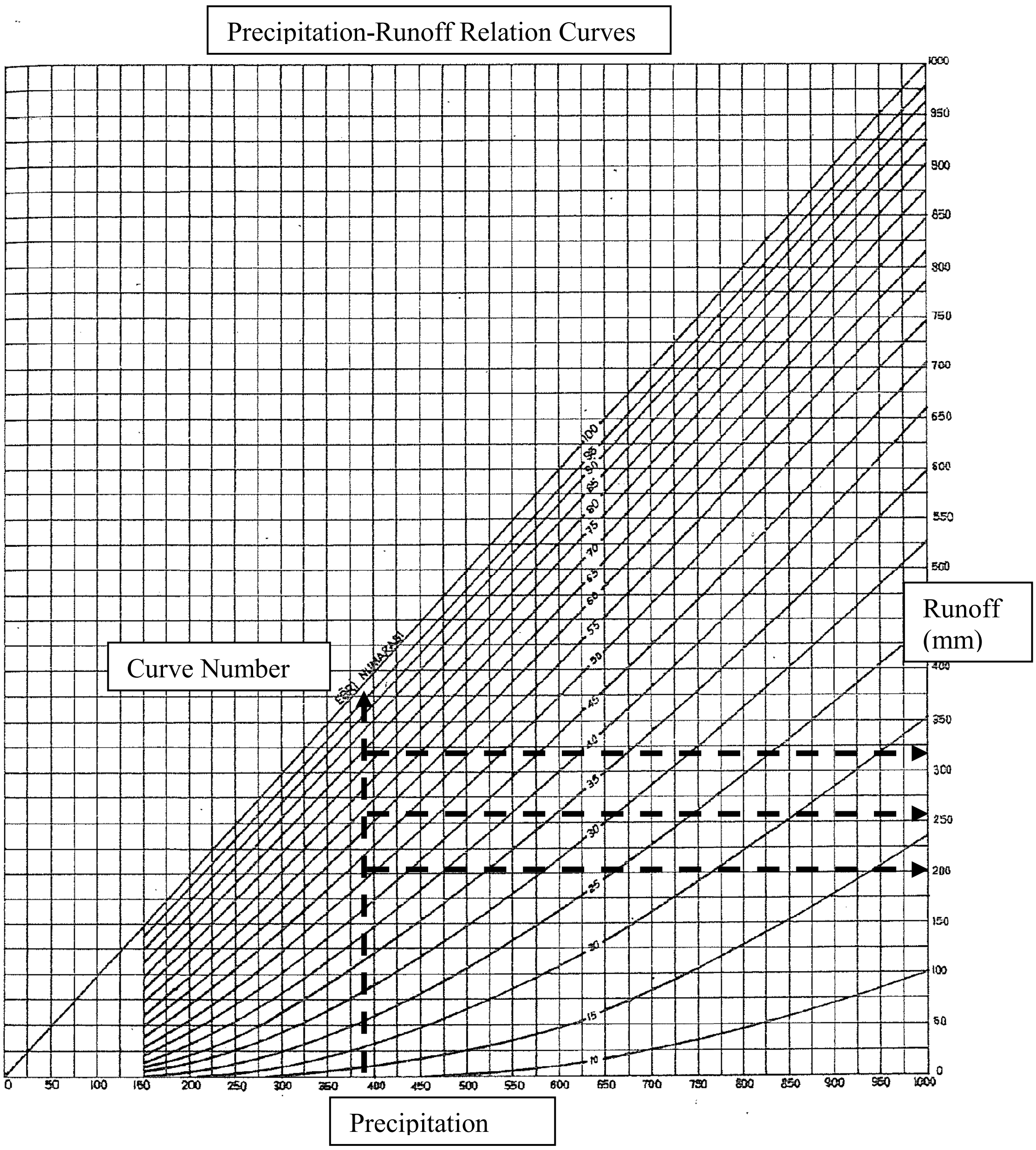


Figure 3.10 Precipitation-Runoff Relation Curves (Kızılkaya, 1988)

It is assumed that the subtracting the runoff from the rainfall result in the net recharge. The amount of water that stored in soil and on plants is neglected. So that net recharge is assumed to be the rainfall minus runoff. Net recharge values and the ratio of recharge to rainfall are given in Table 3.8.

Table 3.8: Net Recharge of Study Area

Land use	Curve Number	Runoff (mm/y)	Net Recharge (mm/y)	Recharge /Rainfall (%)
Urban	(74+82)/2=78	315	381-315=66	17
Forest	(55+70)/2=63	255	381-255=126	33
Rural	(35+70)/2=53	200	381-200=181	48

Maximum recharge value as 181 mm/year in the basin is rated as 8 due to DRASTIC Index values. Rural area is rated 8 because of land use permits higher infiltration. The forest area is rated 6. In urban, water passage through soil is not allowed as much as rural or forest so the rating of 3 is assigned. Recharge rating index are given in Table 3.9.

Table 3.9: Recharge Rating Index

Land-use	Net Recharge (mm/y)	Original DRASTIC Range (mm/y)	Original DRASTIC Rating
Urban	66	51-102	3
Forest	126	102-178	6
Rural	181	178-254	8

In the starting point of the calculations, it is assumed that the basin's annual precipitation is 381.1 mm which is not true for the whole basin. Luckily precipitation of the basin is not spread within a large interval; all assumed annual rainfall gave the same rating for the assumptions such as the record of Baliseyh is 395mm. Therefore the recharge of rural is calculated as 195 within the interval of 178-254 in DRASTIC range. When it is checked for the rating variability depending on assumption then it is seen that the net recharge is obtained in the ranges of selected ratings. As explained in this subsection by using SCS method the net recharge rating map is obtained as shown in Figure 3.11.

