INVESTIGATION OF THE AQUIFER VULNERABILITY IN THE BAKIRÇAY BASIN, TURKEY

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ABSTRACT

INVESTIGATION OF THE AQUIFER VULNERABILITY IN THE BAKIRÇAY BASIN, TURKEY

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Intensifying industrial, population and agricultural activities have increased the contamination possibility on highly demanded groundwater resources. Bakırçay located at lower North Aegean region of Turkey is one of those basins which has been subjected to such activities. Therefore, aquifers located in the basin are vulnerable. The main purpose of this study is to quantify the contamination vulnerability of the groundwater resources present in the Bakırçay Basin. The DRASTIC methodology which was modified by integrating the land use map of the study area, was applied. The DRASTIC includes hydrogeological factors which control surface infiltration of waters to the aquifer: depth to groundwater (D), net recharge (R), aquifer media (A), soil media (S), topography slope (T), impact of vadose zone media (I), and hydraulic conductivity of the aquifer (C). Available hydrogeological data from various sources for the basin and the data provided from the groundwater flow model established to acquire some parameters due to missing data were utilized to generate groundwater vulnerability map using geographic information system (GIS) tools. The results of this study show that 4.9% of the study area has very high, 20.2% high, 6.2% medium, 24.5% low and the remaining 44.3% of the area has very low contamination vulnerability of the groundwater resources.

Keywords: Aquifer Vulnerability, DRASTIC Methodology, Vulnerability Map, Bakırçay Basin, GIS

ÖZ

BAKIRÇAY HAVZASINDAKİ AKİFERLERİN KİRLENME HASSASİYETİNİN ARAŞTIRILMASI, TÜRKİYE

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Yoğunlaşan endüstriyel, nüfus ve tarımsal faaliyetler, yüksek oranda talep edilen yeraltı suyu kaynaklarındaki kirlenme olasılığını artırmaktadır. Türkiye'nin Alt Kuzey Ege bölgesinde yer alan Bakırçay, bu tür faaliyetlere maruz kalan havzalardan biridir. Bu nedenle, havzada bulunan akiferler kirlenme potansiyeli taşımaktadır. Bu çalışmanın temel amacı, Bakırçay Havzasında bulunan yeraltı suyu kaynaklarının kirlenme hassasiyetini belirlemektir. Çalışma alanının arazi kullanım haritası entegre edilerek modifiye edilen DRASTIC Metodu uygulanmıştır. DRASTIC, suların akifere yüzeyden süzülmesini kontrol eden hidrojeolojik faktörleri içerir: yeraltı suyuna derinlik (D), net beslenme (R), akifer ortamı (A), toprak ortamı (S), topoğrafya eğimi (T), vadoz zonun etkisi (I) ve akiferin hidrolik iletkenliği (C). Havza için çeşitli kaynaklardan elde edilen mevcut hidrojeolojik veriler ve eksik veriler nedeniyle bazı parametreleri elde etmek için kurulan yeraltı suyu akış modeli ile sağlanan verilerden yararlanılarak yeraltı suyu hassasiyet/duyarlılık haritası coğrafi bilgi sistemi (CBS) araçları kullanılarak oluşturulmuştur. Bu çalışmanın sonuçları, çalışma alanının %4.9'unun çok yüksek, %20.2'sinin yüksek, %6.2'sinin orta, %24.5'inin düşük ve kalan %44.3'lük kısmının yeraltı su kaynaklarının kirlenmeye karşı hassasiyetinin çok düşük olduğunu göstermektedir.

Anahtar Kelimeler: Akifer Kirlenme Hassasiyeti, DRASTIC Metodu, Hassasiyet Haritası, Bakırçay Havzası, CBS

TO MY DEAR SISTER, MELTEM

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LIST OF ABBREVIATIONS

AET: Actual Evapotranspiration

CLC: CORINE Land Cover

CN: Curve Number

CORINE: Coordination of Information on the Environment

DRASTIC: **D**epth to Water, **R**echarge, **A**quifer Media, **S**oil Media, **T**opography Slope, **I**mpact of Vadose Zone, Hydraulic **C**onductivity

DSI: State Hydraulic Works

EPA: Environmental Protection Agency

GIS: Geographic Information System

MTA: Mineral Research and Exploration Institute

MWBM: Monthly Water Budget Method

NWWA: National Water Well Association

PET: Potential Evapotranspiration

PMWIN: Processing Modflow for Windows

RMSE: Root Mean Square Error

SCS: Soil Conservation Service

USA: United States of America

US: United States

CHAPTER 1

INTRODUCTION

For human life, groundwater is a crucial renewable resource. It is present in permeable geologic formations known as aquifers as a component of the hydrologic cycle. However, as a result of rising urbanization and human activities, the amount and quality of groundwater have been decreasing and deteriorating, respectively. Bakırçay Basin in the Lower North Aegean part of Turkey is also located in a risky area where the quality and quantity of groundwater may be adversely affected (BSNFB, 2016).

1.1. Purpose and Scope

The main purpose of this study is to determine how vulnerable the Bakırçay Basin's groundwater resources are to contamination. The DRASTIC Methodology developed by Aller et al. (1987) covering **D**epth to groundwater, **R**echarge, **A**quifer media, **S**oil media, **T**opographic slope, **I**mpact of vadose zone and hydraulic **C**onductivity effects is a very useful approach for the determination of the aquifer vulnerability to contamination and was chosen to be applied in the study area. Apart from the original DRASTIC parameters, it is also aimed to see the effect of land uses on the contamination susceptibility of the aquifers. The purpose of the research is reached by accomplishing the following major objectives:

(1) Compilation of existing data for the DRASTIC parameters.
(2) Estimations of the groundwater level, precipitation recharge and hydraulic conductivity distributions for the aquifers by developing numerical groundwater flow model for the basin.
(3) Estimation of the contamination vulnerability ratings for each DRASTIC and land use parameters throughout the study area.
(4) Establishment of both individual and combined DRASTIC vulnerability maps in a GIS environment.

1.2. Previous Studies

Basin Studies

The 1/100000 scaled geological map covering the Bakırçay Basin was prepared by Mineral Research and Exploration Institute (MTA, 1989).

Some hydrogeological studies were carried out in the study area. In 1976, Bakırçay Plain Hydrogeological Investigation Report was prepared by DSI (State Hydraulic Works) (DSI, 1976). In addition, Master Plan Hydrogeology Report of the Northern Aegean Basin was prepared in 2016 by private companies for the State Hydraulic Works of Turkey (BSNFB, 2016).

In the study carried out by Gündoğdu et al. (2004), contamination sources were determined in the Bakırçay River, samples were taken from the points determined depending on the potential contaminant sources, topographic structure, stream branches, and the pollution analysis of the basin was made. When the data were examined, it was observed that in general, all parameter values were in the 4th class water quality according to the Water Pollution Control Regulation limits. Pollution is concentrated from Soma Thermal Power Plant process and cooling water, domestic wastewater, olive oil and dairy products, etc. It is understood that it originates from industrial enterprises, mining activities and agricultural activities (spraying, fertilizing). As a result, necessary precautions and suggestions for the protection and control of water quality in the Bakırçay Basin have been put forward (Gündoğdu et al., 2004).

The lower section of the Bakırçay Basin (between Bergama and Çandarlı) was studied in terms of hydrogeological and hydrogeochemical characteristics in a research carried by Somay and Gemici (2015). Surface and groundwater samples (cold and hot waters) were collected in the field and sent to international laboratories for chemical and isotopic analysis. Both the geothermal area and the wetland area were of sea water origin. Other waters in the research region were typically mixed water, with no prominent cations or anions. According to the heavy metal results, Arsenic values in the samples taken from the Bakırçay river, many surface waters and Aşağışakran, Çandarlı-Dikili and Bergama were above the drinking water standards (>10 ppb) (Somay and Gemici, 2015).

In the research conducted by Danacıoğlu and Tağıl (2017), it was aimed to apply the Revised Universal Soil Loss Equation (RUSLE) approach to quantify the amount of water-related soil loss in the Bakırçay Basin and to analyze its link with existing land use/cover by disclosing the erosion risk condition (Danacıoğlu and Tığıl, 2017).

Sangu et al. (2020) was discussed variations in the direction of extensional stresses across the Plio-Quaternary based on fault slip data gathered in the Bakırçay Basin. The region's neotectonic characteristics and paleostress pattern were investigated using fault geometries and kinematics derived from extensive field observations and measurements. The main features of the faults in the Bakırçay Basin are revealed by this study (Sangu et al., 2020).

Kazancı wanted to evaluate the water quality in the Bakırçay River basin, which is known to be subjected to high industrial and agricultural pollution loads, in his master's thesis in 2021. The impacts of human and natural occurrences in the basin on conservative water quality parameters and nutrients were shown using a mathematical model system named AQUATOOL. The pollution load in the Bakırçay Basin and its effects have been revealed in this study, indicating that if anthropogenic loads are not decreased, the basin's water quality would reach a point of no return for many years (Kazancı, 2021).

Vulnerability Studies

By the end of the 1960s, the idea of groundwater vulnerability has been developed in France to make people aware of groundwater contamination (Vrba and Zoporozec, 1994).

Process-based methods, statistical methods, and index-overlay methods have all been developed for groundwater vulnerability evaluations (Babiker et al., 2005). Aller et al. (1987) developed the DRASTIC approach, which is an index-overlay method, and was approved by the US Environmental Protection Agency (EPA) and the National Water Well Association (NWWA) (Aller et al., 1987). Later, this method was used in many studies to assess groundwater vulnerability to contamination.

Babiker et al. (2005) show that combining DRASTIC and a geographic information system (GIS) can be an effective tool for evaluating groundwater pollution risk and estimate the aquifer vulnerability of the Kakamigahara groundwater basin in central Japon (Babiker et al., 2005).

In a study carried out in the Küçük Menderes river basin of Turkey in 2009, chemical parameters were integrated into the DRASTIC Method as a new parameter by Pusatlı et al. (2009).

Breabăn and Paiu (2012) focused on determining the aquifer vulnerability using the DRASTIC method to see whether there were any relationships between that and the nitrate levels in the wells in Barlad, Romania and the adjacent settlements (Breabăn and Paiu, 2012).

Yin et al. (2013) used the DRASTIC model in a GIS platform to create a vulnerability map for the Ordos Plateau in China which was aimed to identify the locations with the greatest potential for groundwater pollution based on hydrogeological parameters (Yin et al., 2013).

Jang et al. (2017) conducted an investigation on the use of a binary classifier calibration approach with a genetic algorithm (Bi-GA) to calibrate DRASTIC weights, as well as detecting places with high potential aquifer vulnerability and identifying possible aquifer monitoring locations applying geographical information system in Indiana, USA (Jang et al., 2017).

In a study carried out in the Sharon region of Israel's coastal aquifer in 1998, land use was integrated into the DRASTIC Method as a new parameter (Secunda et al., 1998). The method of integrating the DRASTIC map with the land use map to create a modified DRASTIC map was then used in studies across the globe such as Greece (Panagopoulos et al., 2006), China (Huang et al., 2017), Iran (Amiri et al., 2020; Dizaji et al., 2020), Nigeria (Ifediegwu and Chibuike, 2021), Malaysia (Shamsuddin et al., 2021), Turkey (Soyaslan, 2020) and more.

CHAPTER 2

DESCRIPTION OF THE STUDY AREA

2.1. Location

The investigation area called “Bakırçay Basin” is located in the south of the North Aegean region, Turkey (Figure 2.1). The basin is surrounded by the Middle North Aegean Sub-Basin in the north, the Susurluk Basin in the east, the Gediz Basin in the south and the Aegean Sea in the west. It includes Savaştepe, Kırkağaç, Soma, Kınık and Bergama sub-basins. Savaştepe sub-basin covering rather very small plain area located at the northern head of the Bakırçay river is excluded from the study.

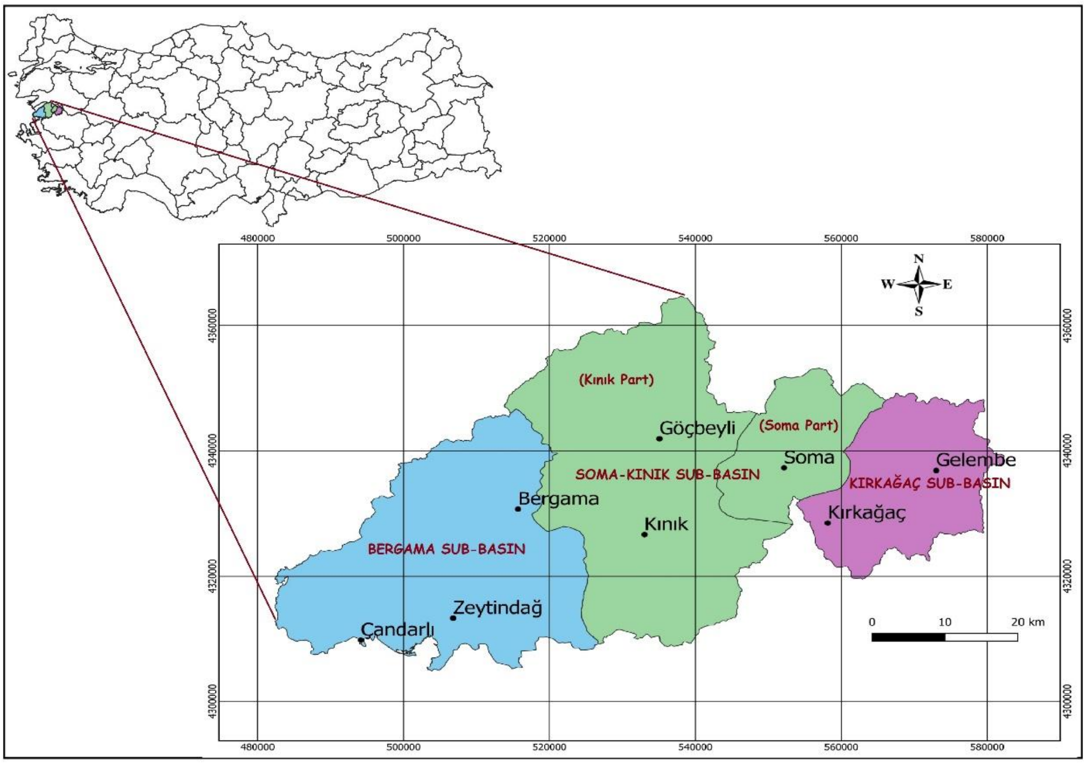


Figure 2.1 Location map of the study area

The investigation area has a total area of 3042.89 km^2 including 1069.17 km^2 of Bergama sub-basin, 1539.04 km^2 of Soma-Kınık sub-basin and 434.68 km^2 of Kırkağaç sub-basin.

2.2. Climate

The climate of the study area is Mediterranean climate with hot and dry summers and warm and rainy winters. The average annual temperature in the sub-basins varies between 15-17 °C and the annual average precipitation varies between 548-865 mm. Dominant wind directions are NE in Bergama and Kınık, N in Kırkağaç, and NW in Soma.

Precipitation and temperature data will be discussed in detail in the “Hydrology” chapter.

2.3. Population

Population of the study area is obtained from the Population Record System Based on Address (ADNKS) data. Table 2.1 below compares the information regarding the total amount of rural population which was distributed in four different districts in İzmir and Manisa cities from 2014 to 2020.

Table 2.1 Population data on the basis of sub-basins for the last seven years (adapted from population record system based on address. https://www.tuik.gov.tr/)

Sub-Basin	**Total Population per year**						
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Bergama	101813	101917	10209	102961	103185	103867	104944
Kınık	28072	28052	28265	28271	29803	28802	28691
Kırkağaç	45730	43274	43436	42716	39790	38459	38245
Soma	105518	107075	108213	108838	108981	109946	110935

Overall, the population in Kırkağaç witnessed a fall while the number of people in Bergama and Soma districts increased. In addition, among the four regions, Kınık was the one showing the smallest change in terms of population.

In 2014, the most crowded district was Soma, with 105518 and this figure was followed by Bergama, Kırkağaç and Kınık, with 101813, 45730, 28072, respectively populations. At the end of the period, in 2020, Kırkağaç experienced a significant decrease by more than a tenth of its population, reaching 38245, although Soma exceeded 110000. Also, the quantity of people in Bergama and Kınık increased by nearly 3% and 2%, respectively.

2.4. Agricultural Activities

Agricultural activities in the study area are summarized below under sub-basin headings.

Bergama

Bergama is one of the most developed and richest districts of İzmir in terms of agricultural products. Therefore, its economy is based on agriculture. Tobacco, cotton, olive, grape, tomato, corn, and wheat are the main crops grown. Recently, mushroom production and greenhouse cultivation have gained importance. Pine nuts are produced in Kozak Plateau and a development cooperative has been established in the region (Bergama Governorship, n.d.).

Soma

Soma is divided into three main regions in terms of agriculture. These are Gediz plain, Bakırçay plain and Demirci mountainous regions. Soma has not developed much in terms of agricultural activities. There are not many agricultural areas due to the coal basins. In the agricultural areas, wheat, barley, tobacco production and olive cultivation are carried out (Soma Municipality, n.d.).

Kınık

Most of the villages in Kınık region are built on mountainous land. 65% of the land is forest, 30% is cultivated land and 5% is meadows and pastures. The main agricultural products grown in the district are corn, wheat, cotton, tomato, pepper, melons, tobacco and olive (Kınık Governorship, n.d.).

Kırkağaç

The economy of the Kırkağaç region is largely based on agriculture. Small-scale industrial establishments use olives, tomatoes, grapes, etc. produced in the region as raw materials to process products. It is the hometown of the nationwide famous Kırkağaç melons. In recent years, animal husbandry has come to the fore with projects carried out on the basis of both cooperatives and individuals. Due to this increase in the district, products such as silage corn and vetch clover have started to be grown as forage crops in the region (Kırkağaç Municipality, n.d.).

Livestock

Livestock activities in the study area are summarized below under sub-basin headings.

Bergama

Dairy and livestock farming are continued in many rural areas in Bergama, while not to the same level as agricultural activities (Bergama Municipality, n.d.).

Soma

Although not well established, cattle, sheep and goat breeding are still performed in Soma. Beekeeping activities have developed in the villages of Beyce, Vakifli, Boncuklu, Naldöken and Çinge Ç. Hamidiye. Additionally, fish farms and cooperatives were established in Sevişler Dam (Soma Municipality, n.d.).

Kınık

In the lowland regions of Kınık, cattle and sheep-goat breeding are carried out to a small extent. In the rural areas of the district, domestic cattle and sheep-goat breeding are carried out. In the last five years, saanen goat breeding tends to grow steadily in the district (Kınık Governorship, n.d.).

Kırkağaç

Cattle, sheep and goat breeding are carried out in Kırkağaç District, and approximately 20% of the cattle population consists of domestic breeds and 80% of them are cultural and cross breeds (Kırkağaç Governorship, n.d.).

2.6. Industrial Activities

Industrial activities in the study area are summarized below under sub-basin headings.

Bergama

Bergama, whose economy is mostly based on agriculture and animal husbandry, is important in the field of tourism with its cultural and historical riches, as well as in the field of mining with its underground and surface sources. As underground riches, there are gold mines, perlite reserves, lignite, granite and quarries. It is also rich in hot spring waters and springs. Bergama-Ovacık gold mineral deposit has a large quantity of reserves (Bergama Governorship, n.d.).

Soma

Soma is a district in Turkey that is famous for its coal enterprises. The basis of the economy of the district is the lignite enterprise and its developed sectors. In addition to very high-quality coal, there are also zinc, lead, magnesite, and boron salt deposits in the region. With the discovery of coal in Soma in 1913, lignite mining started. It supplies 22% of Turkey's need for salable coal. Soma Thermal Power Plant (SEAS) fulfills the electricity needs of West and Northwest Anatolia from the shortest distance and provides economic and social development to the region (Soma Municipality, n.d.).

Kınık

Workshops and factories where industrial agricultural products (cotton, tobacco, olive) were processed first started to be established in 1971 and gave a rapid acceleration to the economy. Since 1990, as a result of the work of the private sector and from its sub-districts; There are 4 tomato paste factories, 4 ginning factories, 3 olive oil enterprises and a dairy. Some facilities in the district are the most modern facilities in the country. The organized industrial zone established in the Taşağıl area of Kınık Kocaömer Village is an important industrial zone consisting of 18 large factories. 8 textile factories, which are industrial establishments based on agriculture, are in a position to strengthen the economy of Kınık in the field of agriculture. The planning of the organized industrial zone has led to the growth of expectations for the development of the industrial sector in Kınık. Under the leadership of İzmir Governor's Office and Kınık Municipality, infrastructure works are about to be completed in the planned industrial zone. The construction of the food industry facility, whose construction has been completed, is about to be completed.

Also, there are various applications for the perlite expansion plant and Kınık mine fields capacity increase and additional facilities in the region (Kınık Municipality, n.d.).

Kırkağaç

Kırkağaç district is located on the Kırkağaç plain and Yunt Mountain foot. It was not developed much due to Soma, which is 13 km away. Its economy is entirely based on agriculture. In small-scale industrial establishments, olives, tomatoes, grapes etc. produced in the region are processed as raw materials. There are also marble quarry enterprises around Kırkağaç (Kırkağaç Municipality, n.d.).

The distribution of the activities will be discussed in detail in the "Land Use" section of "Application of Drastic Method" chapter where effects of such activities on the vulnerability will be included through the newly introduced Land Use layer.

CHAPTER 3

GEOLOGY

The detailed geology of the Bakırçay basin has been studied by relevant institutions, organizations, especially MTA and DSI, universities, and individuals. Within the scope of this study, the geological map of the Bakırçay Basin was prepared by using the hydrogeological investigation reports of DSI (1976), BSNFB (2016) and maps of MTA (1989) (Figure 3.1). Besides, geological cross-sections of the study area are given in Figure 3.2 below.

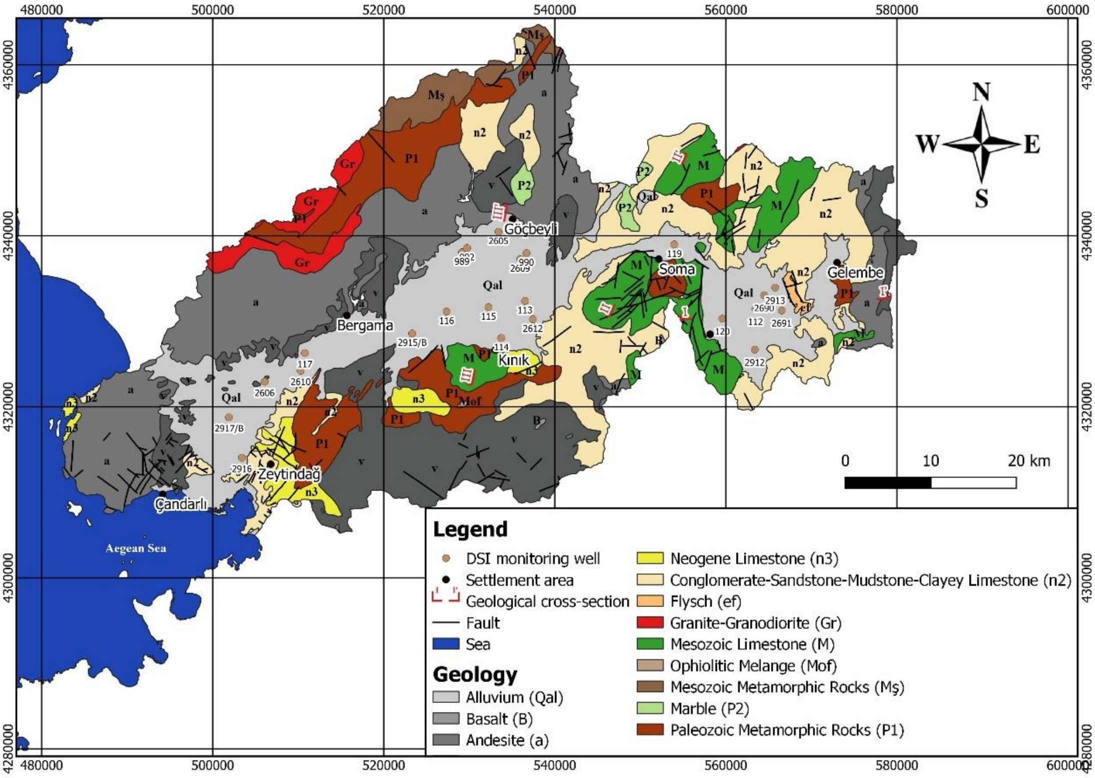


Figure 3.1 Geological map of the study area. Compiled from DSI (1976), MTA (1989), and BSNFB (2016)

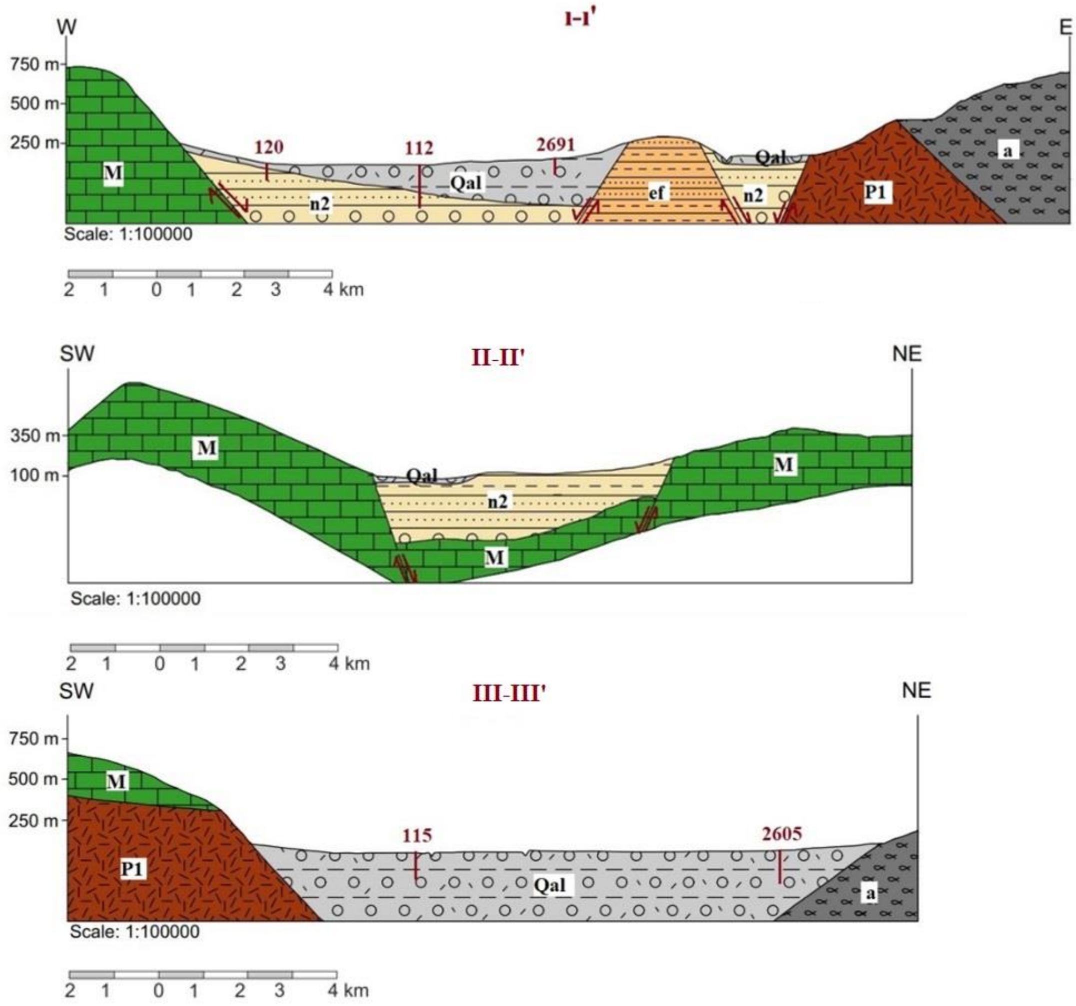


Figure 3.2 Geological cross-sections of the study area (Modified from DSI, 1976)

Paleozoic metamorphic rocks (P1) and marbles (P2) form the basement of the study area. These units are overlain by Mesozoic rocks which contains Metamorphic rocks (Mş), Ophiolitic Melange (Mof), Limestone (M) and Granite-Granodiorite (Gr) from oldest to youngest. Mesozoic rocks are overlain by Tertiary units which contain Eosen Flysch (ef), Neogene undifferentiated continental deposits (n2), Neogene Limestone (n3), Miocene volcanic rocks (v), andesite (a) and basalt (B) from oldest to youngest. The upper part of it is composed of Quaternary fill which is Alluvium (Qal). The stratigraphic section of the basin is shown in Figure 3.3.

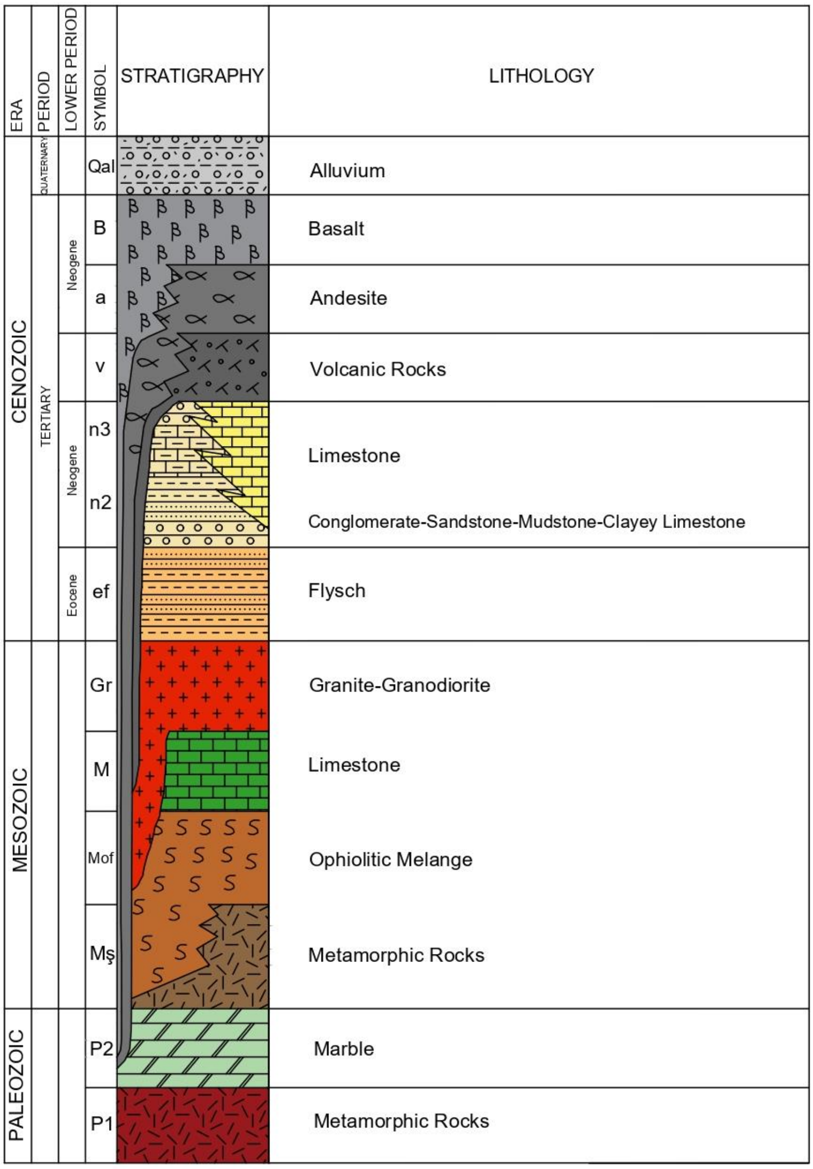


Figure 3.3 Stratigraphic section of the study area (Modified from BSNFB, 2016)

The following information is summarized from the reports of DSI (1976) and BSNFB (2016).

2.5. Paleozoic Units

Metamorphic Rocks (P1)

Metamorphic units (P1) outcrop in the northern and middle parts of the Bakırçay basin, generally at high elevations. The Paleozoic Metamorphic Units are known as the unit contain the Kazdağ metamorphics. When the Kazdağ Group successions are evaluated, they indicate interrelated environments. The metaophiolites in the core of Kazdağı represent the ocean ridge and crust, the overlying thin-bedded marbles and carbonate schists, the pelagic limestones and clastic successions deposited on the oceanic crust, and the subsequent amphibolite-marble alternations represent the oceanic plateaus and submarine mountains.

Marble (P2)

Marble units (P2) outcrop in the northeast of the Bakırçay basin. It consists of Carboniferous and Permian aged marble olistoliths and olistostromes of various sizes, which are found in blocks within the Paleozoic complex series (P1) and the Karakaya Formation (Mf). These limestones and marbles, including cherty and banded recrystallized marble block types, are commonly found in various sizes within the formations of the Karakaya Complex that crops out in the study area.

Although it has more or less different characteristics in different parts of the basin, Paleozoic marbles are generally observed in high elevations, massive but in most places with a joint system.

2.6. Mesozoic Units

Metamorphic Rocks (Mş)

Mesozoic aged metamorphic units (Mş) outcrop in the north of the basin at high elevations. It is known as the Karakaya Formation or complex. The Karakaya Formation was first defined by Bingöl (1968) as the Karakaya Series, and later by Bingöl et al. (1973) as the Karakaya Formation. This formation includes detrital and volcano-sedimentary rocks in the Karakaya complex. The unit is generally composed of sandstone, metasandstone, shale, mudstone, radiolarite, metaconglomerate, basic volcanics and limestone. The lithologies in the formation, which do not show a regular succession, are located in a lateral and vertical transition or block position with each other. The blocks are mostly composed of Carboniferous and Permian aged limestone olistoliths and olistostromes of various sizes. The unit has been affected heterogeneously by tectonic deformation. In areas protected from tectonic deformation, the main lithology of the formation is sandstone-shale alternation. There are regional variations in the ratio and thickness of these two lithologies. In some locations, sandstones are more abundant, and, in some locations, shales form the dominant lithology. In places where dark-colored shales are concentrated, graphite slabs and green-red colored siliceous mudstone-radiolarite levels are also observed. In addition, basic pyroclastic material (tuff, tuffite, agglomerate) is present in epiclastics with lateral transition at different levels.

Ophiolitic Melange (Mof)

The ophiolitic melange units have the smallest unit area in the basin. It is composed of serpentinite, chert, diabase, and limestones, which form blocks of various sizes within the flysch facies clastic rocks consisting of rock assemblages of Upper Cretaceous-Paleocene age (Erdoğan, 1990). The variegated colored unit, in which various lithologies are in tectonic contact with each other, in large and small blocks, consists of ophiolite melange.

Limestone (M)

Mesozoic limestone units outcrop widely in the basin. Mesozoic aged limestones are in some places overlain by Paleozoic metamorphics (P1), unconformably or with tectonic contact with them, and in some places, they are surrounded by younger units (mostly Neogene clastics, n2). Mesozoic limestones are mostly Jurassic-Cretaceous (Erdoğan et al., 1990; Hacımustafaoğlu and Kun, 1990).

Mesozoic limestone (M) is generally composed of medium-thick bedded, oolite, bioclast and intraclast micritic and sparitic limestone in places. The limestones, which start with a sharp contact on the Karakaya Formation, consist of medium-thick bedded, cherty limestones whose layer thicknesses change frequently in the lateral direction and wedge into each other. Although radiolarian micritic limestones are observed in the succession, the succession is mostly composed of platform-type sparitic limestones containing oolite, intraclast and bioclast.

Granite-Granodiorite (Gr)

Granite and granodiorites outcrop in the northwest of the basin. This pluton, which is a granodioritic and granitic intrusion and named Kapıdağ Granite (Ketin, 1946), is typically observed on the Kapıdağ Peninsula in the Susurluk Basin, outside the North Aegean basin. Petrographic examination of the samples contains quartz, feldspar, biotite, less hornblende, and very little opaque minerals. Hydrothermal aplite and pegmatite phyllones and pneumatolytic quartz veins are also encountered. The unit is locally tonalite, diorite and quartz diorite, and in some parts, it shows granitic gneiss features. The Kapıdağ pluton is calc-alkaline in nature and is located in the "granodiorite" area of the Streckeisen (1976) triangular diagram (Ercan and Türkecan, 1984).

2.7. Cenozoic Units

Eocene Flysch (ef)

The flysch unit is the second smallest unit in terms of area in the basin. It is located in the southeast of the Bakırçay basin. It is generally composed of alternating sandstone, claystone, marl, shale, and occasional conglomerate. Stratification is prominent and generally thin-medium bedded. It is folded in most places. In some areas, the layers are cut by local, small-scale faults.

Neogene Conglomerate, Sandstone, Mudstone, Clayey Limestone (n2)

The unit is one of the units covering large area in the basin. The formation consisting of Neogene aged conglomerate, sandstone, mudstone and clayey limestone. It also contains tuff and chert in some areas. It has a medium-thin layered structure. It is folded in most places.

The unit begins unconformably with conglomerates containing all pebbles of basement rocks on the older rock units. The unit continues upwards with alternation of claystone and marl, passes into clayey limestones, and continues with limestones and silicified limestones. This sedimentary sequence, which was formed in the terrestrial environment, is followed in the whole area with tuff, agglomerate, and lavas as lateral and vertical transitions. The Neogene deposits, with a thickness of about 300 m, were probably formed in small continental basins that are not directly related to each other.

Neogene Limestone (n3)

It outcrops generally in the southwest of the basin. It is seen as independent spreads in four different places in the basin. Throughout the basin, the Neogene aged clayey limestone-limestone (n3) unit is partly clayey-marly, partly fractured-cracked, and karstic. It has a bedded structure.

Miocene Volcanic Units (v), Andesite (a) and Basalts (B)

Volcanics (v) consisting of undifferentiated tuffs and agglomerates have a wide distribution in the basin. It is generally composed of andesitic-basaltic-rhyolitic-dacitic lava, tuff-tuffite and agglomerates.

Andesite and basalts occur in small outcrops in Tertiary volcanics. They are found in volcano-sediments, especially in the south of the basin, independently of each other but with enough area to be mapped, separately.

Basaltic lavas show joint and flow structure reminiscent of bedding. It usually shows a hyalocrystalline subophytic texture. The phenocrysts are composed of labradorite (clay mineralized, sometimes sericitized), basaltic hornblende, augite, and secondarily biotite. The matrix material showing a subophytic texture is composed of plagioclase microliths, augite microcrystals and opaque mineral in volcanic glass. Excess vesicles, chlorite and chalcedony filled amygdala are observed. The basalts and andesites, which are the latest volcanic products, are probably accepted as Upper Pliocene aged because they overlie the Miocene-Pliocene aged Neogene deposits (MTA, 1989).

Quaternary Alluvium

Alluvial units, consisting of clay, sand, and gravel sized material, spread over wide plains and river valleys in the basin. Alluvium is one of the units with the largest exposure in the basin hence, it is present throughout the study area.

CHAPTER 4

HYDROLOGY

4.1. Meteorology

Temperature and precipitation data were obtained from the meteorological stations of Bergama, Soma, Kınık and Kırkağaç representing each sub-basin in the study area (Appendix A). Locations of the meteorological stations are shown in Figure 4.1.

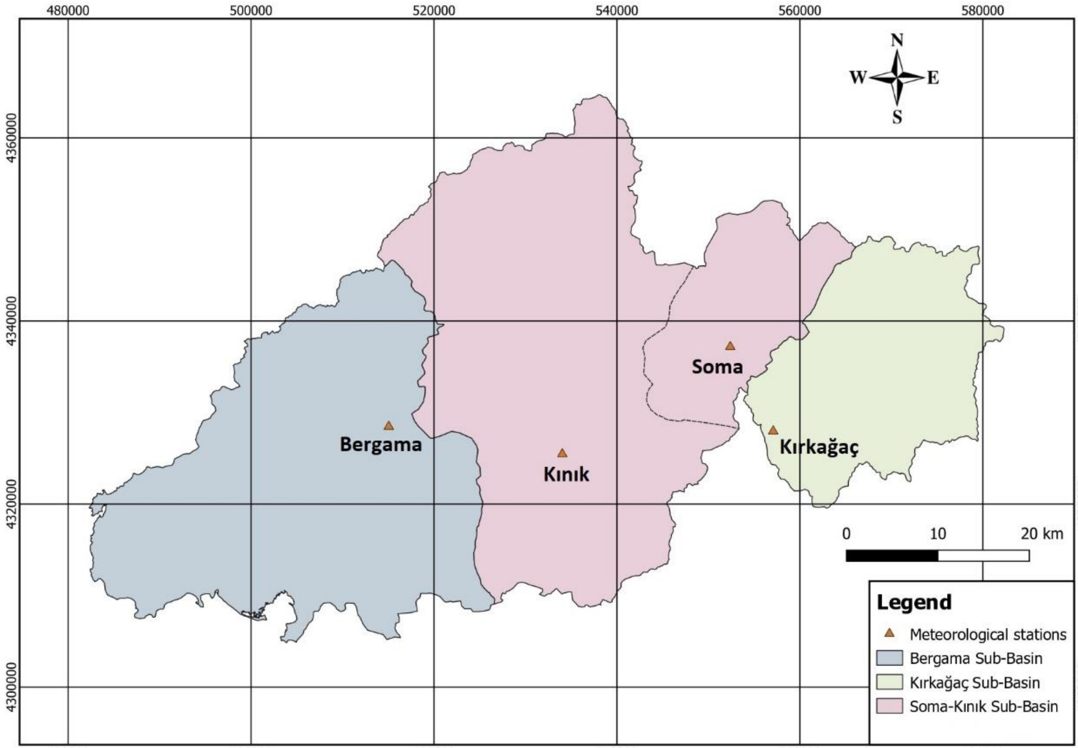


Figure 4.1 Locations of the meteorological stations

Available data for Bergama station covers the years of 1964-2020, for Soma station covers the years of 1965-1982 and 1998-2020, for Kınık station covers the years of 1964-1998 and 2017-2020, and for Kırkağaç station covers the years of 1986 and 2018-2020. The missing data at Soma and Kınık stations were completed by correlating them with the data of Bergama station on a monthly basis. On the other hand, the missing data of Kırkağaç station was completed by correlating with the data of Soma station, since it is closer. The correlation graphs are given in Appendix A.