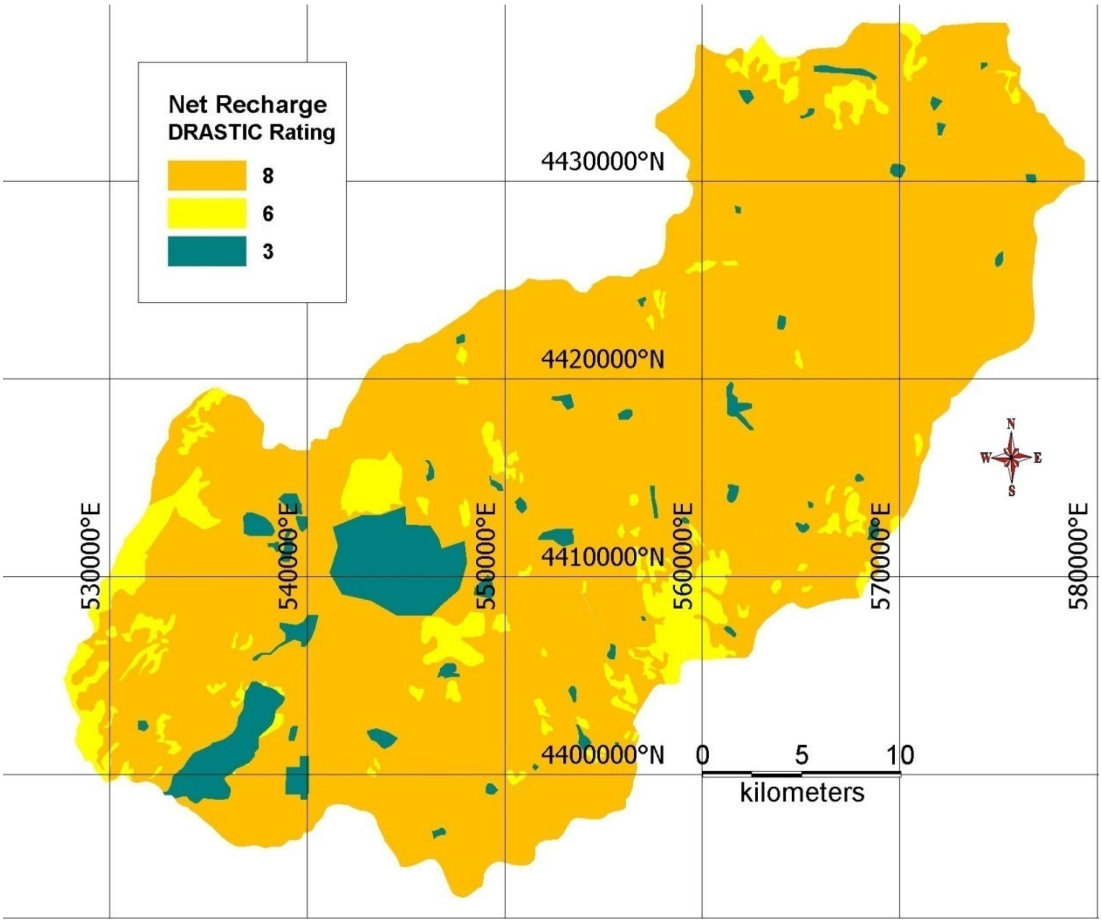


Figure 3.11: Recharge Rating Map

Kırıkkale city center is the biggest human populated part of the area of which DRASTIC Index of 3 is assigned. General land use of the basin is agricultural or empty areas and it is rated as 8.

In addition to infiltration from precipitation, sources of recharge including irrigation, artificial recharge and wastewater application must be considered (Aller et al., 1987). However they are not considered because of missed information. Furthermore to obtain reliable results the amount of water affecting the recharge will be defined.

3.2.3 Aquifer Media

Aquifer is the saturated permeable geologic formation, which contains and transmits water in economic amounts, under ordinary hydraulic gradients, for water supply and has generally sand and gravel (Usul, 2009). Water is stored in the spaces of the rock formations. Also other type of water storage is in the fractures of the non granular rocks in the aquifer media.

The aquifer media control possible attenuation of the contaminant (Varol and Davraz, 2010). As mentioned earlier, water moves horizontally and sometimes vertically in the aquifer media zone. The lengths of the waterway and the followed path have important effects on contaminant time of travel. Furthermore, the groundwater paths also control the contact area between the formation and the contaminant. Actually travel time assists the attenuation process. For example, sorption, reactivity and dispersion can be described as the types of attenuation. Aquifer media fractures, grain size, openings decrease contaminant travel time which means less attenuation capacity. For the healthiness of the analysis, decision maker should be careful about the indexing fractured Media while using DRASTIC Method. Short paths decrease attenuation so the media will become more vulnerable. In general, the larger the grain size and the more fractures or openings within the aquifer, the higher permeability and the lower the attenuation capacity of the aquifer media (Aller et al., 1987). In the case study area the geological settings are rated according to the permeability that described in Table 3.3 then the DRASTIC Ratings given in Table 3.10.

Table 3.10: Aquifer Media Rating Table

Formation	Aquifer Media Rating
Terrace	10
Gravel-Sand-Clay	9
Gravel-Sand-Clay	8
Basalt	7
Conglomarate-Sandstone-Limestone-Claystone	6
Granit	5
Serpantin-Radiolorit-Limestone	4
Marble	2

The Aquifer Media DRASTIC Rating map is created as seen in Figure 3.12. Water movement in the red zones, which are corresponding to the gravel river bed, is easier and transportation of contaminant could be possible.