4.1.1. Temperature

The temperature data for the years between 1964 and 2020, in which the missing meteorological data were completed with monthly and annual correlations, are given in Appendix A. Annual average temperature graphs for each basin are given in from Figure 4.2 to Figure 4.5 below. As seen in figures, the average temperature values for Bergama, Soma, Kınık and Kırkağaç are 16.40 °C, 15.57 °C, 16.08 °C and 15.71 °C, respectively.

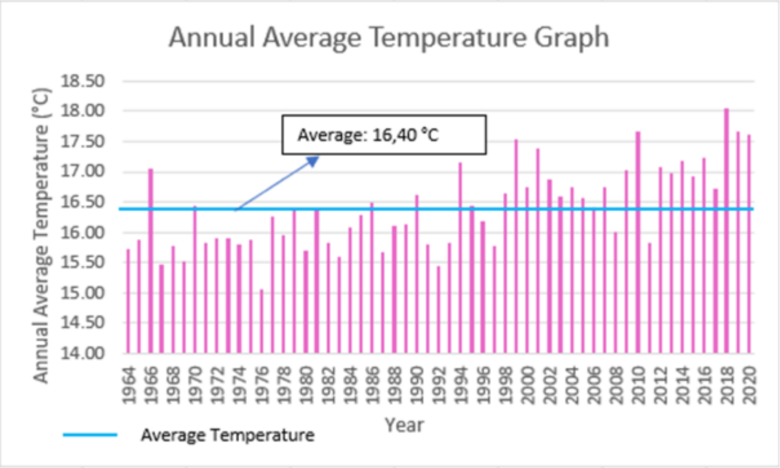


Figure 4.2 Annual average temperature graph for Bergama station

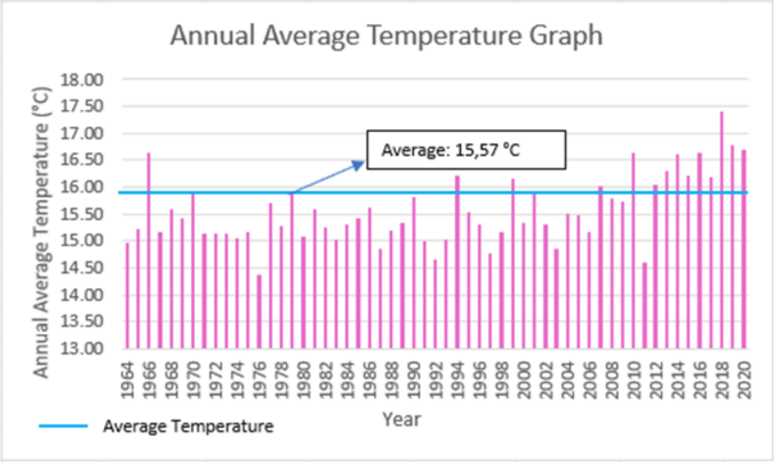


Figure 4.3 Annual average temperature graph for Soma station

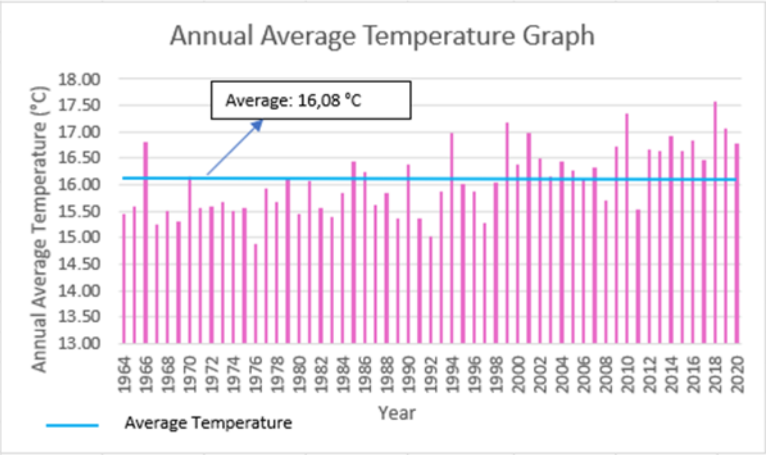


Figure 4.4 Annual average temperature graph for Kınık station

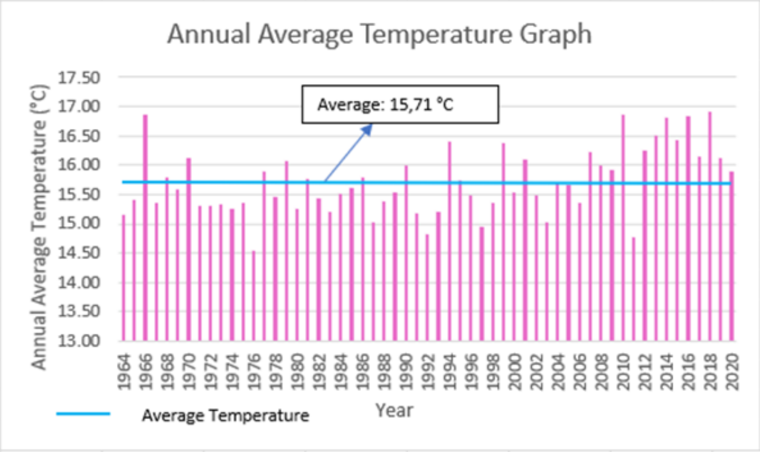


Figure 4.5 Annual average temperature graph for Kırkağaç station

The long-term monthly average temperature values of Bergama, Soma, Kınık and Kırkağaç meteorological stations are given in Table 4.1 for the period of 1964-2020. The warmest month in the area is July, with maximum average monthly temperatures of 26.84 °C. In addition, January is the coldest month with the lowest average temperature value of 5.71°C. The monthly average temperature graph for each meteorological station is given in Figure 4.6.

Table 4.1 Monthly average temperatures in long term (1964-2020)

Sub-Basin	Average Temperature (°C) in long term (1964-2020)												
	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
Bergama	6.69	7.69	10.06	14.44	19.62	24.45	26.84	26.45	22.56	17.31	12.17	8.45	16.40
Soma	5.73	6.82	9.41	13.85	18.90	23.55	25.96	25.61	21.64	16.47	11.28	7.59	15.57
Kınık	6.44	7.49	9.77	14.04	19.15	24.20	26.40	26.12	22.32	17.01	11.92	8.12	16.08
Kırkağaç	5.71	6.82	9.45	13.97	19.10	23.83	26.25	25.91	21.88	16.58	11.36	7.64	15.71

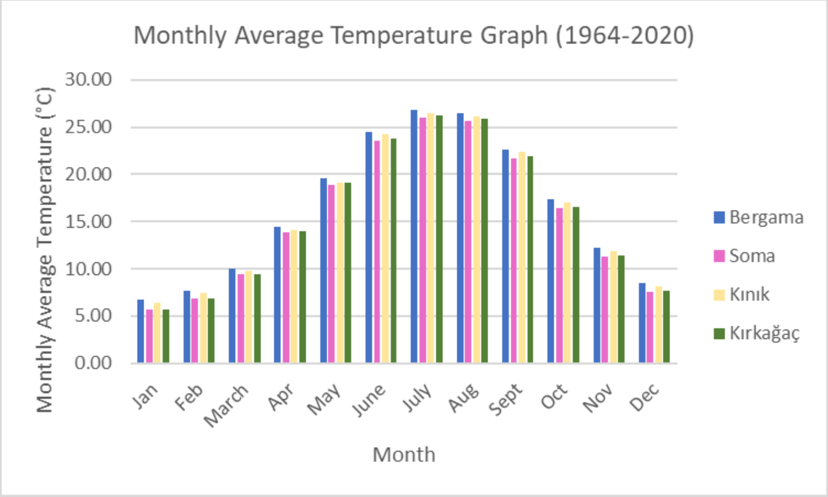


Figure 4.6 Monthly average temperature graph for each station

4.1.2. Precipitation

The precipitation data for the years between 1964 and 2020, in which the missing meteorological data were completed with monthly and annual correlations, are given in Appendix A. The long-term monthly average precipitation values of Bergama, Soma, Kınık and Kırkağaç meteorological stations are given Table 4.2 for the period of 1964-2020. As seen in this table, the mean annual precipitation values for Bergama, Soma, Kınık and Kırkağaç are 646.14 mm, 622.61 mm, 548.88 mm, and 864.97 mm, respectively. While January is the wettest month for Soma and Kırkağaç, December is the wettest month for Bergama and Kınık stations. In addition, the driest month for all stations is August (Table 4.2). The monthly average precipitation graph for each meteorological station is given in Figure 4.7.

Table 4.2 Monthly average precipitations in long term (1964-2020)

Sub-Basin	**Average Precipitation (mm) in long term (1964-2020)**												
	Jan	**Feb**	**March**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Bergama	102.95	85.97	68.99	56.21	32.56	16.05	6.66	6.11	18.01	46.34	87.27	119.01	646.14
Soma	100.46	86.38	67.71	56.00	44.67	19.84	6.84	5.80	20.88	41.94	71.90	100.18	622.61
Kınık	85.50	70.02	60.24	49.81	27.68	18.90	8.82	3.28	17.59	43.34	67.06	96.64	548.88
Kırkağaç	121.19	106.78	87.90	75.43	64.42	39.30	27.05	26.23	41.05	63.95	91.44	120.23	864.97

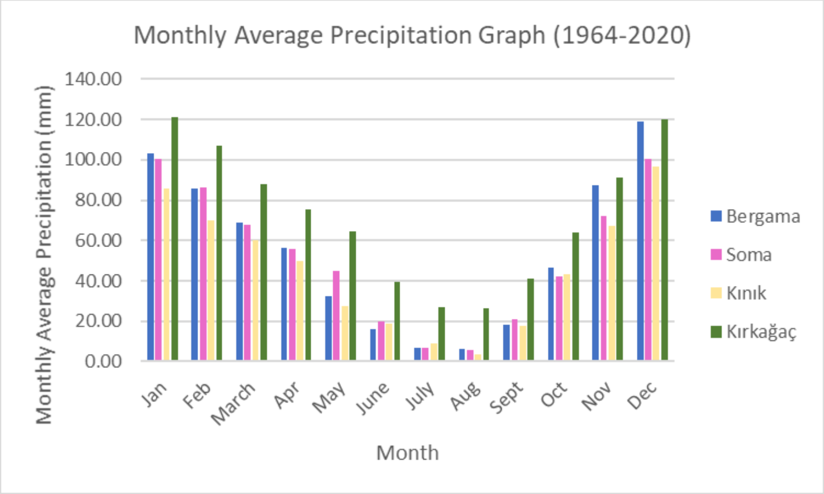


Figure 4.7 Monthly average precipitation graph for each station

Annual precipitation and cumulative deviation graphs of each station shown in figures from Figure 4.8 to 4.11. The mean annual precipitations of Bergama, Kınık and Soma stations are similar to each other while Kırkağaç station received much more precipitation than the others because this station located in mountainous region. Cumulative deviation graph of each station shows that wet and dry periods coincide each other except Kırkağaç station. General trend of the wet period is observed between 1964 and 1987 and rest of the years represents the dry periods.

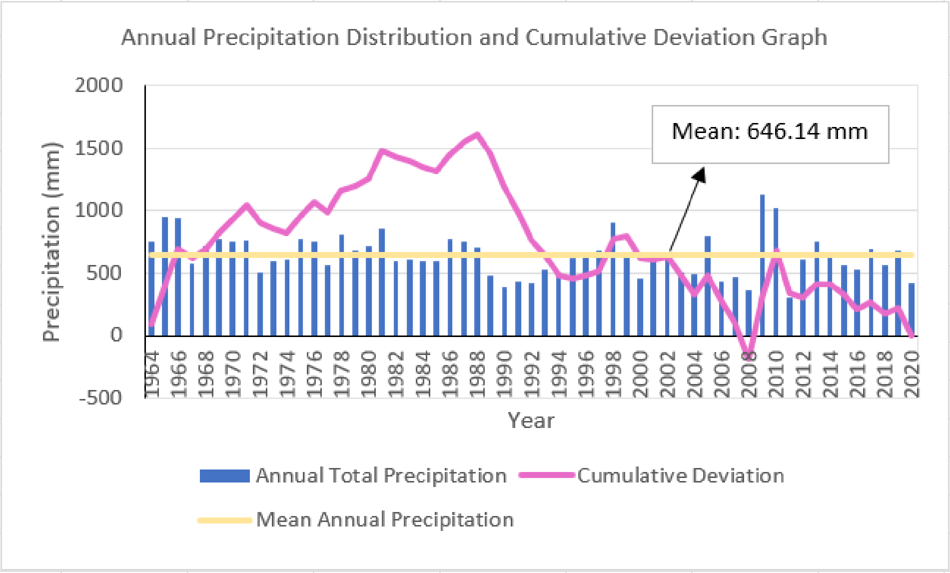


Figure 4.8 Annual precipitation distribution and Cumulative deviation graph for Bergama station

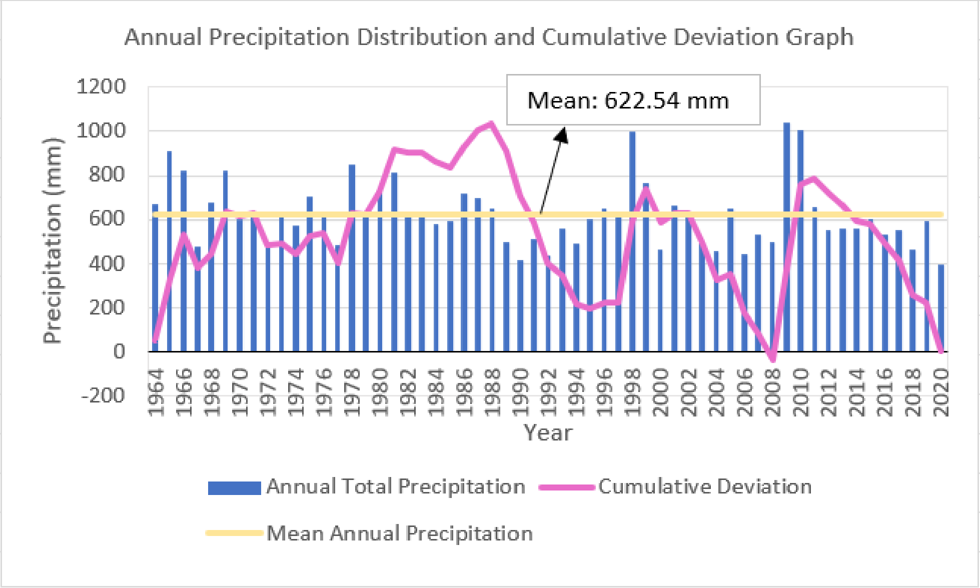


Figure 4.9 Annual precipitation distribution and Cumulative deviation graph for Soma station

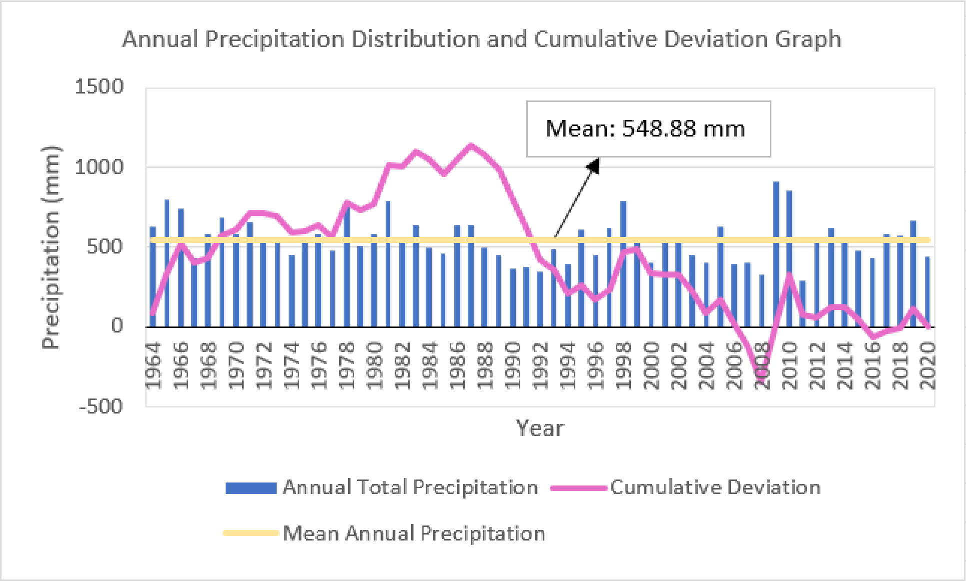


Figure 4.10 Annual precipitation distribution and Cumulative deviation graph for Kınık station

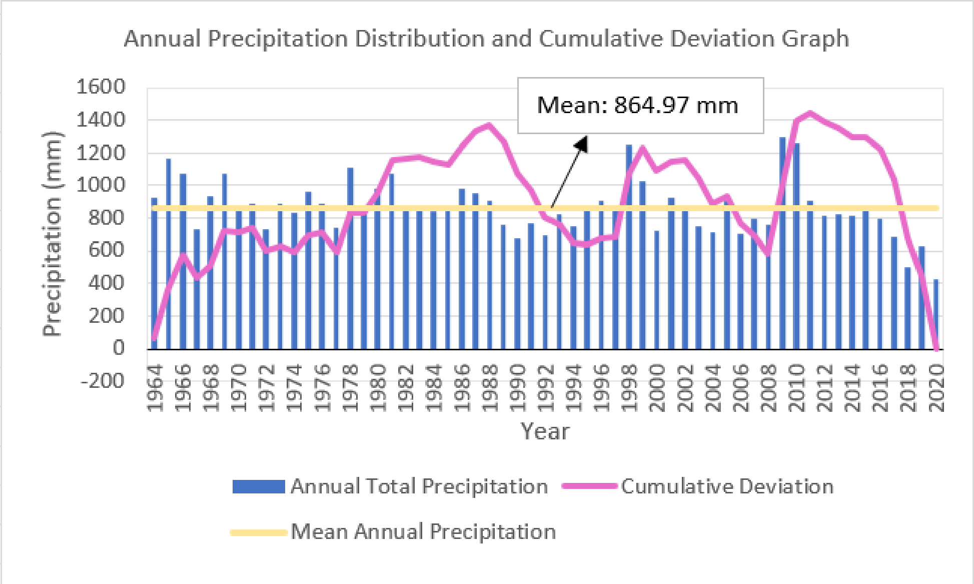


Figure 4.11 Annual precipitation distribution and Cumulative deviation graph for Kırkağaç station

4.2. Monthly Water Budget

The monthly water balance calculations for each sub-basin were carried out using the model of McCabe and Markstrom (2007) developed for the U.S. Geological Survey.

The components considered in the calculations are shown in Figure 4.12. The Thornthwaite equation was used to determine evapotranspiration (Thornthwaite and Mather, 1957).

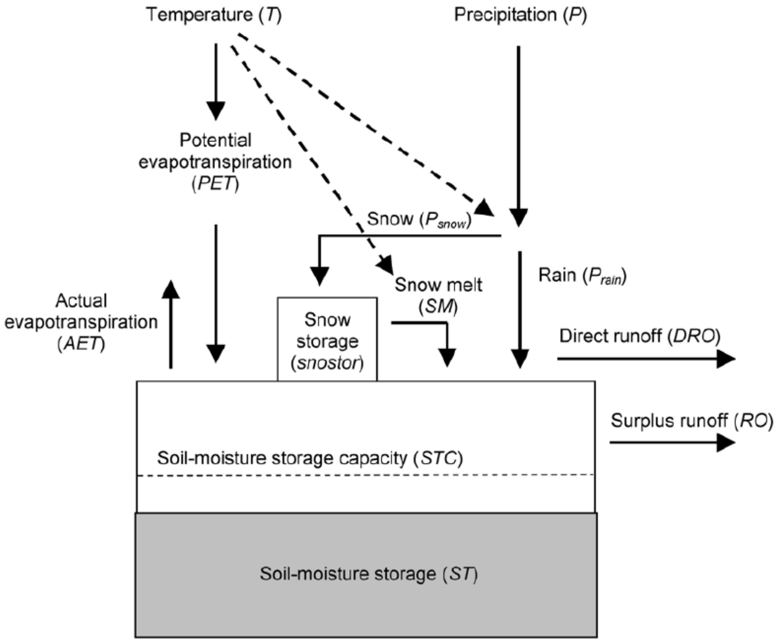


Figure 4.12 Water balance model components from McCabe and Markstrom (2007)

Monthly total precipitation is classified as rain or snow according to the mean monthly temperature. If the mean monthly temperature is less than the threshold temperature for snow [taken as T_{snow}= -10°C; as suggested by McCabe and Wolock, 1999) based on an analysis of water-balance results for a number of sites], all precipitation is regarded as snow. On the other hand, if the mean monthly temperature greater than threshold temperature for rain [taken as T_{rain}=3.3°C; as suggested by McCabe and Markstrom (2007) for elevations below 1000 m], all precipitation can be regarded as rain. When the monthly temperature is between these ranges, how much snow can be contributed to the total precipitation is calculated by the following formula (McCabe and Wolock, 2007).

$$P_{snow} = P \times \left[\frac{T_{rain} - T}{T_{rain} - T_{snow}}\right]$$

The fraction of snow melt (SMF) is calculated using the monthly average temperature, the maximum melt rate (meltmax), T_{rain} and T_{snow} in the following formula. The meltmax is generally set to 0.5 (McCabe and Wolock, 1999) in this type of calculations.

$$SMF = \frac{T - T_{snow}}{T_{rain} - T_{snow}} \times meltmax$$

If the SMF value is greater than the meltmax, SMF is equal to the meltmax.

Curve Number

As different from the method of Gregory et al. (2007), who used a user defined input coefficient, surface direct runoff was calculated with the Curve Number (CN) Method developed by the Soil Conservation Service (SCS, 1964) in this study. The related equations used in this method are given below.

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)}$$

where

Q is runoff in $[L]$
P is Rainfall in $[L]$
S is potential maximum soil moisture holding capacity after runoff begins in $[L]$
I_a is initial abstraction in $[L]$

$$I_a = 0.2S$$

$$S = \frac{1000}{CN} - 10$$

The Curve Number was estimated by evaluating the land use and hydrological soil group characteristics together for a given location in the sub-basins.

First of all, the land uses of the sub-basins were determined with the help of the land use map of the basin prepared by BSNFB (2016) (Figure 4.13). CORINE (Coordination of Information on the Environment) Land Cover (CLC) developed by the European Environment Agency (2000) was used for the land use classification for

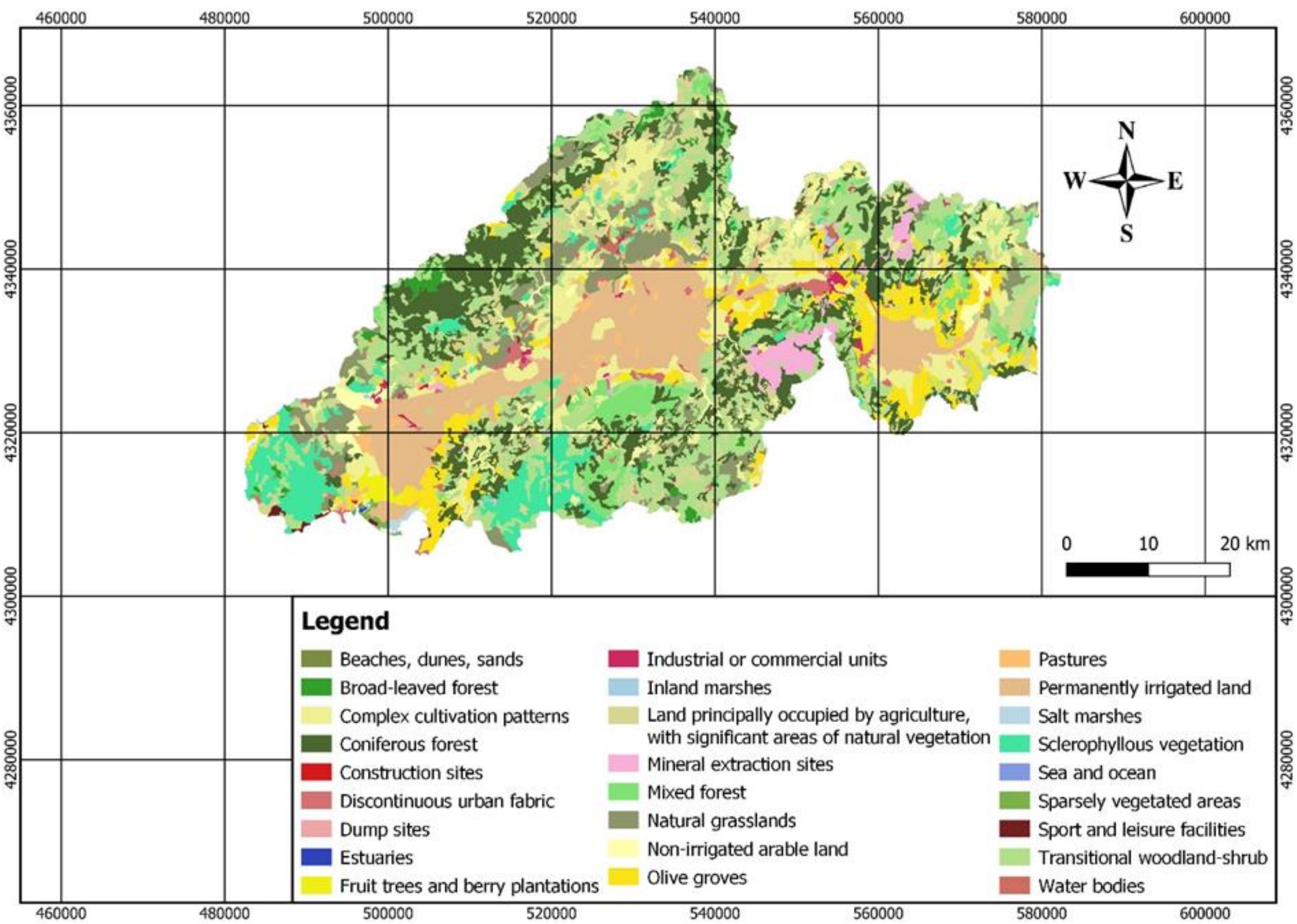


Figure 4.13 CORINE land cover classification for Bakırçay basin after BSNFB (2016)

the study area. The land use classes are grouped as agricultural, forest and semi natural area and artificial surface areas for the CN applications.

In order to determine the hydrological soil groups, initially the major soil types in the sub-basins were determined using data of Topraksu (1974) which is further classified into the Hydraulic soil groups (A, B, C and D) according to the infiltration capacities for agricultural, forest and semi natural areas (Table 4.3). For artificial surfaces very low infiltration is assumed.

Table 4.3 Characteristics and textures for hydrologic groups (Hawkins et al., 2009)

Hydrologic soil group	Characteristics	Texture
A	Low runoff potential and high infiltration rates, consisting primarily of deep, well- to excessively drained sand or gravel.	Sand, loamy sand, sandy loam
B	Moderate infiltration rates when wetted consisting of moderately deep to deep, moderately well-drained to well-drained soils of moderately fine to coarse texture.	Silt loam or loam
C	Low infiltration rates when wetted consisting primarily of (1) soils that have an underlying layer impeding downward movement of water and (2) soils with moderately fine to fine texture.	Sandy clay loam
D	Very low infiltration rates and high runoff potential when wetted, consisting primarily of clay soils with (1) high swelling potential, (2) high permanent water table, (3) clay or claypan near the surface, or (4) shallow soils over nearly impervious material.	Clay loam, silty clay loam, sandy clay, silty clay, or clay

At the last stage, Curve Numbers are determined for a given land use group together with already determined hydrologic groups using the detailed land use criteria listed in Appendix C (Cronshey et al., 1986). In order to determine a single representative curve number for each sub-basin to use in the budget calculations, the curve numbers determined for each land use group were reduced to one for each sub-basin considering land use related area percentages (area weighted average). The estimated curve numbers for Bergama, Soma, Kınık and Kırkağaç sub-basins to be used in the monthly water budget estimations are 65.6, 74.5, 59.7, and 60.6, respectively. These estimates are based on the current land use applications. However, it should be kept in mind that before especially 1970s-1980s certain land use applications were not existed.

The water budget calculated for each sub-basin using the long-term (1964-2020) monthly averages of temperature and precipitation together with runoff which is estimated based on the Curve Number method is listed in Table 4.4 where it is assumed that all calculated infiltration amount would infiltrate to subsurface. In other words, surplus runoff is taken as zero.

Table 4.4 Monthly water budget for the sub-basins

Bergama Sub-Basin														
Parameter	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Total**	**Percentage**
Monthly Average Temp.(°C)	6.69	7.69	10.06	14.44	19.62	24.45	26.84	26.45	22.56	17.31	12.17	8.45		
Precipitation	102.95	85.97	68.99	56.21	32.56	16.05	6.66	6.11	18.01	46.34	87.27	119.01	646.14	
PET	10.44	13.15	25.72	51.90	97.99	144.78	175.97	157.92	105.60	61.53	29.17	15.12	889.29	
Direct Surface Runoff	21.80	11.89	1.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.01	28.36	69.91	10.82
Soil Moisture	133.20	133.20	133.20	133.20	67.77	2.28	0.00	0.00	0.00	0.00	52.09	127.62	782.56	
Change in Soil Moisture	0.00	0.00	0.00	0.00	-65.43	-65.50	-2.28	0.00	0.00	0.00	52.09	75.53	-5.58	0.86
AET	10.44	13.15	25.72	51.90	97.99	81.55	8.94	6.11	18.01	46.34	29.17	15.12	404.43	62.59
Subsurface Infiltration	70.72	60.93	41.43	4.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	177.38	27.45
														100%

Soma Sub-Basin														
Parameter	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Total**	**Percentage**
Monthly Average Temp.(°C)	5.73	6.82	9.41	13.85	18.90	23.55	25.96	25.61	21.64	16.47	11.28	7.59		
Precipitation	100.46	86.38	67.71	56.00	44.67	19.84	6.84	5.80	20.88	41.94	71.90	100.18	622.61	
PET	9.21	12.13	25.26	51.37	94.86	137.28	163.68	149.84	100.14	59.02	27.72	14.12	844.64	
Direct Surface Runoff	33.92	22.48	5.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.31	30.30	98.63	15.84
Soil Moisture	86.90	86.90	86.90	86.90	36.71	0.00	0.00	0.00	0.00	0.00	37.87	86.90	509.08	
Change in Soil Moisture	0.00	0.00	0.00	0.00	-50.19	-36.71	0.00	0.00	0.00	0.00	37.87	49.03	0.00	0.00
AET	9.21	12.13	25.26	51.37	94.86	56.55	6.84	5.80	20.88	41.94	27.72	14.12	366.70	58.90
Subsurface Infiltration	57.32	51.76	36.84	4.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.73	157.28	25.26
														100%

Kınık Sub-Basin														
Parameter	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Total**	**Percentage**
Monthly Average Temp.(°C)	6.44	7.49	9.77	14.04	19.15	24.20	26.40	26.12	22.32	17.01	11.92	8.12		
Precipitation	85.50	70.02	60.24	49.81	27.68	18.90	8.82	3.28	17.59	43.34	67.06	96.64	548.88	
PET	10.30	13.15	25.36	50.62	95.05	142.71	168.18	154.62	104.34	60.70	29.00	14.75	868.77	
Direct Surface Runoff	7.88	2.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	10.34	20.94	3.81
Soil Moisture	171.50	171.50	171.50	170.69	103.64	28.82	2.04	0.24	0.12	0.11	38.08	109.63	967.87	
Change in Soil Moisture	0.00	0.00	0.00	-0.81	-67.05	-74.82	-26.78	-1.80	-0.12	-0.01	37.98	71.55	-61.87	11.27
AET	10.30	13.15	25.36	50.62	94.73	93.72	35.60	5.08	17.71	43.35	29.00	14.75	433.36	78.95
Subsurface Infiltration	67.32	54.24	34.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	156.45	28.50
														100%

Kırkağaç Sub-Basin														
Parameter	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Total**	**Percentage**
Monthly Average Temp.(°C)	5.71	6.82	9.45	13.97	19.10	23.83	26.25	25.91	21.88	16.58	11.36	7.64		
Precipitation	121.19	106.78	87.90	75.43	64.42	39.30	27.05	26.23	41.05	63.95	91.44	120.23	864.97	
PET	8.90	11.83	24.95	51.47	95.86	139.61	166.66	152.73	101.63	59.13	27.60	13.93	854.30	
Direct Surface Runoff	25.71	16.89	4.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.84	22.52	74.55	8.62
Soil Moisture	165.10	165.10	165.10	165.10	133.66	52.45	8.10	1.89	1.20	6.02	65.01	148.79	1077.52	
Change in Soil Moisture	0.00	0.00	0.00	0.00	-31.44	-81.21	-44.35	-6.21	-0.69	4.82	58.99	83.78	-16.31	1.89
AET	8.90	11.83	24.95	51.47	95.86	120.51	71.40	32.44	41.75	59.13	27.60	13.93	559.76	64.71
Subsurface Infiltration	86.59	78.07	58.36	23.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	246.98	28.55
														100%

Monthly distributions of actual evapotranspiration (AET), soil moisture content, direct surface runoff and infiltration prepared using the averages of the sub-basins for the study area is shown in Figure 4.14. The graph for each sub-basin is given in Appendix B.

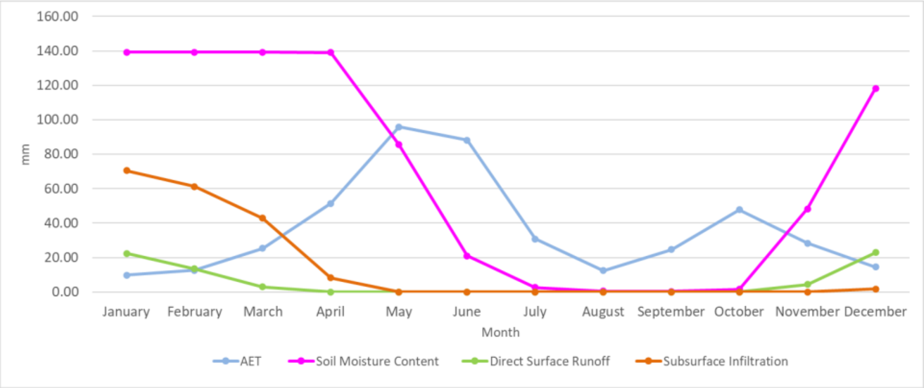


Figure 4.14 Monthly water budget components

According to the graph for the basin as a whole, AET and soil moisture are highest in the wet season between January and June, and then decline in the dry period following June. When the monthly water budget components of the sub-basins are compared, AET, soil moisture and subsurface infiltration are high in the Kırkağaç sub-basin, while direct surface runoff is high in Soma sub-basin. The reason why AET, soil moisture and subsurface infiltration values are higher in Kırkağaç sub-basin is interpreted as the region that receives the most precipitation. On the other hand, the highest direct surface runoff in Soma can be related to the higher curve number value of the sub-basin.

4.3. Surface Waters

River and Streams

The surface water drainage map of the area is shown in Figure 4.15. Bakırçay River, which was named Bakırçay after the Gelembe Stream, which originates from the foothills of Kocadağ, passes through the Karakurt Strait and enters the Kırkağaç plain, is the most important river in the basin and flows about in southeast-northwest direction in the plain. The river flowing northeast-southwest direction passes thorough Soma, Kınık and Bergama sub-basins before discharging to Aegean Sea in Çandarlı Gulf. According to DSI measurements, the catchment area of Bakırçay River is 2,887 km^2 and its flow rate is 14,485 m^3/s, and the total amount of water it discharges in a year is around 465 million m^3 (BSNFB, 2016). Bakırçay River is fed by many tributaries of various sizes originating from Madra (northwest of the basin) and Yunt (south of the basin) mountains. These are Gelembe, Yağcılar, Ilıca, Kara, Kırkgeçit, Kestel, and Sınır streams along the flow direction of Bakırçay. The flow rates of these tributaries as measured in DSI monitoring stations are listed in Table 4.5. Except for Yağcılar Stream, none of these side streams carry water in summer (DSI, 1976; Gültekin et al., 1998).

Table 4.5 Stream observation stations information

Stream Observation Station Number and Name	**X Coord.**	**Y Coord.**	**Measurement Date**	**Annual Average Flow Rate (hm³ /year)**
04-003 Gelembe Stream(upstream)(Bakırçay)	569604	4330397	1962-1967	40.08
04-024 Gelembe Stream(downstream)(Bakırçay)	559567	4334037	1971-1995	42.38
04-033 Yağcılı Stream	546027	4343388	1985-1997	36.95
04-008 Bakırçay-1	541413	4336760	1963-1969	138.2
04-007 Yortanlı Dam downstream (Ilıca Stream)	527063	4336433	1963-1967	112.47
04-037 Kırkgeçit Stream	526599	4326953	1990-2004	16.83
04-06B Kestel Stream	517029	4329487	1963-1988	14.7
04-019 Sınır Stream	514311	4321229	1978-2004	12.24
04-002 Bakırçay downstream-1	509308	4322670	1960-1996	458.04
04-001 Bakırçay-downstream-2	500818	4311726	-	-

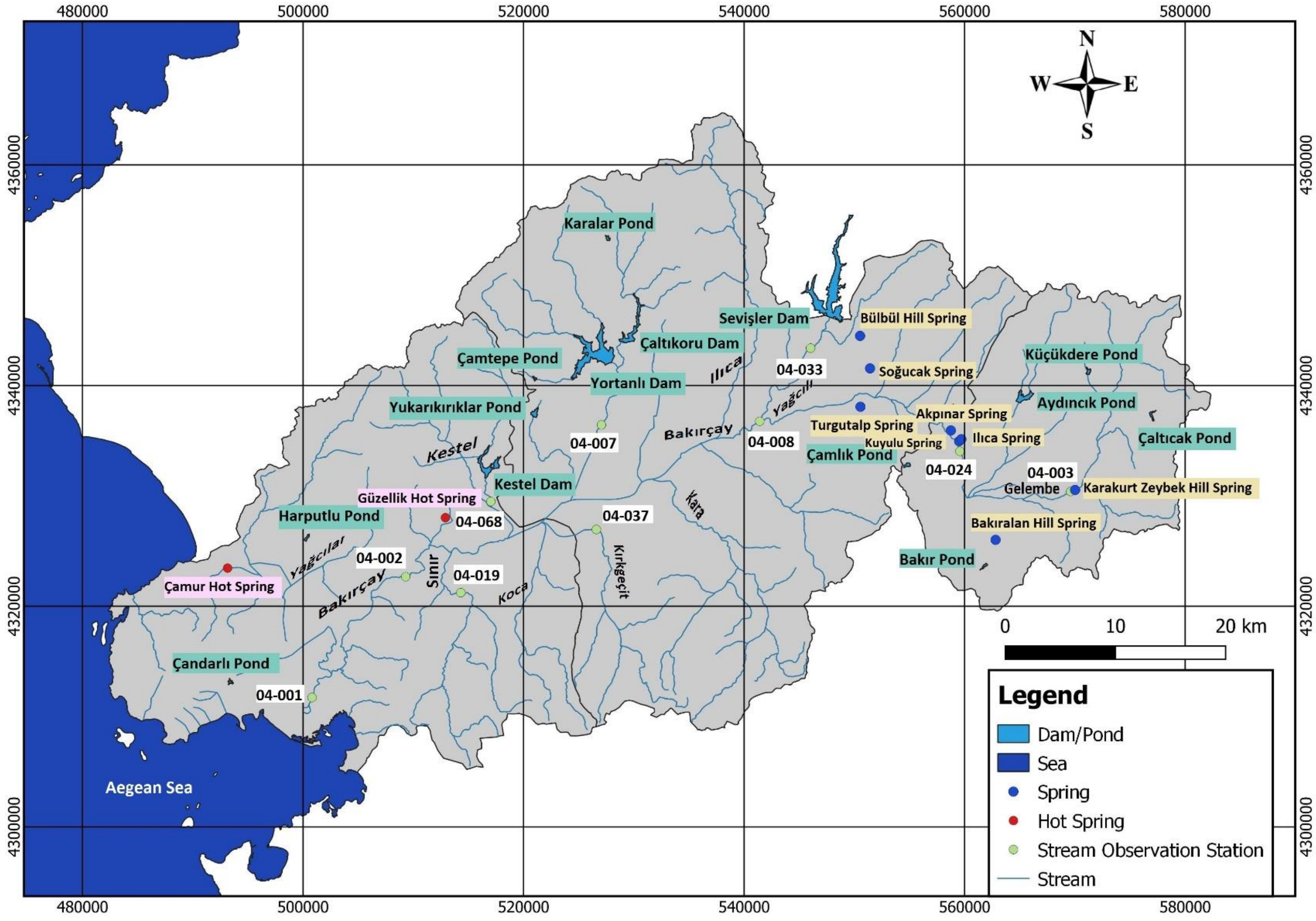


Figure 4.15 Water resources location map of the study area

Dams and Ponds

There is no natural lake in the basin. However, there are ten ponds and four dams built by DSI (Table 4.6). The locations of dams and ponds are shown in Figure 4.15.