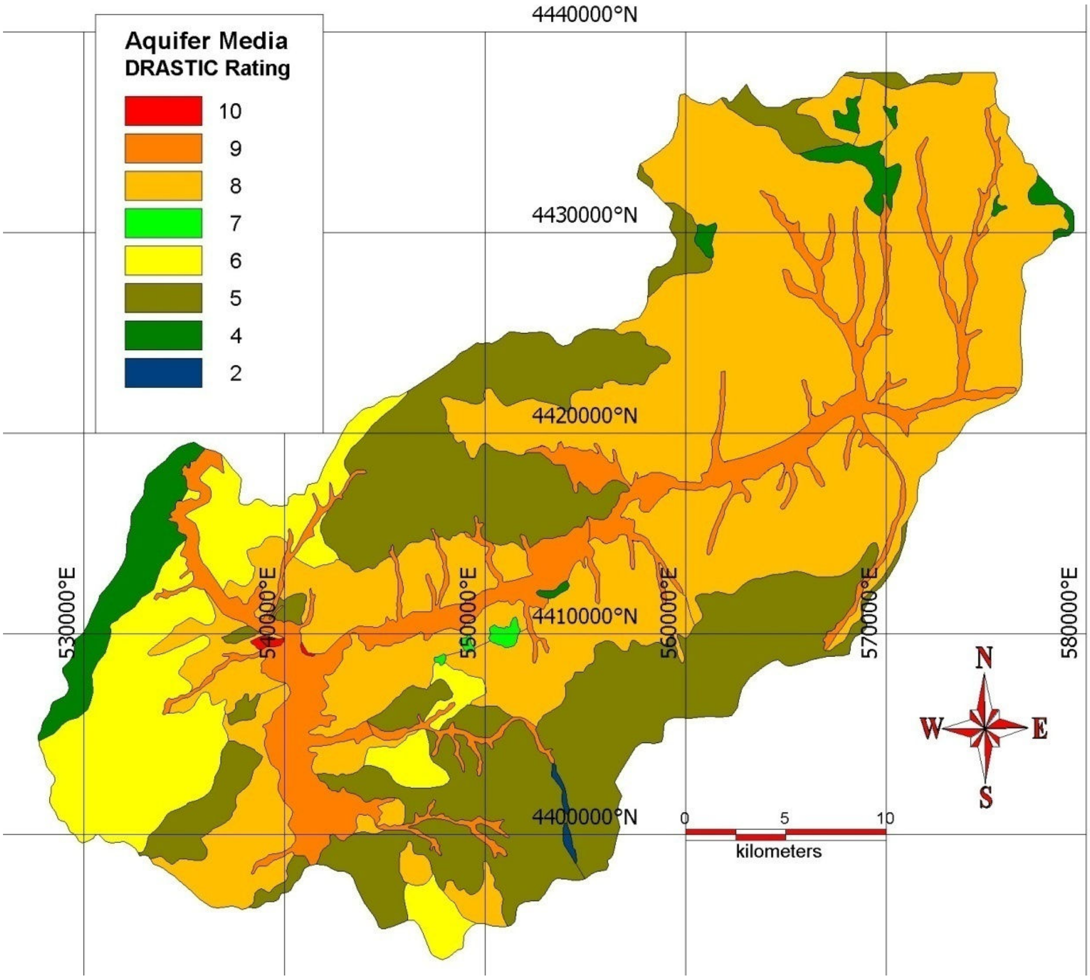


Figure 3.12: Aquifer Media Rating Map

3.2.4 Soil Media

Soil has a significant impact on the amount of recharge that can infiltrate into the ground, and hence on the ability of a contaminant to move vertically into the vadose zone (Chitsazan and Akhtari, 2009). Soil media could be described as the layer over the unsaturated (vadose) zone. Generally, the thickness of the soil media varies from zero to 1.5 m in depth. All the vegetation and farming activities are done in soil media which controls the contaminant passage to the vadose media. During infiltration process, contaminants are carried by recharge. Depending on the thickness and content of soil media, the process of attenuation occurs. Moreover, where the soil zone is fairly thick, the attenuation processes of filtration, biodegradation, sorption and volatilization may be quite significant (Aller et al., 1987). On the other hand, agricultural activities on the soil cause the usage of pesticides which is a contaminant source. Land use and the permeability of the soil layer affect the vulnerability. Silt and clay materials are small sized so low permeability means less contaminant transport. At the same time, organic content of the soil layer is playing an active role in attenuation.

Generally, for identifying the soil media rating, soil association map of the county could be used. In addition to maps, descriptive reports are useful for soil media description. Then thickness of the soil texture should be investigated.

Composition of the soil should vary. Soil can be mixture of different substances. While defining the permeability for finding the DRASTIC index, portions of the soil are reviewed and the major part is accepted that is main participator of the compound. Also, shrinkage and swelling factor for the clays permit the fractures for the contaminant vertical movement. In conclusion, it should not be forgotten that vulnerability increases due to the soil water transfer capacity.

Soil maps of the area should be prepared by Rural Services, but in 2005 with the accepted law by government, the General Directorate of the Rural Services joined to

Special Provincial Administrations. Unfortunately, the soil map of the region could not be found. Instead of Soil texture map, the geological map is transformed to the soil map considering permeability.

The presence of fine-textured materials such as silts and clays can decrease relative soil permeability and restrict contaminant migration (Chitsazan and Akhtari, 2009). Depending on the observations given in The Report, east and northeast part of the valley contain clay, however west part and Kırıkkale city neighborhoods consist of gravel. Consequently, east part is rated as 6; on the other hand west part is rated as 8 for the Gravel-Sand-Clay zones. Soil media ratings are presented read in Table 3.11.

Table 3.11: Soil Media Rating Table

Geological Formation	Soil media Rating
Terrace	10
Gravel-Sand-Clay	9
Gravel-Sand-Clay	8
Basalt	7
Conglomarate-Sandstone-Limestone-Claystone	6
Granit	5
Serpantin-Radiolorit-Limestone	4
Marble	2

The soil media map is created as a thematic map in MapInfo by using DRASTIC ratings in Figure 3.13. The red and orange colored regions are permeable so that DRASTIC Index is higher.

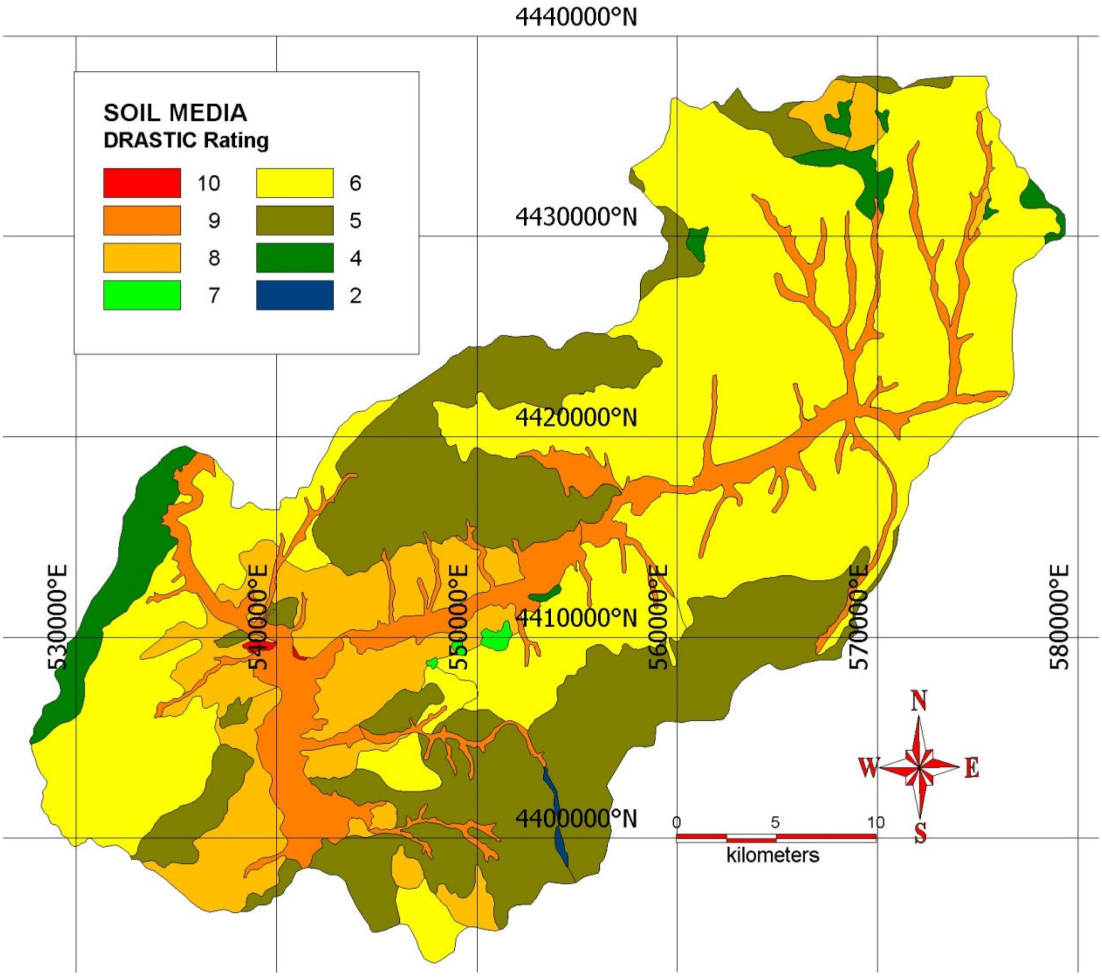


Figure 3.13: Soil Media Rating Map

In the preparation of this soil media layer geological map is used as a basis but this situation could not match with application of DRASTIC Method. However, as stated by Aller et al., (1987) that in the event of a difficult decision, such as the absence of soil map the user may wish to evaluate other information such as organic matter content or permeability in making a soil media selection. Finally soil media rating map is obtained by using permeability properties of the basin.