Table 4.6 Features of dams and ponds in the basin

Dam/Pond Name	**Sub-Basin**	**Stream**	**Purpose of Usage**	**Year**
Kestel Dam	Bergama	Kestel Stream	flood control and irrigation	1989
Yortanlı Dam	Soma-Kınık	Yortanlı Stream	irrigation	2010
Sevişler Dam	Soma-Kınık	Yağcılı Stream	industrial water supply and irrigation	1981
Çaltıkoru Dam	Soma-Kınık	İlyas Stream	irrigation	2011
Çandarlı Pond	Bergama	Değirmen Stream	water supply and irrigation	2016
Harputlu Pond	Bergama	Hamam Stream	irrigation	2013
Yukarıkırıklar Pond	Soma-Kınık	Nohutluk Stream	irrigation	2014
Çamtepe Pond	Soma-Kınık	Pelitçe (Hayıtlı) Stream	irrigation	2018
Karalar Pond	Soma-Kınık	Köyyeri Stream	irrigation	2016
Çamlık Pond	Kırkağaç	-	irrigation	2013
Aydıncık Pond	Kırkağaç	Akçay Stream	irrigation	2014
Küçükdere Pond	Kırkağaç	Küçükdere Stream	irrigation	2015
Çaltıcak Pond	Kırkağaç	In Stream	irrigation	2014
Bakır Pond	Kırkağaç	Kemirağa Stream	irrigation	2009

As seen in the Table 4.6, most dams and ponds in the basin are used for irrigation purposes. Apart from this, Kestel Dam is also used for flood control. Sevişler Dam, one of the important dams in the basin, supplies industrial water to the Soma Thermal Power Plant in addition to being used for irrigation purposes. Çandarlı Pond is also used for drinking water purposes.

CHAPTER 5

HYDROGEOLOGY

5.1. Springs

The information of the springs in the basin is obtained from The State Hydraulic Works (DSI, 1976; BSNFB, 2016). The distribution of the springs in the basin is given in Figure 4.15. Almost all springs are located at northeast of the basin in Kırkağaç and Soma sub-basins. For springs, the flow rates, and the geological units from which they discharge are listed in Table 5.1.

Table 5.1 Springs information

Name	**Sub-Basin**	**Geologic Formation DSI (1976)**	**Flow Rate(l/s) DSI (1976)**	**Flow Rate(l/s) BSNFB (2016)**
Bakıralan Hill Spring	Kırkağaç	Neogene Conglomerate, Sandstone, Mudstone, Clayey Limestone (n2)	5	-
Karakurt-Zeybek Hill Spring	Kırkağaç	Miocene Andesite (a)	50	-
Ilıca Spring	Soma-Kınık	Mesozoic Limestone (M)	300	87
Kuyulu Spring	Soma-Kınık	Mesozoic Limestone (M)	300	100
Akpınar Spring	Soma-Kınık	Mesozoic Limestone (M)	200	140
Bülbül Hill Spring	Soma-Kınık	Marble (P2)	100	-
Turgutalp Spring	Soma-Kınık	Mesozoic Limestone (M)	300	191
Soğucak Spring	Soma-Kınık	Quaternary Alluvium	4	-
Güzellik Hot Spring	Bergama	Miocene Andesite (a)	1	-
Çamur Hot Spring	Bergama	Miocene Andesite (a)	4	-

The springs associated with relatively high flow rate amounts discharges from Mesozoic limestone units. The flow rates given in the table are averages covering certain year periods. The measurement year periods of Turgutalp, Ilıca, Akpınar and Kuyulu springs are 1977-2014, 1975-1986, 1971-1986 and 1975-1983, respectively. No measurements were made in the following years. When the available spring flow rates (1976 and 2016) are compared, all flow rates have declined.

5.2. Wells

In the study area, apart from the water supply wells drilled by DSI, there are many private wells which are partly registered, drilled for different purposes (drinking-use, irrigation, industry, etc.). The number of wells drilled by DSI, BSNFB (2016) and private sector in the sub-basins before 2016 is given in Table 5.2 as taken from BSNFB (2016). The distribution of all wells in the basin is shown in Figure 5.1. The detailed information about the monitoring wells is given in Appendix D.

Table 5.2 Number of wells in each sub-basin

Sub-basin	**Number of DSI wells (water supply)**	**Number of Private wells**	**Number of DSI monitoring wells (monthly)**	**Number of DSI monitoring wells (seasonal)**	**Master Plan wells (BSNFB, 2016)**
Kırkağaç	13	-	8	16	3
Soma-Kınık	26	995	11	15	12
Bergama	8	523	6	4	11
Total	47	1518	25	35	26

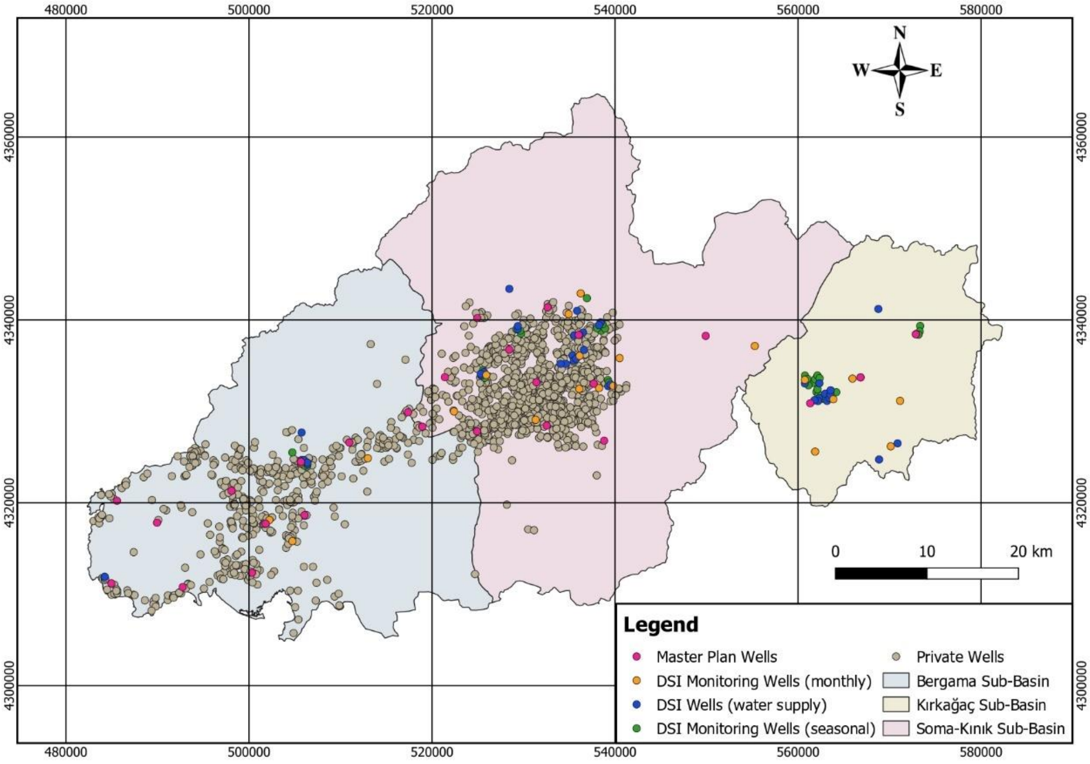


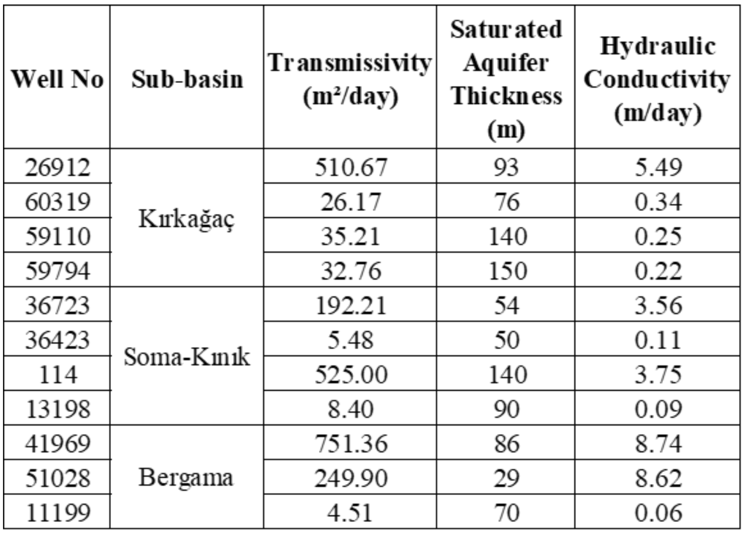
Figure 5.1 Distribution of wells in the study area

5.3. Hydrogeological Properties of Geological Formations

The geological formations in the Bakırçay basin are evaluated in terms of lithological, structural, and hydrogeological properties and classified in terms of permeability/hydraulic conductivity using data of DSI (1976) and BSNFB (2016).

Hydraulic conductivity values determined from pumping test results in alluvium aquifers are listed in Table 5.3. Detailed information about the wells is given in Appendix D.

Table 5.3 Transmissivity, saturated aquifer thickness and hydraulic conductivity information from monitoring wells of DSI (1976) and BSNFB (2016).



Well No	Sub-basin	Transmissivity (m²/day)	Saturated Aquifer Thickness (m)	Hydraulic Conductivity (m/day)
26912	Kırkağaç	510.67	93	5.49
60319		26.17	76	0.34
59110		35.21	140	0.25
59794		32.76	150	0.22
36723	Soma-Kınık	192.21	54	3.56
36423		5.48	50	0.11
114		525.00	140	3.75
13198		8.40	90	0.09
41969	Bergama	751.36	86	8.74
51028		249.90	29	8.62
11199		4.51	70	0.06

5.3.1. Low Permeable-Impermeable Rocks

Paleozoic metamorphic units (P1), which form the basement of the Bakırçay Basin, generally contain few fractures and cracks. Locally, joint systems are concentrated due to faulting and therefore they carry local groundwater controlled by fracture and crack systems in areas where their spread is high in the basin. When going deep in the formation, the cracks and fractures are almost non-exist. Therefore, these units do not show regional aquifer characteristics and form an impermeable basement meaning that Paleozoic metamorphics (P1) are low permeable-impermeable formations.

Like Paleozoic metamorphics, Mesozoic metamorphics (Mş) are lithologically composed of rocks such as graphiteschist, clayey schist, phyllite, calcschist, and these units are lithologically-structurally low permeable-impermeable formations. The Mesozoic ophiolitic melange (Mof) is also lithologically low permeable-impermeable, especially due to the weathered and chloritized serpentine it contains. The Eocene flysch (ef) is mainly composed of claystone-marls and sandstone interlayers from place to place. Due to these lithological features, they are low permeable-impermeable formations. Since they cover less area in the basin, they do not have aquifer characteristics. The granite-granodiorite type igneous rocks (Gr), which are relatively common in the basin, are also low permeable-impermeable.

All these low permeable-impermeable units given above do not show aquifer characteristics due to their lithological and structural features. However, in some places they give seasonal resource discharges when they have wide spreads according to BSNFB (2016).

5.3.2. Semi-Permeable Rocks

Neogene aged terrestrial sediments (n2) in the basin are generally contain sandstone, mudstone, clayey limestone, marl, locally conglomeratic levels, and volcanic sedimentary levels. Because of these features, they are permeable to semi-permeable rocks. If the clayey limestone, sandstone, and conglomeratic levels of this unit are dominant, groundwater can be obtained at an economical level. However, since there are impermeable units such as mudstone, claystone, and marl above and below these units, their feedings may be weak and over time. The flow rate in the wells drilled in this unit decreases and even some wells dry up. This unit shows aquifer feature on a local basis in the basin.

The volcanic units (v) in the basin, which are generally composed of tuff-agglomerate levels, are also considered generally as low permeable to semi-permeable.

5.3.3. Permeable-High Permeable Rocks

The permeable- high permeable rocks in the Bakırçay basin are given below.

-Paleozoic marbles (P2),
-Mesozoic limestone (M),
-Neogene clayey limestone, limestone (n3)

-Neogene basalts and andesites (B, a)

-Quaternary alluvium (Qal)

The aquifer characteristics of permeable- high permeable formations in the basin will be given in detail in the relevant sub-basin sections later.

Quaternary alluviums, especially common in Bergama Plain and Soma Plain, are widespread and have rich aquifer characteristics. Alluvium in Kırkağaç Plain is clayey in the west of the plain and around Kırkağaç. In the middle and east of the plain, it is sandy and pebbly. In the Soma Plain, alluvium is made up of silty sand and gravel. Bergama-Kınık-Göçbeyli Plain is the plain where alluvium is the most common. It is clayey in the east, northeast and south of the plain, and sandy and pebbly in other parts. In addition, Paleozoic marbles have secondary porosity and permeability with the development of dissolution gaps, fracture and crack systems and show aquifer characteristics. Mesozoic limestones are also karstic and have fracture and crack system. In regions where it is widespread and thick, it has a rich aquifer feature. Neogene basalts and andesites have cooling cracks due to their formation, as well as secondary fracture-crack structures due to intense tectonic movements in the region.

The permeability and aquifer characteristics of the geological units in the Bakırçay basin are summarized in Table 5.4.

5.4. Aquifers

In the Bakırçay basin, three groundwater sub-basins, namely Kırkağaç, Soma-Kınık and Bergama, were established by State of Hydraulic Works of Turkey, considering the aquifer characteristics (Figure 5.2). The characteristics of the aquifers in these sub-basins given below are summarized from works of BSNFB (2016).

Table 5.4 Permeability and aquifer characteristics of the formations

Formation Name	**Symbol**	**Porosity and Permeability Feature**	**Aquifer Feature**
Quaternary Alluvium	Qal	It is heterogeneous. Sand-gravel levels are highly porous and permeable to high permeable.	Where it is common and coarse-grained, it has aquifer features.
Neogene Limestone	n3	Carbonated levels are permeable.	It shows aquifer features on a local basis.
Neogene Conglomerate, Sandstone, Mudstone, Clayey Limestone	n2	Sandstone and conglomerate levels are porous and Semi-permeable.	It shows aquifer features on a local basis.
Neogene Andesite, Basalt	a, B	It is mostly disconnected cracked, permeable.	It shows aquifer features on a local basis.
Neogene Volcanic Rock	v	It is mostly disconnected cracked, low permeable-semi-permeable.	It may show aquifer features on a local basis.
Eocene Flysch	ef	It is less fractured-cracked and low permeable-impermeable.	It shows aquifer features on a local basis.
Mesozoic Limestone	M	It has secondary porosity. Permeable to high permeable.	It has aquifer features. Discharge through springs.
Granite-Granodiorite	Gr	It is less fractured-cracked and low permeable-impermeable.	It does not have an aquifer feature.
Mesozoic Opholitic Melange	Mof	It is less fractured-cracked and low permeable-impermeable.	It does not have an aquifer feature.
Mesozoic Metamorphic Rocks	Mş	It is less fractured-cracked and low permeable-impermeable.	It does not have an aquifer feature.
Paleozoic Marble	P2	It has secondary porosity. Permeable.	It has an aquifer feature. Discharge through springs.
Paleozoic Metamorphics	P1	It is less fractured-cracked and low permeable-impermeable.	It does not have an aquifer feature.

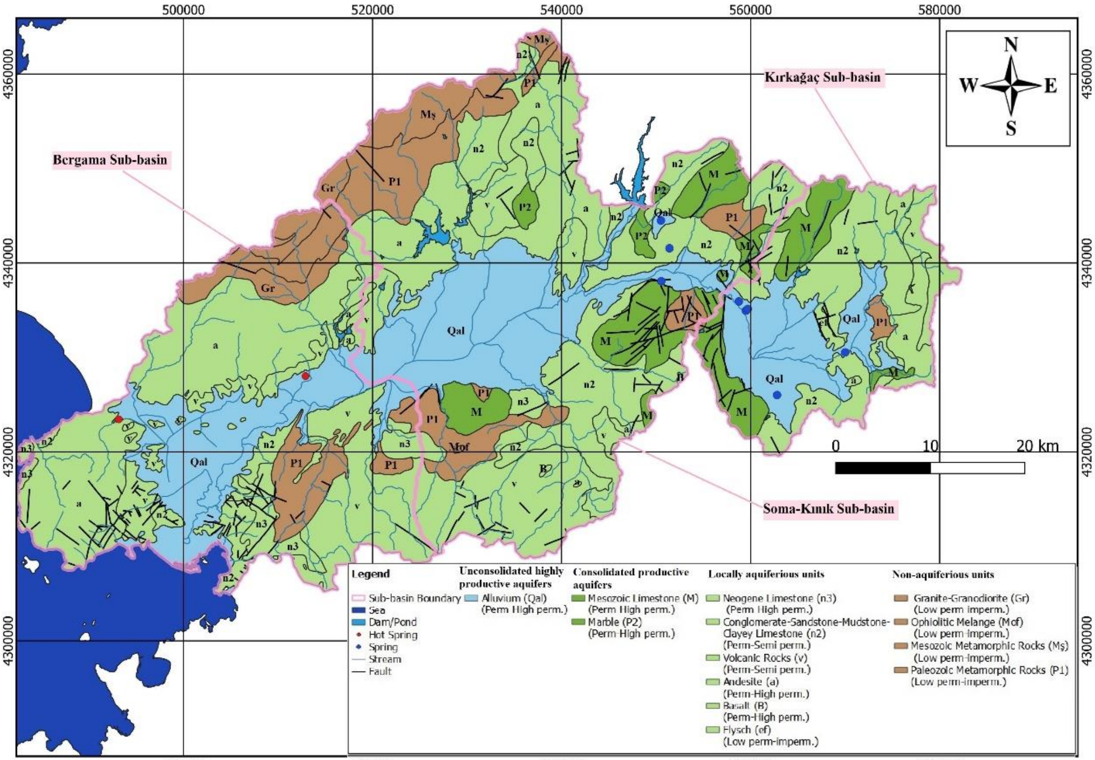


Figure 5.2 Hydrogeological map of study area

5.4.1. Kırkağaç Sub-Basin Aquifers

Neogene volcano-sediments (v, low-semi permeable) in the east and border region of the sub-basin, Neogene lacustrine-terrestrial deposits (n2, semi permeable) and Mesozoic limestones (M, permeable-high permeable) in the north, Neogene terrestrial sediments (n2) in the south, Mesozoic limestones in the southwest, and Quaternary alluviums (Qal, permeable-high permeable) and Flysch (ef, low permeable-impermeable) in the middle part are present.

Quaternary alluviums are the only aquifer units that can be economically exploited by drillings in the sub-basin. The spread of alluvium in Kırkağaç Plain is 112.72 km^2. The spread of the Gelembe Plain, which is further upstream, is 32.78 km^2. In Kırkağaç Plain, the dominant material in the alluviums around Kırkağaç center is clay, and sand-gravel predominates towards the east. The average thickness of the alluvium in Kırkağaç Plain is around 100 m. When moving away from the middle of the plain towards the edges, the thickness varies between 55-75 m. As it can be seen in Table

5.3, the conductivity values of the alluvium unit determined in the DSI wells in Kırkağaç sub-basin range from 0.22 m/day to 5.49 m/day.

Mesozoic limestones with karstic characteristics are also aquifers but they discharge their waters through springs, and it is not possible to exploit them with boreholes since they are in high topographic elevations. The thickness of the Mesozoic limestone unit, located to the west of Ilıca and Akpınar springs, is around 300 m.

5.4.2. Soma-Kınık Sub-Basin Aquifers

Soma-Kınık sub-basin is consists of a flat plain containing Quaternary alluvium through which the Bakırçay river flows.

The east of the sub-basin is covered with semi-permeable Neogene terrestrial sediments (n2) and permeable Mesozoic limestones, while in the north, it is covered with permeable-semipermeable Neogene volcano-sediments and impermeable-low permeable Paleozoic and Mesozoic metamorphics. Volcanics consisting of tuff-agglomerates deposited in large areas in the northern and southern elevations of the basin and in the middle part of the sub-basin permeable Quaternary alluviums were deposited in a wide area.

The most important aquifer unit in this sub-basin is Quaternary alluvium. Mesozoic limestones located on metamorphic schists in different places in the south and southeast of the lower basin also show aquifer characteristics and discharge through springs.

The area of the Soma-Kınık sub-basin alluvial unit is 316.36 km^2. The thickness of the alluvium varies between 40-50 m in the Soma Plain. As seen in Table 5.3, the hydraulic conductivity values of the alluvium unit determined in the DSI wells in the Soma-Kınık sub-basin range from 0.09 m/day to 3.75 m/day.

The depth of the Mesozoic limestones, which are the other aquifers in the sub-basin, is around 400 m. These limestones discharge through springs. There is no drilling well was found directly on the Mesozoic limestone.

5.4.3. Bergama Sub-Basin Aquifers

There are generally volcanic units in the north, west and east of Bergama sub-basin, Neogene terrestrial sediments (n2, semi permeable), Paleozoic metamorphics (P1, low permeable-impermeable) and carbonate rocks (n3, permeable-high permeable) in the east, Quaternary alluviums formed by Bakırçay and other streams in the middle of the sub-basin.

Quaternary alluviums are the most important aquifer rock in the sub-basin, and many private boreholes have been drilled in this aquifer. The area of Quaternary alluvium in Bergama sub-basin is 229.53 km^2. In the wide plain in the middle of the sub-basin, the thickness is around 100 m in the middle parts and 50 m at the edges. As seen in Table 5.3, the conductivity values of the alluvium unit determined in the DSI wells in the Bergama sub-basin range from 0.06 m/day to 8.74 m/day. Although there are boreholes in the Neogene units located in the south of the sub-basin, these units do not show aquifer characteristics in the sub-basin as they are generally clayey and marly. Also, there are few boreholes drilled in the andesites forming the high elevations in the west of the sub-basin. When the well information is evaluated, it can be said that andesites are weak aquifers in terms of groundwater productivity.

5.5. Groundwater Levels

Basin wide groundwater level measurements were carried out in the wells opened in alluvium units in 1976 by DSI and in 2015 dry-2016 wet seasons by BSNFB (2016) for master plan works including private wells as well. The distribution of wells excluding the private wells, used to measure water levels is shown in from Figure 5.3 to Figure 5.5 where water levels of 1976, dry season of 2015 and wet season of 2016 are also shown. Almost all the wells penetrate only alluvium units. Therefore, the maps have been prepared by considering only the alluvium unit. In addition, it is known that some private wells are used in addition to DSI and master plan wells while preparing water level maps. The general groundwater flow direction is from northeast to southwest in the alluvium aquifer. Groundwater-Bakırçay river flow relations indicate both gaining and loosing conditions in general. The comparison of groundwater level temporal changes will be discussed later in the groundwater modeling chapter.

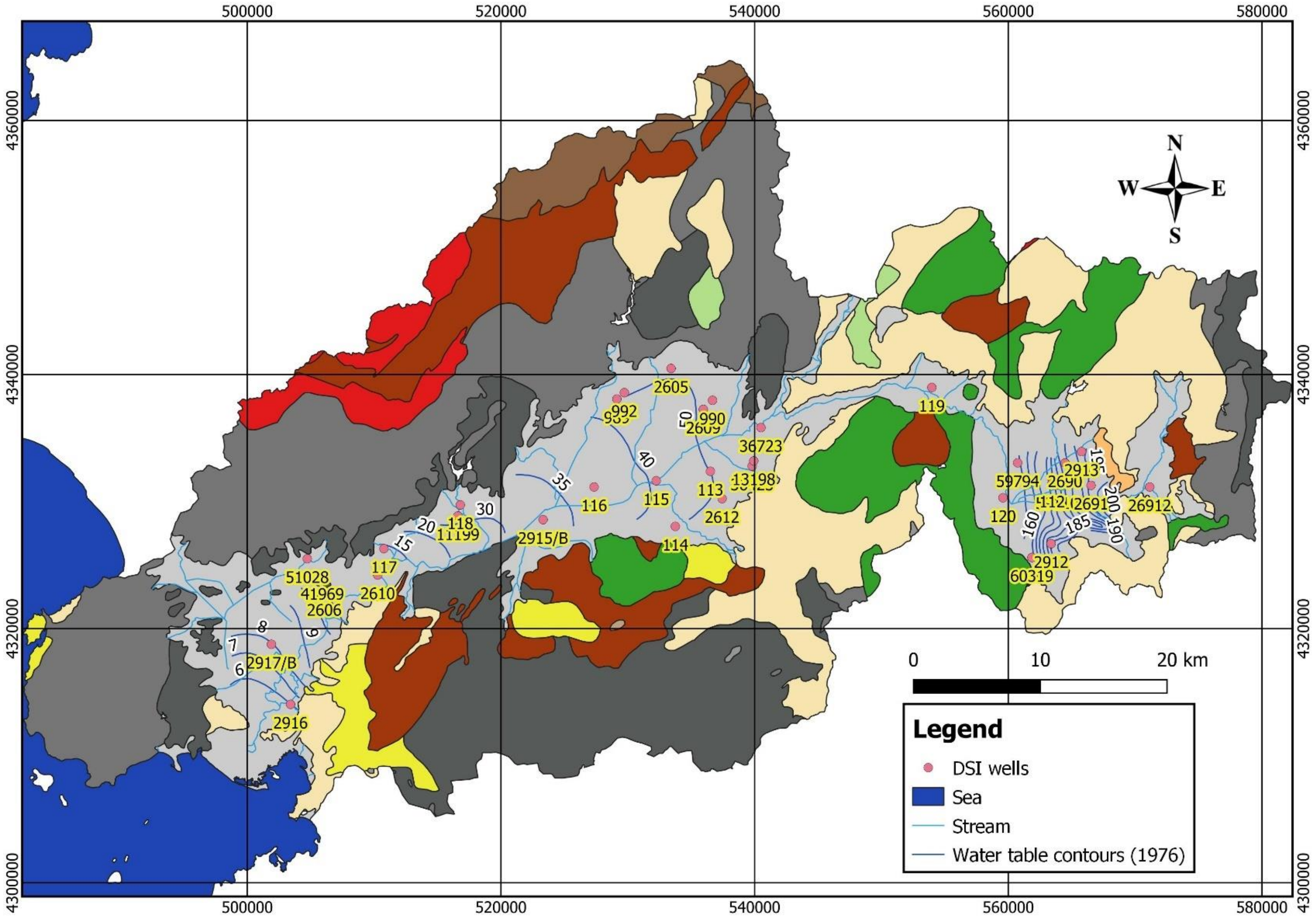


Figure 5.3 Groundwater levels of 1976 in the basin after DSI (1976)

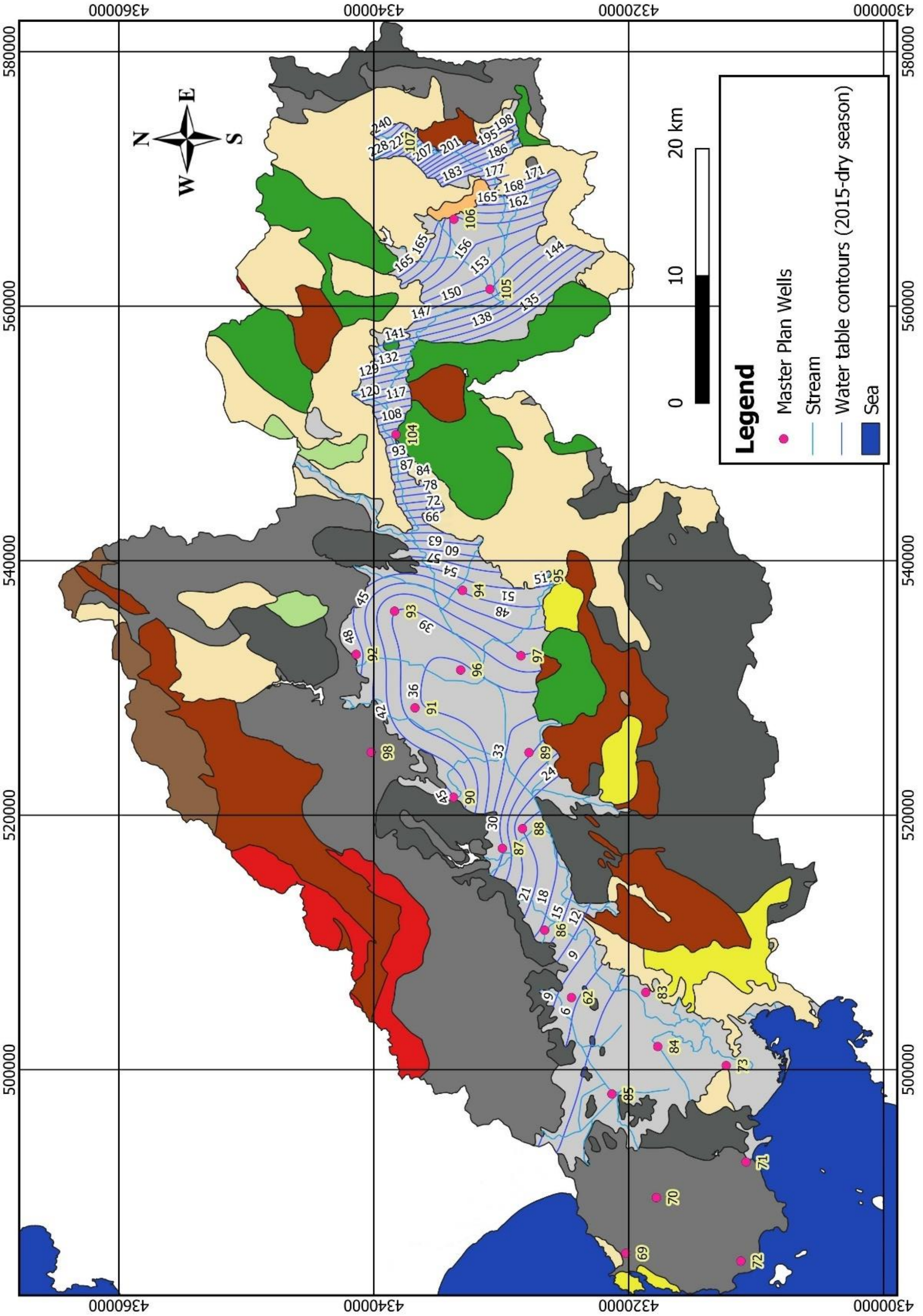


Figure 5.4 Groundwater levels of 2015 dry season in the basin compiled from (BSNFB, 2016)

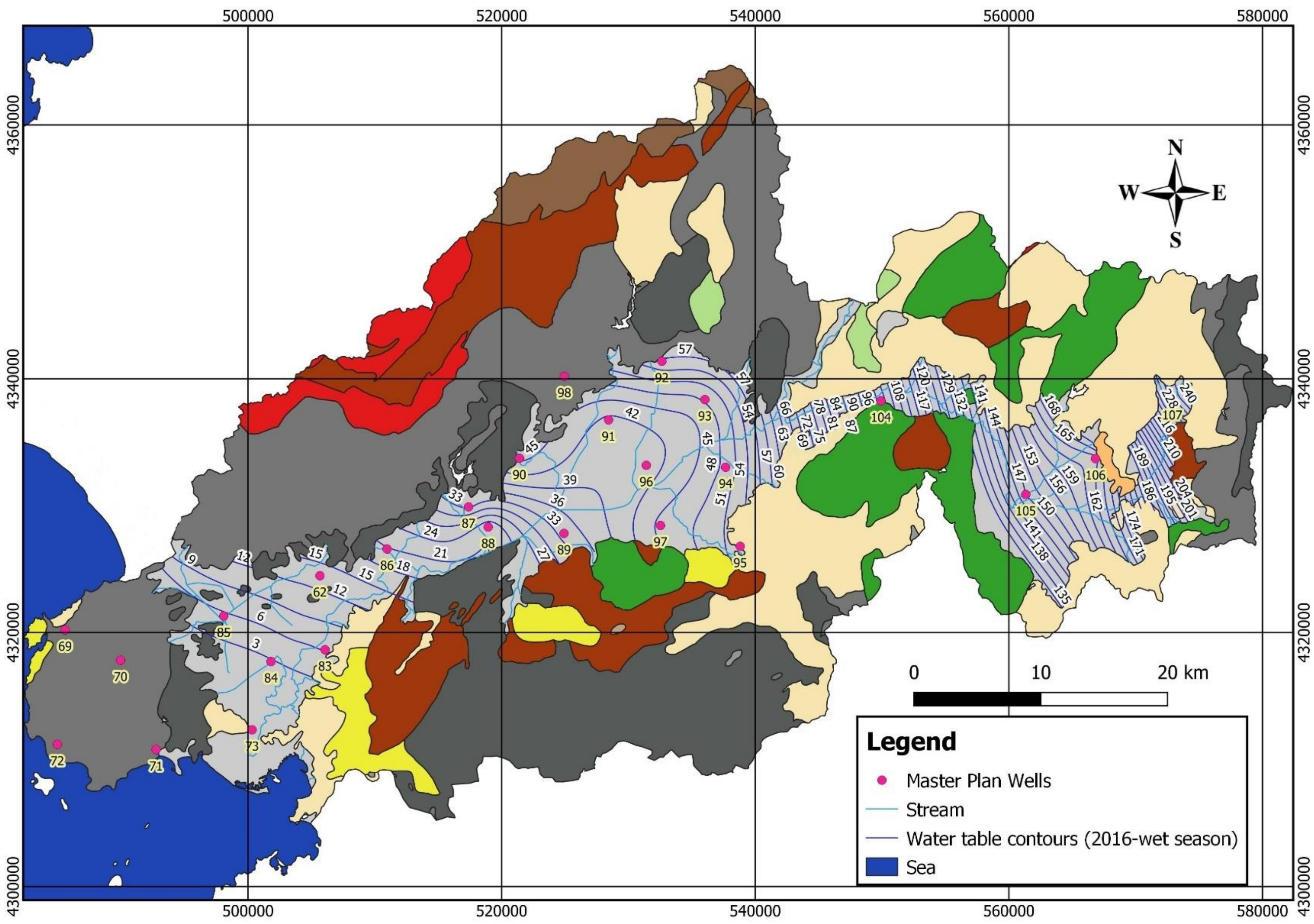


Figure 5.5 Groundwater levels of 2016 wet season in the basin compiled from BSNFB (2016)

CHAPTER 6

GROUNDWATER FLOW MODELING

In order to obtain current depth to groundwater, hydraulic conductivity and recharge distributions in the basin for DRASTIC evaluations, the steady state 2-dimensional numerical flow model is developed for the basin. In the modeling process, the modular three-dimensional finite difference groundwater flow code of MODFLOW was used to perform the flow simulations (McDonald et al., 1988) with the Processing Modflow for Windows (PMWIN) interface (Chiang and Kinzelbach, 1991).

In the first step, the developed model is calibrated using DSI measured groundwater levels of year 1959-1969 which were assumed to be representative of the steady state levels in the basin. In the calibration processes, recharge and hydraulic conductivity values are adjusted. The decrease percentages (dp1) of the recharge values with respect to the initial recharge entries, which are determined from the monthly water budget method (MWBM) using 1969 precipitation and temperature data as it will be explained later, are noted for each sub-basin area.

In the second step, due to lack of present pumpage rates applied in the area, in order to introduce pumpage related groundwater level decreases into the calibrated model, the recharge amounts in the areas of pumping wells (see Figure 5.1) are decreased by calibration with the average groundwater levels of the years 2015-2016 using trial-error method. Although it is not the same as applying pumpage, considering lack of information, very vast area spreading of the wells, quantity of the wells, and basin wide nature (regional scale) of the developed model, the approach (pumping related groundwater level decrease by decreasing the recharge values) is assumed to be a reasonable assumption and serves the purpose. Here, it is further assumed that the pumpage activities are constant and the system is in a steady state. Initially, the recharge values obtained from the MWBM using temperature and precipitation of year 2015 are reduced by multiplying with the decrease percentages (dp1) determined in the first step and are introduced into the model. The recharge values corresponding to the areas of pumping wells are further decreased with trial-error method by calibrating the model against the measured average groundwater levels of the years 2015-2016 and the percentage decreases (dp2) of the recharge values in pumpage areas are noted.

In the third step, the model is used to estimate groundwater levels of year 2020 by entering the recharge data determined from the MWBM using precipitation and temperature data of year 2020 after recalculating them in related locations considering the decrease percentages dp1 and dp2 obtained earlier. By doing so, with the dp1 application; the initial recharge entries of year 2020 are adjusted to the calibration of the first step (representing 2020 recharge values to be used in DRASTIC evaluations) and with the dp2 application in pumping areas; the recharge entries of year 2020 are further adjusted to the pumping effects. The run results of the third step are later used to obtain the depth to water values in the sub-basins to use in DRASTIC evaluations.

6.1. Conceptual Model

In the study area, alluvium (Qal), Neogene Conglomerate, Sandstone, Mudstone, Clayey Limestone (n2), Eocene Flysch (ef), Neogene limestone (n3) and Mesozoic limestone (M) units are assumed to be a part of a single unconfined aquifer system which is heterogeneous and anisotropic in terms of hydraulic conductivity distribution. The other units are taken as impervious.

The area is discretized into 60 rows, 100 columns with total 6000 cells. Each cell has a dimension of 1000 m X 1000 m. The model domain and the grids are shown in Figure 6.1.

Figure 6.1 Model grids, boundary conditions and locations of the observation wells in the study area

6.2. Boundary Conditions and Observation Wells

Metamorphic and volcanic units in the north and south of the basin are considered no flow boundaries. The shore line in the southwest of the study area, where the Bakırçay river discharges into the sea, is taken as constant head boundary. Furthermore, dams are taken as constant head boundaries. Because the dams are constructed between the years of 1981 and 1988, their boundary conditions are added to the model accordingly. Due to small sizes with respect to the modeled area, ponds are not taken into consideration as constant head boundaries. Bakırçay river, which arises from the northeast of the basin and flows into the Aegean Sea in the southwest of the area, is taken as the river boundary. Springs are incorporated into the model as drain boundaries. These boundaries are shown in Figure 6.1.

In addition, 43 observation wells are added to the model, 24 of which belong to the DSI (1976) and 19 of which were drilled as a part of the master plan work carried out by BSNFB (2016) (Figure 6.1).

6.3 Input Parameters

The model input parameters include:

- model top and bottom elevations,
- initial hydraulic heads,
- hydraulic conductivities,
- precipitation recharge values,
- drain elevations and hydraulic conductances of the units where springs discharge, and
- heads of the Bakırçay river, bottom elevations, hydraulic conductances of the river channel.

The current topographic data of the study area were added to the model as the model top elevation data. The data were interpolated for the entire model domain using the kriging method. Due to the limited amount of data, in place of interpolation, the bottom elevations were fixed to -30 m in Kırkağaç and Soma basins, -90 m in the Kınık sub-basin and -20 to -90 in Bergama sub-basin by evaluating the available unit thickness data, topographic elevation and considering regional flow conditions to be simulated.

The initial hydraulic head for all active cells, excluding the constant head boundaries, was set to 50 m. The initial hydraulic head value was set to zero in the constant head boundaries along the shoreline. Due to lack of data, the dam constant head boundaries are set to the cells in front of the dam sites in the flow direction and for these locations head values are obtained from the groundwater table map of BSNFB (2016). The constant head values are 120 m, 54 m and 41 m in the areas just after the dam bodies of Sevişler, Yortanlı and Kestel dams, respectively.

The hydraulic conductivity values obtained from the pumping test results of the alluvium unit by DSI (1976) and BSNFB (2016) are used as initial entries for the unit. These values are 0.1-8.7 m/day for alluvium of Bergama sub-basin, 0.1-3.8 m/day for alluvium of Soma-Kınık sub-basin and 0.2-5.5 m/day for alluvium of Kırkağaç sub-basin. Hydraulic conductivities of the other units were assigned according to the hydraulic properties of the units from the literature as 6 m/day for Neogene Conglomerate, Sandstone, Mudstone, Clayey Limestone (n2), 2 m/day for Eocene

Flysch (ef), 6 m/day for Neogene limestone (n3) and 5 m/day for Mesozoic limestone (M) units (Freeze and Cherry, 1979; Sakiyan and Yazıcıgil, 2004). These entries later were subjected to the calibration.

Based on MWBM explained in the hydrology chapter, initial recharge values (= sub-surface infiltration) for each sub-basin is estimated assuming no surplus water runoff. For these recharge calculations, the curve numbers determined for each land use as explained earlier were reduced to three land uses grouped as agricultural areas, artificial surfaces, and forest and semi natural areas for each sub-basin. In the reduction, land use related area percentages are taken into account (area weighted average). The estimated curve numbers for runoff calculations in each basin corresponding to these three land use groups are listed in Table 6.1 together with the estimated recharge values.

Table 6.1 Recharge values calculated from MWBM for each sub-basin from 1969 meteorological data

Sub-basin	**Landuse Class**	**Curve Number**	**Recharge (m/year) (initial estimation)**	**Average Recharge (m/day) (initial estimation)**
Bergama	Agricultural area	67.8	0.2281	0.00057
	Artificial surface	83.8	0.1473	
	Forest and semi natural area	62.6	0.247	
Soma	Agricultural area	75.4	0.161	0.00041
	Artificial surface	91.5	0.0786	
	Forest and semi natural area	62.7	0.2061	
Kınık	Agricultural area	56.8	0.2019	0.00043
	Artificial surface	90.8	0.0779	
	Forest and semi natural area	61.8	0.1901	
Kırkağaç	Agricultural area	53.4	0.2986	0.00056
	Artificial surface	90.9	0.0961	
	Forest and semi natural area	72.9	0.2152	

As the initial recharge rates, 0.00057 m/day, 0.00041 m/day, 0.00043 m/day and 0.00056 m/day for Bergama, Soma, Kınık and Kırkağaç sub-basins, respectively were assigned to the sub-basins. These entries later were subjected to the calibration.