3.2.5 Topography

Topography refers to the slope and slope variability of the land surface (Aller et al., 1987). In this manner, topography affects the surface runoff so that proper time for infiltrating of contaminants is controlled. Areas with low slope tend to retain water longer and this allows a greater infiltration of recharge water and a greater potential for contaminant migration (Baalousha, 2006). Steeper slopes mean higher velocities so less time for contaminant vertical movement through soil media and mean less transportation of contaminants. As summary, topography controls water speed that affects the water to settle down or to runoff over the soil surface.

Generally, land use is planned depending on the topographic conditions. Mild topographic places are preferred for the people activities. Grading of mild slope terrain is more economic in construction.

Classifying of soil slope according to the typical range is done by the soil services of the countries. In order to process data easily DRASTIC Method slope ranges correspond to the soil services. The accepted lower limit is between 0-2 percent. The ranges are assigned ratings assuming that 0 to 2 percent slope provides the greatest opportunity for a pollutant to infiltrate because neither the pollutant nor much precipitation exits the area as runoff (Aller et al. 1987). In addition, higher limit is 18 percent which is rated 1 in DRASTIC index. Higher slope mean higher speed of water movement that results as surface runoff.

Slope was calculated in terms of percentage using the resampled version of the original digital elevation data (Elçi, 2010). Resampling was necessary to be consistent with the selected 100 m × 100 m resolution since the DEM had a different resolution (Elçi, 2010). As mentioned before, Digital Elevation Model is used as a basis for this layer in Vertical Mapper program that functions are used to prepare a slope map. To make this procedure clear command should be explained.

Firstly in the menu of Vertical Mapper program, “index tool” is executed to create slope map. The algorithm of slope calculation is the elevation difference divided to the distance between the points.

Then, average value of the slopes is accepted as a result value. Soon, created grid surface is reclassified according to slope index ranges which are explained in the method. The percentages of the point’s data which are reclassified are rated as explained in DRASTIC Method. Then Inverse Distance Weighting (IDW) method is selected for creating the thematic map.

Aggregate coincident points by average are preferred for obtaining the slope map. The surface is separated into 100 m interval cells for the further calculations that will be used for the summation of maps. The slope map is obtained after assigning the ratings of the grid surface point’s data as seen in Table 3.12.

Table 3.12: Range and Rating for Topography (Aller et al., 1987)

Slope %	Rating
0-2	10
2-6	9
6-12	5
12-18	3
>18	1

As a result of the above efforts Topography rating map is obtained as described in DRASTIC Method as seen in Figure 3.14. Color index is formed as the orange and red color indicates for low sloped areas and the darker color represents the higher slope percentages.

The red colored zones are the mild slopes areas near the rivers and creeks. Also human activities are realized in these places which have a DRASTIC Index of greater than 8.