River bed hydraulic conductance in the range of 1000-12500 m^2/day, elevation of the riverbed bottom as 0.7 m below the topographic surface and head in the river as 0.2 m above the elevation of the riverbed are assigned.

Input values of spring drain elevations and hydraulic conductances of the units from which springs discharge are listed in Table 6.2. Hydraulic conductance is approximated using discharge information.

Table 6.2 Drain elevation and hydraulic conductance values for springs

Spring Name	Elevation (m)	Hydraulic Conductance (m^2/d)
Turgutalp	104	1650
Ilıca	149	740
Akpınar	146	1200
Kuyulu Lake	148	864
Çamur Hot Spring	7	17
Bülbül Hill	117	432
Soğucak	117	17
Karakurt Zeybek Hill	174	216
Bakıralan Hill	142	21
Güzellik Hot Spring	24	4

6.4. Model Calibration

The observed and calculated hydraulic head values should be compared during the calibration to determine the accuracy of the model. As explained in the beginning of the chapter, model calibrations were carried in two steps.

Initially, steady state calibration was carried out according to the information of 24 observation wells from 1969 data of DSI (1976). The hydraulic conductivity and recharge values were adjusted to calibrate the model. The calibration results are listed in Table 6.3 are evaluated using the root mean square error (RMSE) and average deviation. The root mean square error and average deviation are determined as 8.9 and 6.3, respectively, using observed and calculated values after the calibration and is considered to be satisfactory for the basin modeling. Predicted head values of Well numbers 112 and 2612 have rather high error association. If these points are ignored, the root mean square error and average deviation decrease to 5.7 and 4.7, respectively. The graph of the observed versus calculated hydraulic heads are shown in Figure 6.2.

Table 6.3 Observed and calculated head values at observation wells after the calibration

Sub-basin	**Well No**	**Observed Head (m)**	**Calculated Head (m)**
Bergama	117	17.50	22.52
	118	41.10	32.22
	2606	15.00	15.79
	2610	12.25	19.24
	2916	6.70	5.25
	2917/B	9.75	12.64
Soma-Kınık	113	46.75	47.50
	114	54.75	47.23
	115	39.90	34.83
	116	37.70	34.77
	119	131.00	136.43
	2605	61.00	46.98
	2609	49.10	48.15
	2612	78.72	52.66
	2915/B	30.57	32.21
	989	43.20	42.98
	990	50.50	49.67
	992	43.80	43.52
Kırkağaç	112	132.60	153.15
	120	159.00	149.90
	2690	175.65	169.62
	2691	161.25	171.39
	2912	181.00	174.50
	2913	189.70	182.56

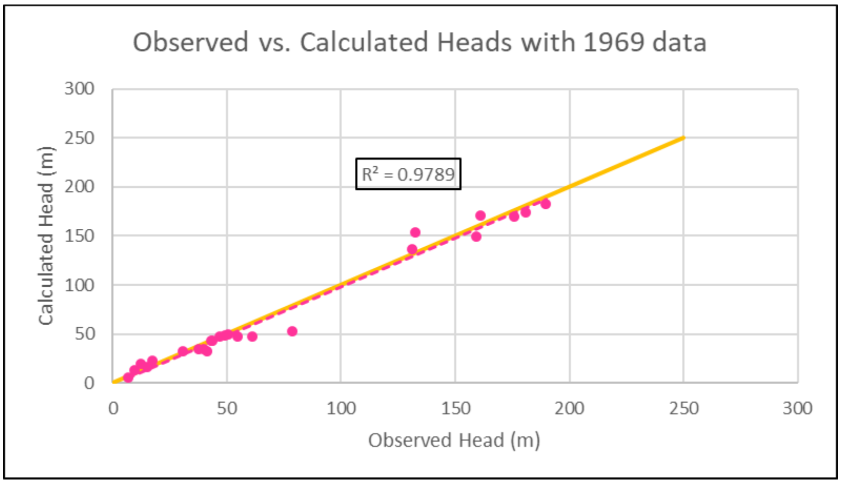
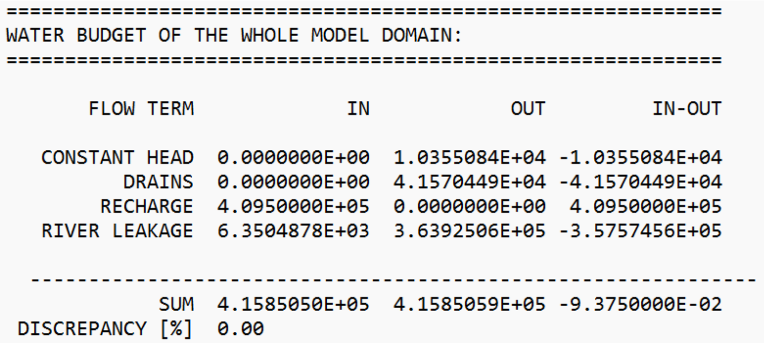


Figure 6.2 The graph of observed vs. calculated heads with 1969 data

Individual sub-basin calibration results have also been evaluated. The root mean square errors (RMSE) are determined as 5.2, 9.1 and 11.1 for Bergama, Soma-Kınık and Kırkağaç sub-basins, respectively.

Water budget of the model run with the 1969 data is given in Table 6.4 below.

Table 6.4 Model water budget results for 1969



```
=============================================================
WATER BUDGET OF THE WHOLE MODEL DOMAIN:
=============================================================

       FLOW TERM             IN            OUT         IN-OUT

   CONSTANT HEAD  0.0000000E+00  1.0355084E+04 -1.0355084E+04
          DRAINS  0.0000000E+00  4.1570449E+04 -4.1570449E+04
        RECHARGE  4.0950000E+05  0.0000000E+00  4.0950000E+05
   RIVER LEAKAGE  6.3504878E+03  3.6392506E+05 -3.5757456E+05

  --------------------------------------------------------------
             SUM  4.1585050E+05  4.1585059E+05 -9.3750000E-02
 DISCREPANCY [%]  0.00
```

According to the results, total drain discharge is about 41571 m^3/day. However, regarding to the field measurements from DSI (1976) given in Table 5.1, the total drain discharge is 109210 m^3/day. This difference is probably largely due to the karstic character of the springs which is not easy to adequately represent within the granular media flow model. In fact, relatively high RMSE associated with Kırkağaç sub-basin is most probably related to this factor. Refinement calibrations were not performed. The budget results indicate that model head predictions where the springs are located should be evaluated cautiously.

The hydraulic conductivity values after the calibration become 8.7 m/day for alluvium unit of Bergama sub-basin, 10 m/day for alluvium unit of Soma-Kınık sub-basin, 2 m/day for alluvium unit of Kırkağaç sub-basin, 2 m/day for Neogene Conglomerate, Sandstone, Mudstone, Clayey Limestone (n2) unit, 2 m/day for Eocene Flysch (ef), 3 m/day for Neogene limestone (n3) and 5 m/day for Mesozoic limestone (M) units. The hydraulic conductivity distribution obtained after the calibration is shown in Figure 6.3. *These are the hydraulic conductivity values that will be used in DRASTIC evaluations.*

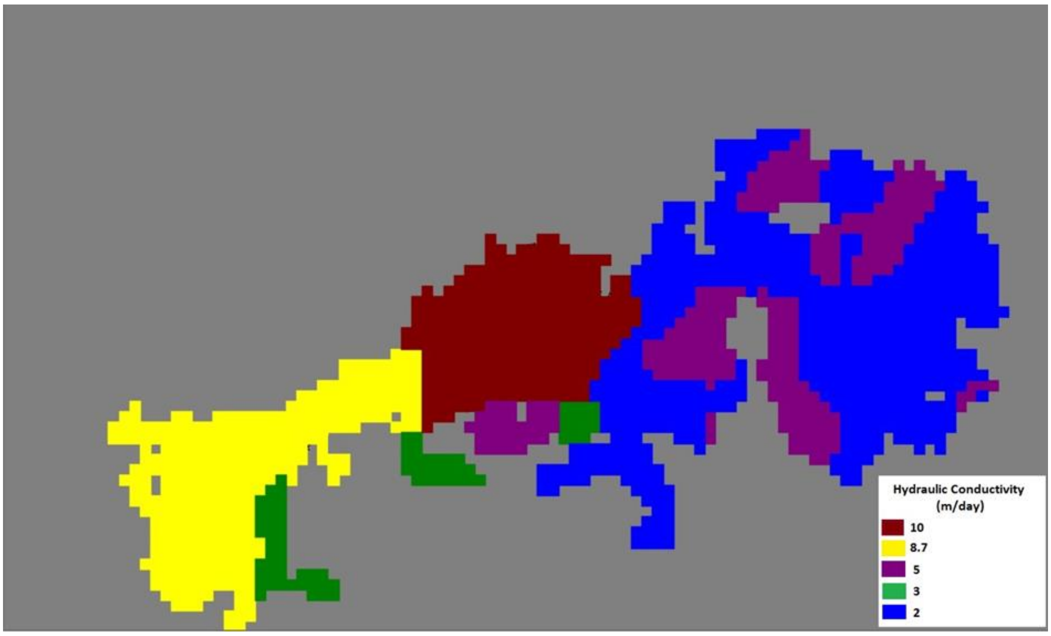


Figure 6.3 Hydraulic conductivity distribution after calibration

Changes have been made to the recharge rates, in particular during calibration. The values before and after the calibration are listed in the Table 6.5. The decrease percentages (dp1) are 53% for Bergama, 49% for Soma, 47% for Kınık and 54% for Kırkağaç sub-basins with respect to the initial entries. The possible reasons of these about fifty percent differences between the monthly water budget recharge predictions versus model recharge predictions are (a) incorporation of surplus water runoff into the recharge water amount, (b) missing crop water usage consideration in the PET calculations which is based on Thornthwaite equation, and (c) low direct runoff estimation in the monthly budget calculations. In any case, considering that model predictions are more reliable, dp1 percentages could be used to determine the actual precipitation recharges for the sub-basins from the monthly water budget calculated recharges at any year.

Table 6.5 Recharge values of year 1969 for each sub-basin before and after the calibration

Sub-basin	**Recharge (m/day)**	
	Before Calibration	**After Calibration**
Bergama	0.00057	0.0003
Soma	0.00041	0.0002
Kınık	0.00043	0.0002
Kırkağaç	0.00056	0.0003

The river hydraulic conductance was also adjusted during the calibration.

After the first calibration was completed, average groundwater level data of 2015-2016 were used for further calibration using 2015 meteorological data in order to include well discharge effects to the groundwater levels as explained in the beginning of the chapter by recharge value adjustment due to the lack of pumping rate information. The distribution of the discharge wells in the basin is shown in Figure 5.1. In this application, the dams constructed in the basin between the years 1969 and 2015 are also incorporated into the model.

The second step calibration results are listed in Table 6.6. The root mean square error and average deviation are found to be 8.6 and 6.6, respectively according to the observed and calculated head values. Predicted head values of well numbers 106 and 107 have rather high error association. If these points are ignored, the root mean square error and average deviation decrease to 6.2 and 5.2, respectively. The graph of the observed versus calculated hydraulic heads are shown in Figure 6.4.

Table 6.6 Observed and calculated head values at observation wells after second step calibration

Sub-basin	**Well No**	**Observed Head (m)**	**Calculated Head (m)**
Bergama	62	10.25	14.61
	83	6.10	8.25
	84	2.80	7.47
	85	5.60	16.63
	86	19.00	23.18
	87	31.65	38.84
Soma-Kınık	88	22.05	33.77
	89	32.25	33.46
	90	45.15	35.68
	91	39.55	40.01
	92	53.10	45.78
	93	43.80	46.23
	94	48.95	45.80
	96	38.25	37.27
	97	43.65	38.95
	104	103.00	110.07
Kırkağaç	105	150.15	139.51
	106	161.50	178.51
	107	235.45	215.42

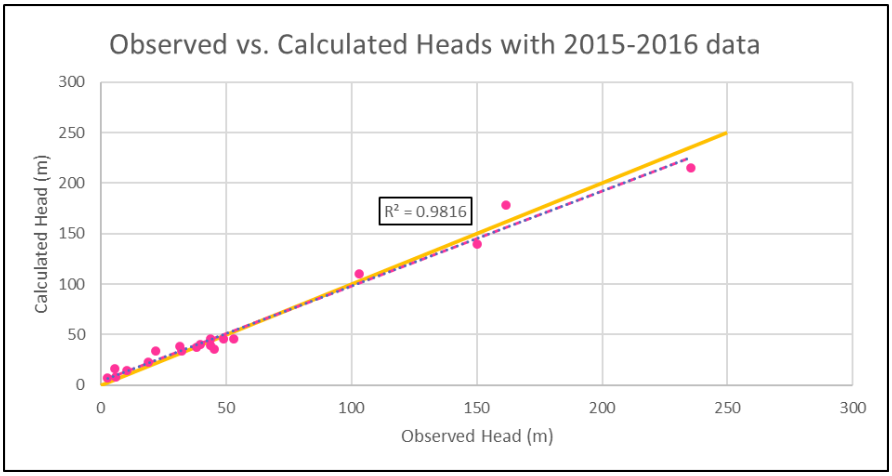


Figure 6.4 The graph of observed vs. calculated heads with 2015-2016 years average data

Individual sub-basin calibration results have also been evaluated. The root mean square errors (RMSE) are determined as 6.2, 6.1 and 16.4 for Bergama, Soma-Kınık and Kırkağaç sub-basins, respectively.

The well discharge adjusted “recharge-discharge” values in the pumping well locations before and after the calibration indicate that the decrease percentages (dp2) are 40% for Bergama, 60% for Kınık, 0% for Soma and 68% for Kırkağaç with respect to the dp1 corrected recharge values. The values subjected to the correction were obtained from the MWBM using precipitation and temperature data of year 2015. Therefore, these percentages could be used to decrease the actual recharge values in order to account the well pumping effect in related areas of the sub-basins. The head distribution representing 2015 levels is shown in Figure 6.5.

As a final step to determine the groundwater levels in the year of 2020, initially the temperature and precipitation data of 2020 were used to obtain the MWBM recharges. These recharge values are converted to the calibrated ones using basin related dp1 percentages. These calibrated recharge values of the year 2020 are determined as 0.000118 m/day for Bergama, 0.000072 m/day for Soma, 0.000103 m/day for Kınık and 0.000089 m/day for Kırkağaç sub-basins. *These are the recharge values that will be used in the DRASTIC evaluations.*

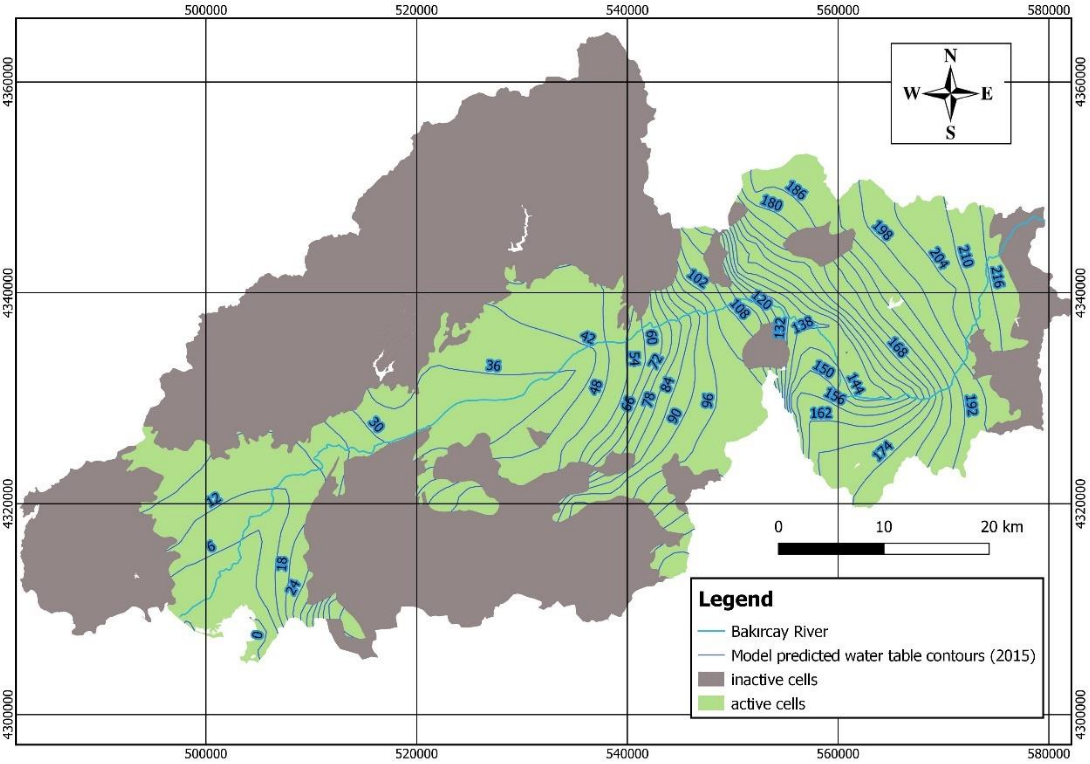


Figure 6.5 Model predicted Groundwater table map of year 2015

The recharge distribution in the year of 2020 is shown in Figure 6.6. According to the results, total annual average recharge values of sub-basins are around 43 mm/year, 26 mm/year, 38 mm/year and 32 mm/year for Bergama, Soma, Kınık and Kırkağaç sub-basins, respectively. Total annual recharge for the study area is calculated about $66x10^6$ m^3/year. The calculations suggest that about 31% (528 mm) of annual precipitation (1687 mm) could infiltrate to the subsurface.

The head distribution in the basin are estimated after applying pumping effect reduction using dp2 percentages to the recharge values of 2020 in related areas. The hydraulic heads obtained from the model are used to prepare groundwater table map (Figure 6.7). *These are the head values that will be used to calculate depth to water values for the DRASTIC evaluations.* In addition, for easier comparison, 2015 water levels have been added to the map in Figure 6.7.

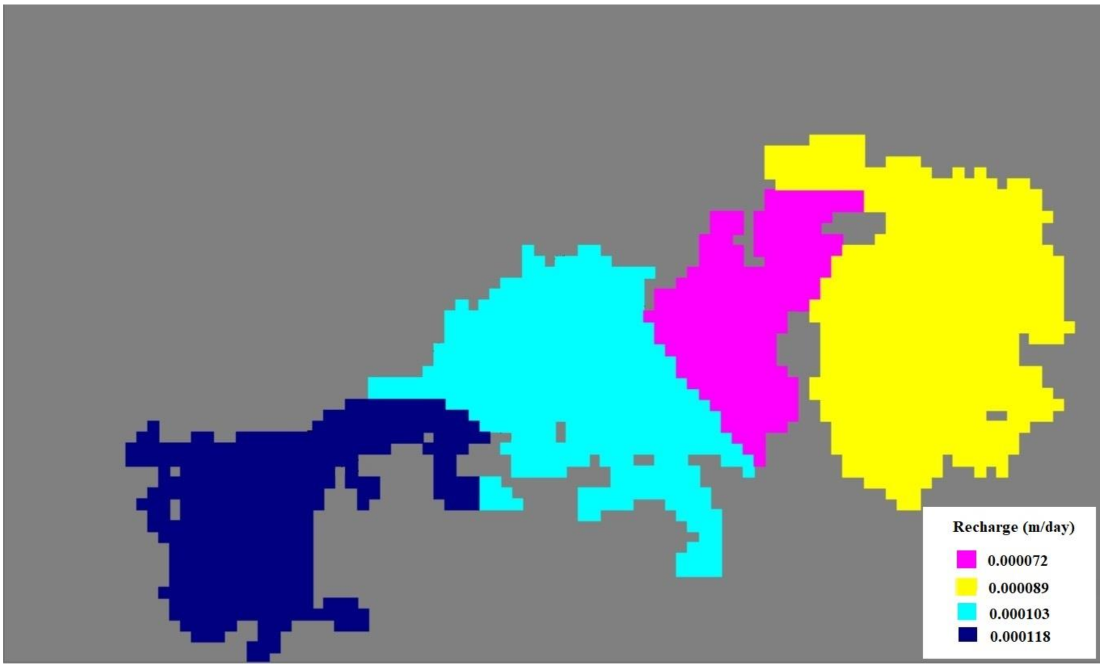


Figure 6.6 Recharge distribution in the year of 2020

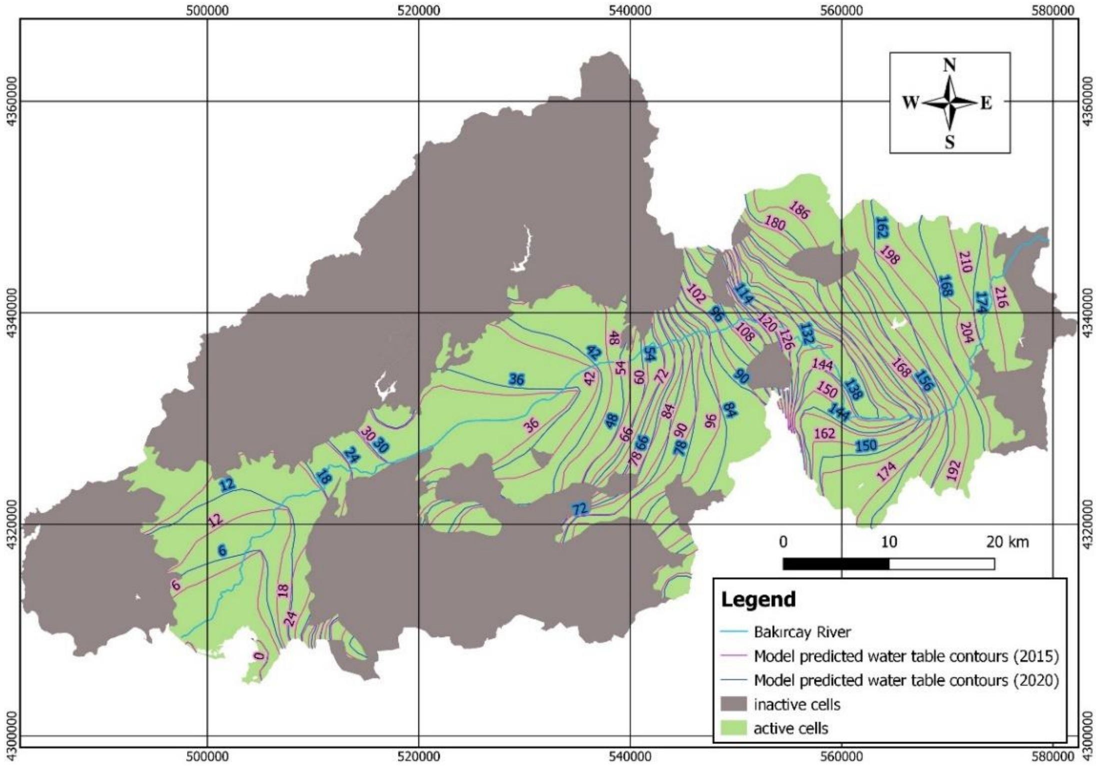


Figure 6.7 Model predicted Groundwater table map with the 2015 and 2020 results

6.5. Groundwater level changes

Groundwater level changes from 1969 to 2020 at observation wells are compared to see the time related changes in the basin. Graphs and maps prepared with the model run results and showing the groundwater level changes of each sub-basin are given from Figure 6.8 to Figure 6.13 below.