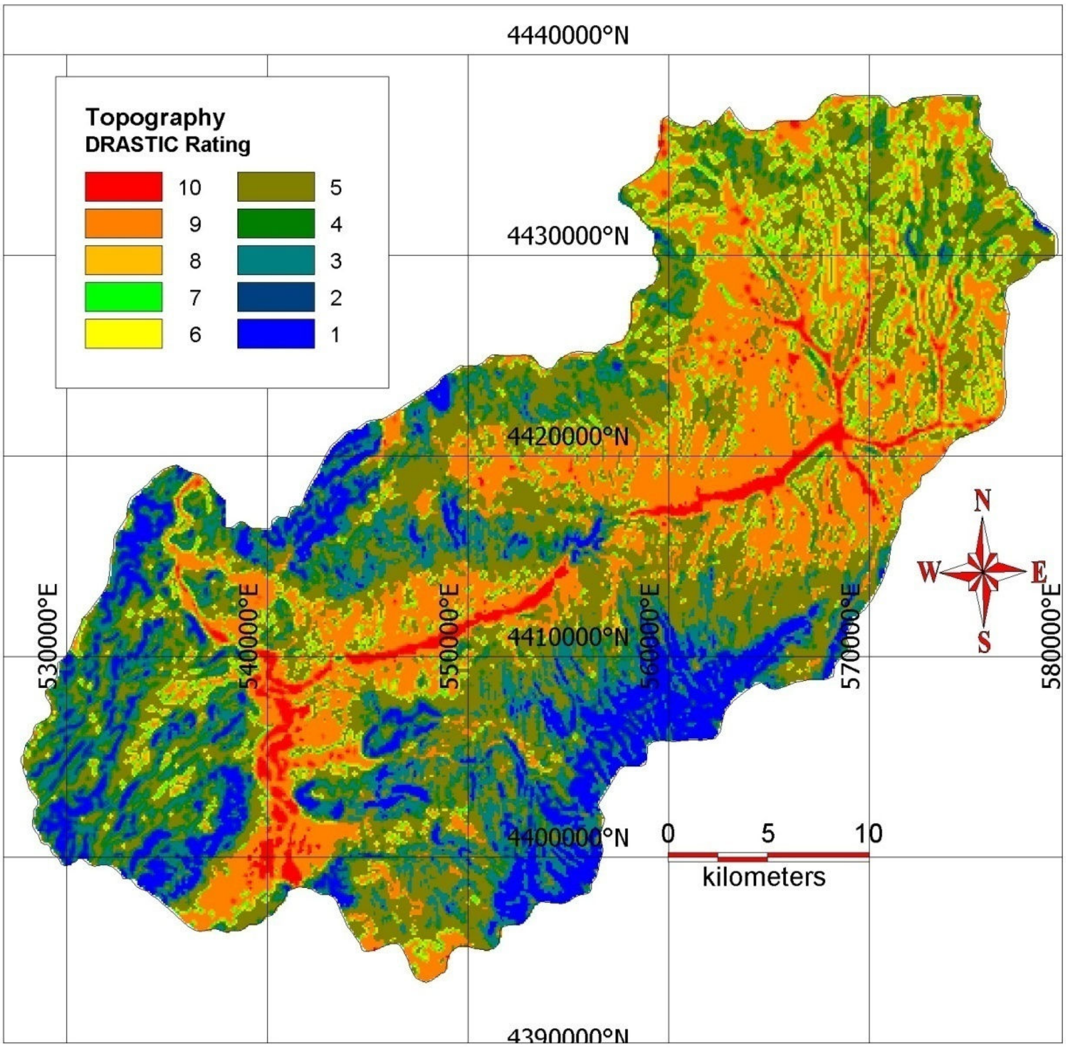


Figure 3.14: Topography Rating Map

3.2.6 Impact of the Vadose Zone Media

The vadose zone could be explained as the unsaturated or the partially saturated zone between the soil layer and groundwater. This factor affects the flow rate at the surface, and consequently affects biodegradation and attenuation (Baalousha, 2006). Furthermore, this zone controls the path of contaminant particles to the aquifer system (Chitsazan and Akhtari, 2009). This media controls the attenuation process due to geological characteristics. Biodegradation, neutralization, mechanical filtration, chemical reaction, volatilization and dispersion are all processes which may occur within the vadose zone (Aller et al., 1987). As mentioned before, the length of the path is one of the major factors for attenuation time. While the path of contaminant transport is getting longer, time to reach groundwater increases. Also, the contact surface of the contaminant with varying geological formations widens. Permeability and the fractures in the media are the adverse effect to attenuation process. In conclusion, if the media has retarding effects to the contaminant transportation, then vulnerability decreases.

In some cases, the thicker vadose zone media had both positive and negative effects. Positive effect can be named as the long attenuation time but the fractures in the media zone transmit the contaminants faster so the attenuation process could be terminated.

The aquifer of the case study is unconfined so that the travel time of the contaminants directly related with permeability. Geological map and the permeability which are given in Table 3.3 are used for assigning the DRASTIC index. The user may choose ratings to reflect grain size, sorting, homogeneity and amount of fine material (Aller et al.,1987). These are the properties of formation that control the water movement. Higher permeability implies the free movement of the contaminants and this make the region vulnerable. Assigned DRASTIC Ratings are the same as seen in Table 3.10.

The impact of the vadose zone media map is obtained as seen in Figure 3.15 by creating thematic map by using the permeability.

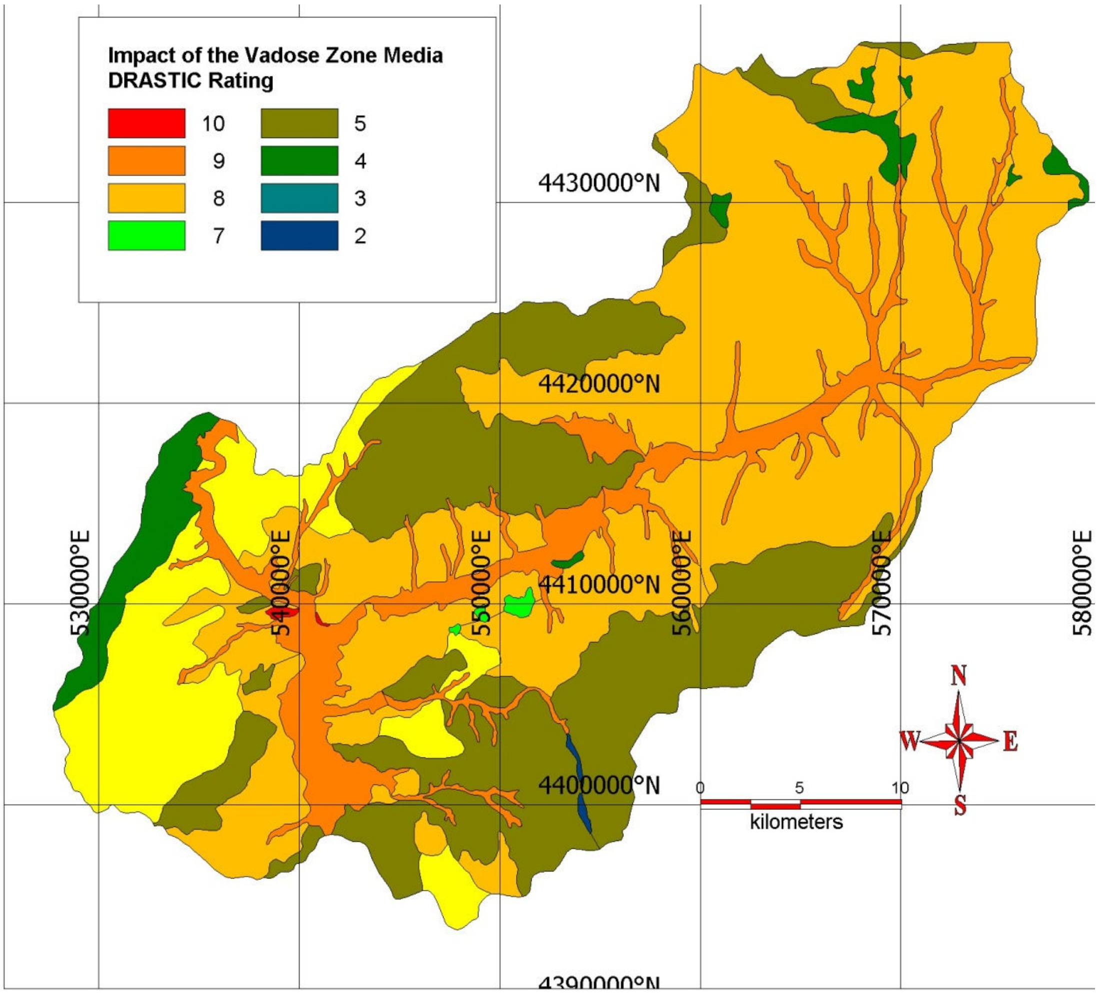


Figure 3.15: Impact of the Vadose Zone Media Rating Map

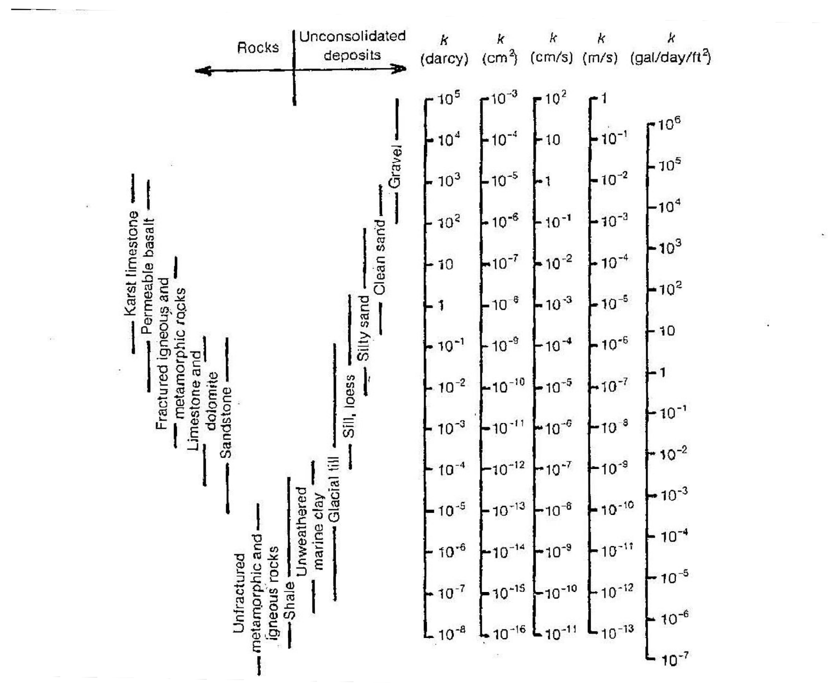
3.2.7 Hydraulic Conductivity

Hydraulic conductivity refers to the ability of aquifer materials to transmit water, which in turn, controls the rate at which groundwater will flow under a given hydraulic gradient (Aller et al., 1987). Hydraulic conductivity is explained as the amount of water flows under an imposed hydraulic gradient. The rate of carried contaminant is directly proportional to the flow rate of groundwater. The void spaces in the aquifer zone permit water to flow.

In field, hydraulic conductivity is obtained by aquifer pumping tests. Of all the factors, this information may be the most difficult to find because it is related very closely to aquifer media, if necessary, hydraulic conductivity may be estimated using Table 3.13 (Aller et al., 1987). In this study hydraulic conductivity of the basin is studied by drilled wells. Unfortunately, well coordinates could not found in The Report and the numbers of well are not satisfactory for the analysis of the whole basin. Hydraulic conductivity is determined according to geological conditions. Geological layers are found on the left side of Table 3.13. It is facilitate to draw an imaginary straight line to read the values of ***k*** with different units which are also shown by parallel lines.

After finding the values for ***k*** from the Table 3.13, then the curve in Figure 3.16 is used to assign DRASTIC index.

Table 3.13 Range of Values of Hydraulic Conductivity and Permeability (Freeze and Cherry, 1979)



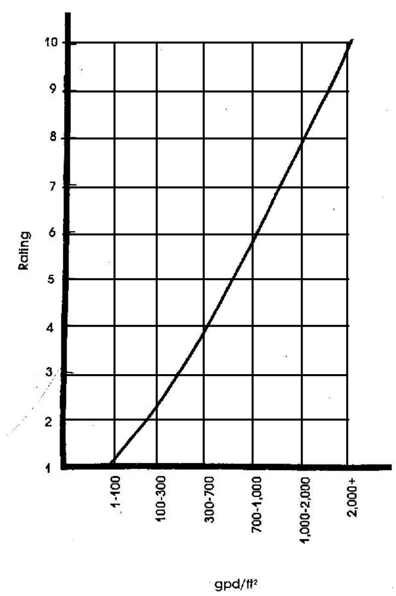


Figure 3.16: Graph of range and ratings for hydraulic conductivity (Aller et al,1987)

Table 3.14: Conductivity Rating Table

Formation	Conductivity Rating
Terrace	10
Gravel-Sand-Clay	9
Gravel-Sand-Clay	8
Basalt	7
Conglomarate-Sandstone-Limestone-Claystone	6
Granit	5
Serpantin-Radiolorit-Limestone	4
Marble	2

Conductivity rating map is created as shown in Figure 3.17. The high permeable zones have the ability of contaminant transport which is consisted of gravel and sand close to river bad had higher vulnerability.

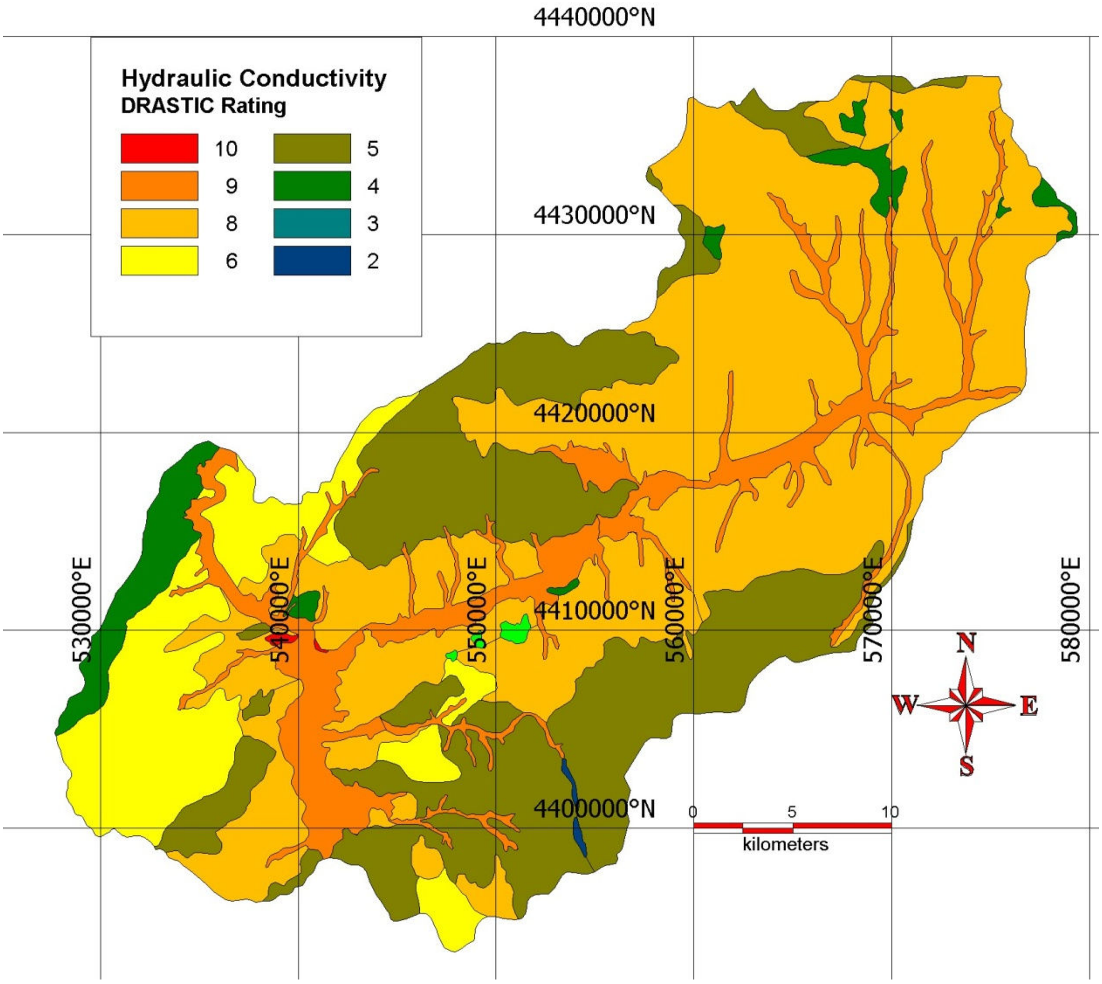


Figure 3.17: Conductivity Rating Map

3.3 DRASTIC Vulnerability Index Map

This study has been performed in order to make an assessment of groundwater vulnerability of Kırıkkale Plain. For this purpose DRASTIC which is a commonly preferred method is used with the help of GIS based computer programs. The major benefit of GIS is that it gives the user a chance to manage data easily. Also it facilitates the process of data. Any change in land use or geological and environmental settings could be easily presented on the vulnerability maps. These updating procedures keep maps dynamic and interactive with their surroundings. DRASTIC Method consists of seven layers which depend on two types of data: thematic data and numeric data. A previous study, a report prepared by DSI in 1979 is used as a data source of some layers, for which thematic data are required such as aquifer media, soil media, impact of the vadose media and hydraulic conductivity. Then a hardcopy map from this report is digitized. The numeric data layers are obtained from different sources that are mentioned in the subsections of this chapter. After creating maps of seven layers; Vertical Mapper which is a computer program is used for superposing the maps with respect to their weights which are described in DRASTIC Method. As a result of this work, DRASTIC Vulnerability Index is calculated. Finally indexes are used for the determination of vulnerability of zones.

Depth to water is the main component of the index and controls the path which the contaminants travel, has the highest weight. Consequently, the thin strata layered zones are highly sensitive to any harm resulting from land use. The middle of the valley, where the elevation varies between 600 m and 900 m, is vulnerable because water table is close to the surface and geological characteristics are highly permeable. These areas are colored with red. Areas with higher elevation, this means greater than 900 m, especially in South and the North parts, are less vulnerable with deeper water table and high slopes are creating surface runoff.

To properly manage and protect the resource, it is therefore important to determine areas where groundwater may be more vulnerable to contamination (Liggett and Talwar, 2009). DRASTIC Rating Index map of the study area is given in Figure 3.18. The DRASTIC index values vary from 44 to 217.

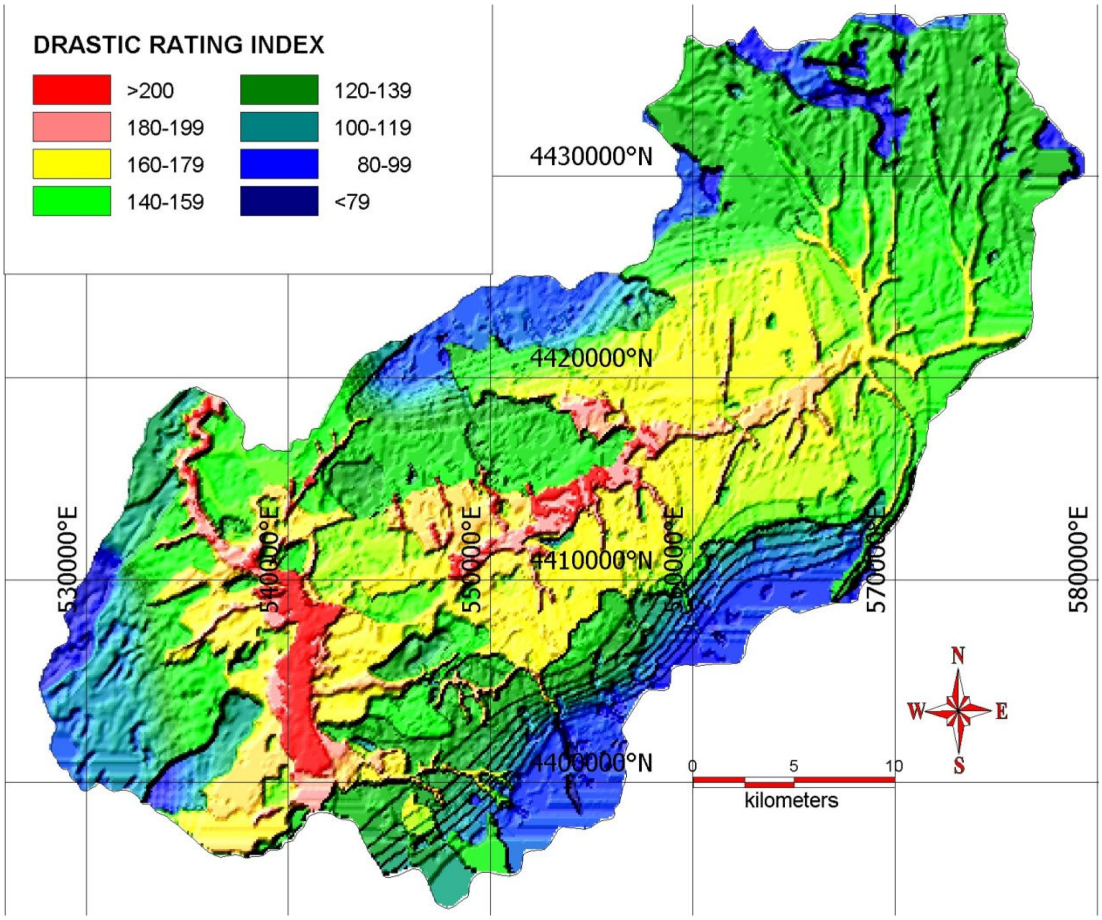


Figure 3.18: DRASTIC Rating Index Map

Vulnerability map of Kırıkkale Plain is prepared by reclassifying the DRASTIC Vulnerability Index into five categories. Aller and her friends (1987) did not propose any index interval for the purpose of vulnerability classing. The original DRASTIC method published by Aller et al.(1987) does not provide vulnerability classification ranges, but allows the user to interpret the vulnerability index using their own field knowledge and hydro geological experience (Gogu et al., 2003).

The commonly used vulnerability index classification system used in the literature defines five classes of vulnerability: very high vulnerability (vulnerability index >199), high vulnerability (160–199), moderate vulnerability (120–159), low vulnerability (80–119), and very low vulnerability (<79) (Gogu et al., 2003). Thus vulnerability zones of the Kırıkkale Plain are obtained according to the indication of indexes as seen in Figure 3.19.

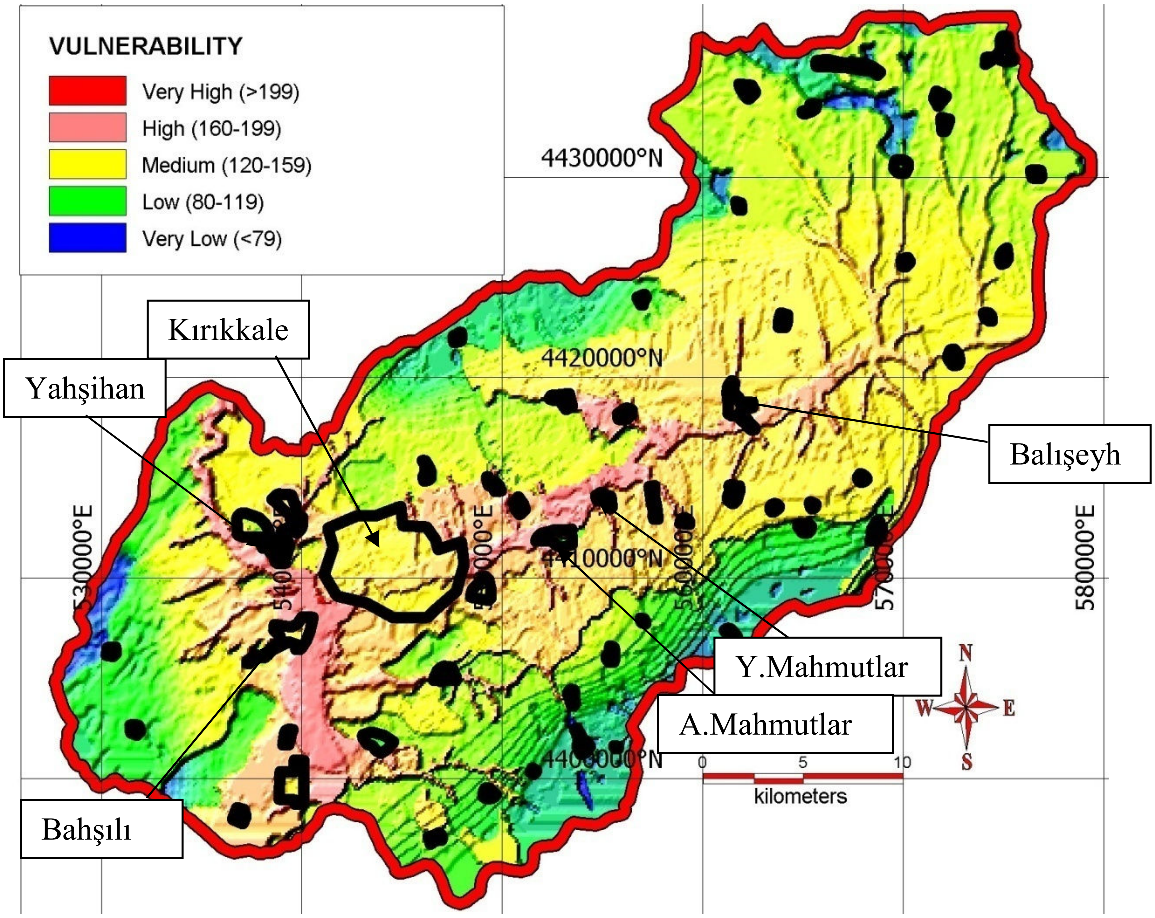


Figure 3.19: Vulnerability Index Map

3.4 Discussion

It is difficult to access data in Turkey. Generally data are collected by different governmental offices and the relations and communication between these offices are inadequate. Another difficulty is the reorganization of the governmental unites. In this study data source is The Report which is prepared by DSİ in 1979. Depth to water table, aquifer media, impact of the vadose zone media are extracted from The Report. Topography map and the recharge map are generated by updated data. Hydraulic conductivity map is built by using an approach depending on geologic layers observations. Soil map is created by an assumption in order to continue to build vulnerability map. It is recognized that the approach adopted to produce the DRASTIC index was limited by the availability of data (Pathak et al., 2008). Note that, the availability of data and interpolation methods used affect the reliability and scale of the final map (Liggett and Talwar, 2009). As a conclusion in order to get more trustful vulnerability map, the data which is required by DRASTIC Method should be updated and completed in order to cover whole basin.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The results of this study may be used as a guideline for the determination of action plans. Authorities who are responsible for the protection of groundwater may define a route for an action plan by utilizing these maps. Groundwater vulnerability assessments are a means to synthesize complex hydrogeologic information into a form useable by planners, decision and policy makers, geoscientists, and the public (Liggett and Talwar, 2009).

The areas, which are covered by the zones of different classification, are given in Table 4.1 in order to develop a plan for protection. Only 0.5 % of the area is in the zone of very low vulnerability, it is not a protected basin in terms of groundwater sources. In an urgent plan, 2.5 % of the study area should be considered, by giving high priority to the areas where the vulnerability is determined as very high.

Table 4.1: Vulnerability Zones Distribution

Zone	Area(km^2)	Percentage %
Very High	28.18	2.5
High	473.34	42
Medium	439.53	39
Low	180.32	16
Very Low	5.63	0.5

Kırıkkale city center is classified as the medium vulnerable zone. However the district of Yahşihan, Aşağı Mahmutlar, Yukarı Mahmutlar and Balışeyh, which are located inside the area of high vulnerability zone, are not as lucky as city center of Kırıkkale.

Vulnerability of groundwater is indicated as higher when decreases on retarding or blocking ability of the earth layers against contaminants reaching the water table have been observed. For different vulnerability classes different strategies should be fallowed. From the view of this window action plans are proposed in Table 4.2.

Table 4.2: Suggested Action Plan for Groundwater Vulnerability Zones

Vulnerability	Suggested Action Plan for Groundwater Vulnerability Zones
Very Low	A report, which is a standard format hydro geological report, showing hazards and risk to groundwater or the environment should be prepared.
Low	Site investigation with monitoring: Requires limited site investigation, groundwater monitoring, testing, and delineation of flow system in addition to desk study (Liggett and Talwar, 2009).
Medium	Detailed site investigation and monitoring: Requires more detailed site investigation including ongoing monitoring and protection design factors (e.g., natural attenuation, physical barriers) in addition to requirements above (Liggett and Talwar, 2009).
High	Need to search for design factors for protecting groundwater. A feasibility plan with on-going monitoring should be considered.
Very High	An immediate action plan is required including above. Any risk containing activity to groundwater is not allowed by the responsible authority.

4.2 Recommendations

The study area is 1127 km^2 and in DSI studies the whole area is separated as Kızılırmak Plain and Çoruhözü Plain. Çoruhözü Plain could be divided into two units according to existing aquifers. As a summary, it is better to divide the basin into two or more subareas for easier data processing.

The social and the economical developments of the study areas should also be considered. The study area has different characteristics in economical aspects such as those related to agriculture or petroleum industry. Due to the variety of activities, content of contaminants vary. Preventing steps for these contaminants should be organized depending on the vulnerability zones.

The important factor, which should not be forgotten, is that vulnerability maps cannot replace the field surveys and investigation. These maps can only be used in order to prioritize the field investigations. Additional and complementary field survey and investigation should be organized.

By uploading the maps of vulnerability zones into web site, an interactive system could be developed. Residents may learn about the groundwater vulnerability zone of their living area via internet. There is utilization in the European countries such as United Kingdom. Government announces the limits of the contaminant discharge through the soil surface according to the vulnerability zones. Then, the public receives the permission of discharge capacity from The Government. These permissions should be renewed every year. At the same time, authorities continue monitoring the high vulnerable zones periodically. It is proposed that a similar procedure may be implemented in Turkey.

In near future it is hoped to see more vulnerability map studies in Turkey that are shared with public. It is expected that the notion of this study will be a reference to inspire future studies as a supporting implementation.

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