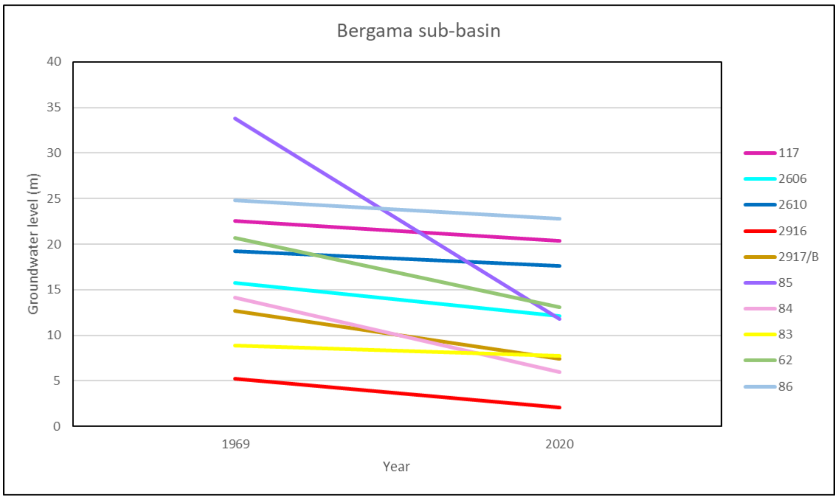


Figure 6.8 Groundwater level changes at observation wells between the years of 1969 and 2020 for Bergama sub-basin

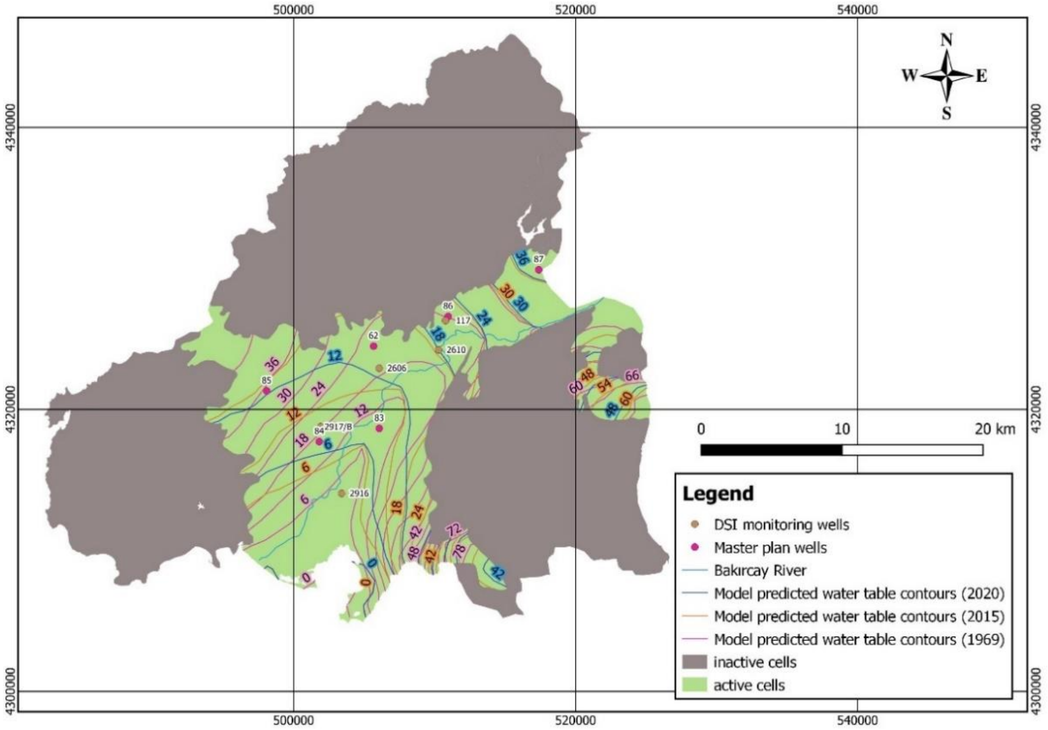


Figure 6.9 Model predicted Groundwater table map of 1969-2020 with monitoring well locations for Bergama sub-basin

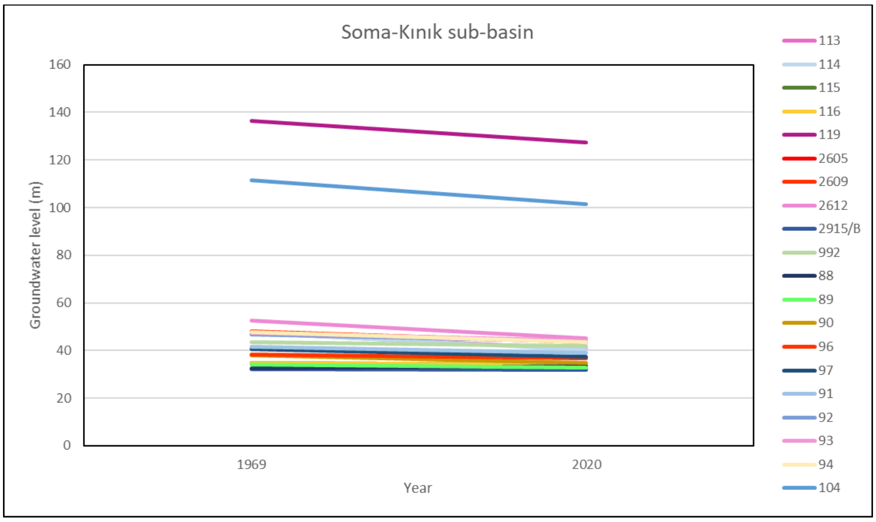


Figure 6.10 Groundwater level changes at observation wells between the years of 1969 and 2020 for Soma-Kınık sub-basin

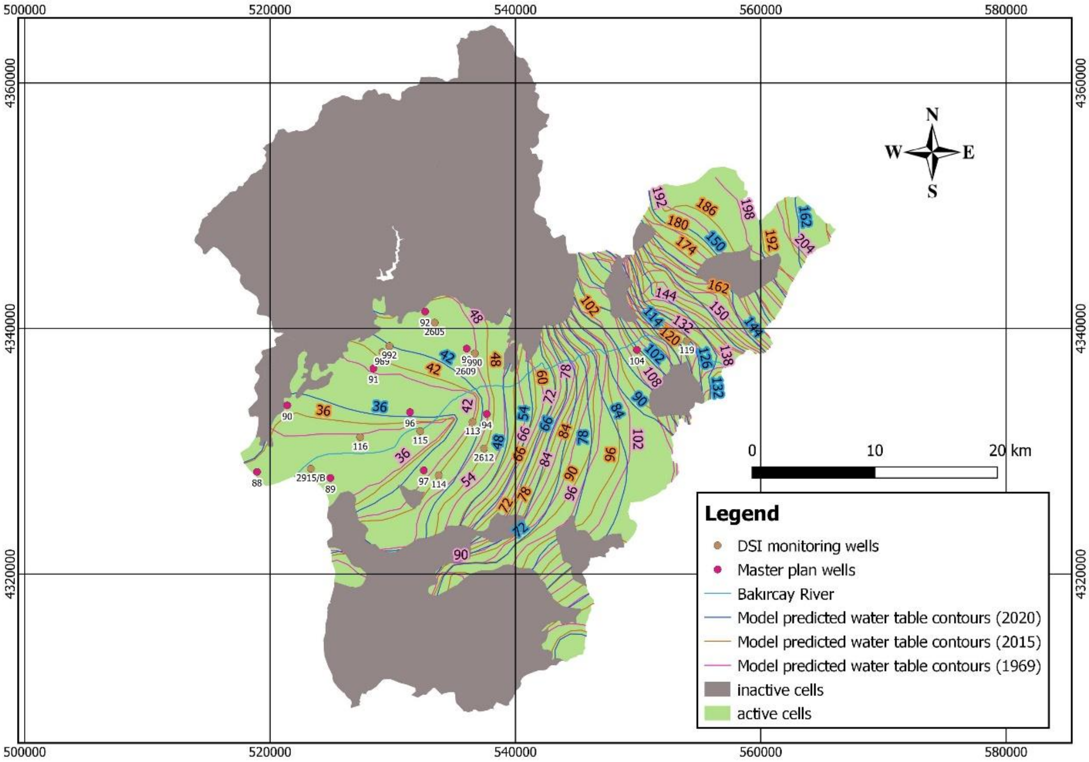


Figure 6.11 Model predicted Groundwater table map of 1969-2020 with monitoring well locations for Soma-Kınık sub-basin

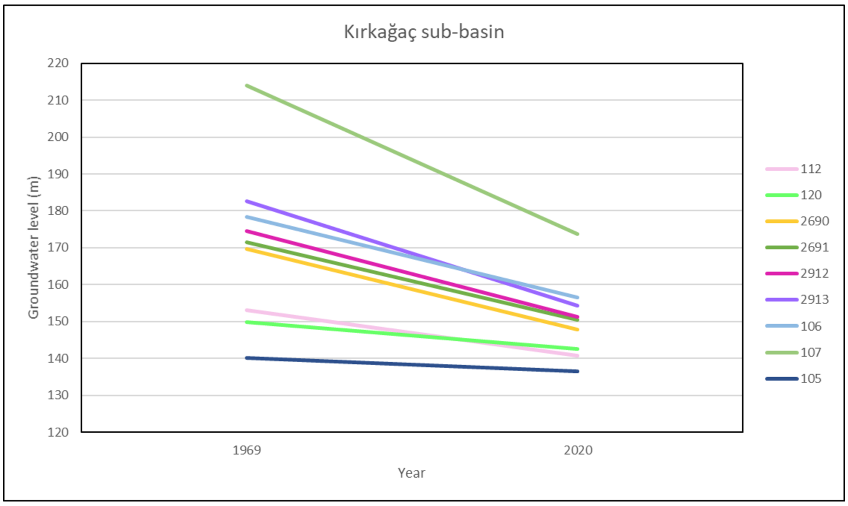


Figure 6.12 Groundwater level changes at observation wells between the years of 1969 and 2020 for Kırkağaç sub-basin

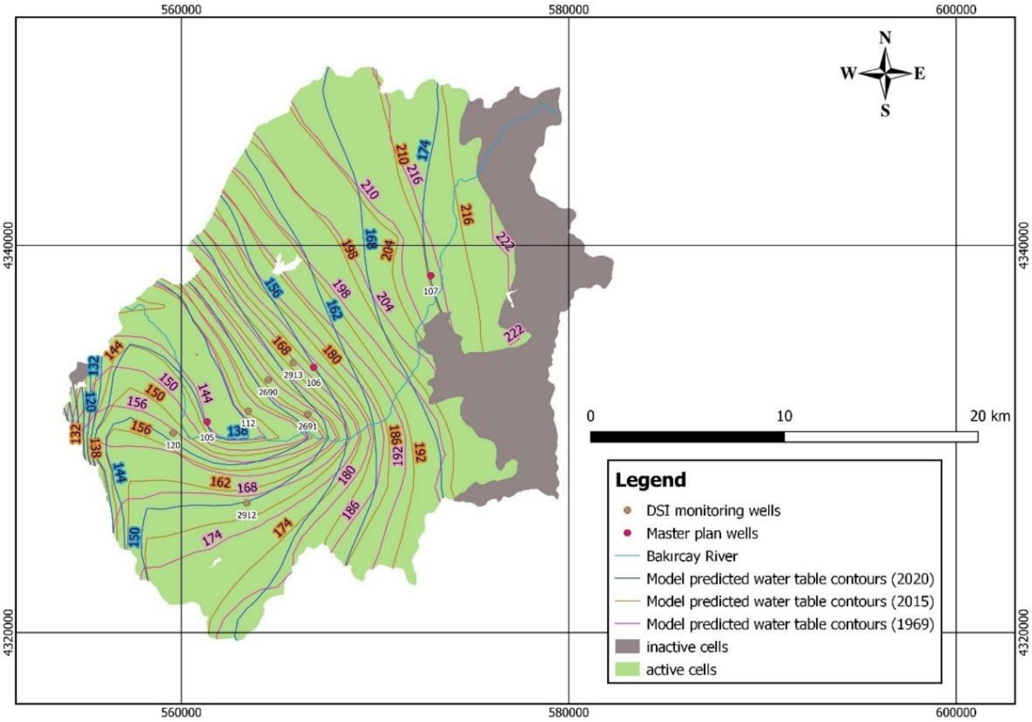


Figure 6.13 Model predicted Groundwater table map of 1969-2020 with monitoring well locations for Kırkağaç sub-basin

As can be seen in the figures, the water levels have decreased over the years, especially in Kırkağaç sub-basin in the east of the basin. According to the graphs given above, the level changes for the Bergama, Soma-Kınık, and Kırkağaç sub-basins are 1.7-22.1 m, 0.5-10.1 m, and 3.8-40.2 m, respectively, at the observation well locations for the years between 1969 and 2020.

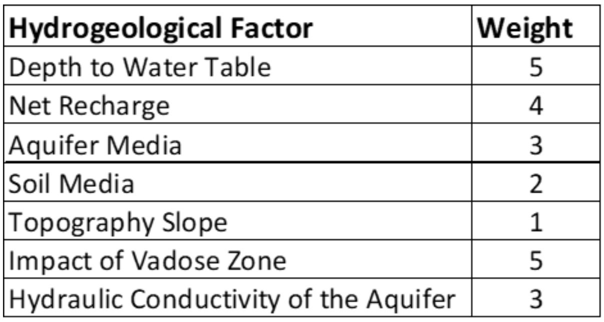
CHAPTER 7

APPLICATION OF DRASTIC METHOD

The DRASTIC method developed by the U.S. Environmental Protection Agency (EPA) is described as the method that would allow the pollution potential of any hydrogeologic setting to be systematically evaluated anywhere (Aller et al., 1987). The main idea of the DRASTIC method is to overlay raster-based maps representing the factors affecting groundwater pollution, and as a result, to calculate the index values showing the vulnerability. The DRASTIC includes seven hydrogeological factors which control surface infiltration of waters to the aquifer: depth to water table (D), net recharge (R), aquifer media (A), soil media (S), topography slope (T), impact of vadose zone media (I), and hydraulic conductivity of the aquifer (C).

Each of the seven factors has a relative weight. A weight value between 1 and 5 was assigned for each factor, with 5 being the most important factor and 1 being the least important factor to contribute to the vulnerability for contamination (Table 7.1).

Table 7.1 Assigned weights for DRASTIC factors (Aller et al., 1987)



Hydrogeological Factor	**Weight**
Depth to Water Table	5
Net Recharge	4
Aquifer Media	3
Soil Media	2
Topography Slope	1
Impact of Vadose Zone	5
Hydraulic Conductivity of the Aquifer	3

Also, each factor is rated on a range of 1 to 10, with 1 being the least pollution potential and 10 being the highest pollution potential. The original weights, rate ranges and rates applied to the DRASTIC method as determined by Aller et al. (1987) are listed in Table 7.2 after unit conversions.

Table 7.2 Ranges, ratings and weights for DRASTIC parameters (Aller et al., 1987)

Factor	Range	Rating	Weight
Depth to water table (m)	0-1.5	10	5
	1.5-4.5	9	
	4.5-9	7	
	9-15	5	
	15-22.8	3	
	22.8-30	2	
	30<	1	
Net Recharge (m/d)	0-0.000139	1	4
	0.000139-0.000278	3	
	0.000278-0.000487	6	
	0.000487-0.000696	8	
	0.000696<	9	
Aquifer Media	Massive Shale	1-3	3
	Metamorphic/Igneous	2-5	
	Weathered Metamorphic/ Igneous	3-5	
	Thin Bedded Sandstone, Limestone and Shale Sequence	5-9	
	Massive Sandstone	4-9	
	Massive Limestone	4-9	
	Sand and Gravel	6-9	
	Basalt	2-10	
	Karst Limestone	9-10	
Soil Media	Thin or Absent	10	2
	Gravel	10	
	Sand	9	
	Shrinking and/or Aggregated Clay	7	
	Sandy Loam	6	
	Loam	5	
	Silty Loam	4	
	Clay Loam	3	
	Nonshrinking and Nonaggregated Clay	1	
Topography Slope (%)	0-2	10	1
	2-6	9	
	6-12	5	
	12-18	3	
	18<	1	
Impact of Vadose Zone	Silt/Clay	1-2	5
	Shale	2-5	
	Limestone	2-7	
	Sandstone	4-8	
	Bedded Limestone, Sandstone, Shale	4-8	
	Sand and Gravel with significant Silt and Clay	4-8	
	Metamorphic/Igneous	2-8	
	Sand and Gravel	6-9	
	Basalt	2-10	
	Karst Limestone	8-10	
Hydraulic Conductivity (m/d)	0-4	1	3
	4-12	2	
	12-29	4	
	29-41	6	
	41-82	8	
	82<	10	

A land use parameter was added to this approach in addition to the DRASTIC original parameters to investigate how land use affects the vulnerability of aquifers to contamination. The weight is assigned as 5 for the land use parameter (Shamsuddin et al., 2021) excluding mineral extraction and dump sites for which weight of 10 is assumed. The range, related ratings and weights are listed in Table 7.3.

Table 7.3 Ranges, ratings, and weights for land use (Modified from Shirazi et al., 2013)

Factor	Range	Rating	Weight
Land use	Mineral Extractian and Dump Sites	10	10
	Agricultural and Artificial Areas	8	5
	Water Bodies	3	
	Wetlands	2	
	Forest and Semi Natural Areas	1	

After the ratings and the weight values are determined, the DRASTIC Index is calculated with the following equation (Aller et al., 1987; Shamsuddin et al., 2021).

DRASTIC Index=
$D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W + L1_R L1_w + L2_R L2_w$

D_R = ratings for the depth to water table

D_W = weights assigned to the depth to water table

R_R = ratings for the net recharge

R_W = weights assigned to the net recharge

A_R = ratings for the aquifer media

A_W = weights assigned to aquifer media

S_R = ratings for the soil media

S_W= weights assigned to the soil media

T_R = ratings for topography slope

T_W = weights assigned to topography slope

I_R = ratings for the impact of vadose zone

I_W = weights assigned to the impact of vadose zone

C_R= ratings for the hydraulic conductivity

C_W = weights assigned to the hydraulic conductivity

$L1_R$ = ratings for the land use of mineral extraction and dump sites

$L1_w$ = weights assigned to the land use of mineral extraction and dump sites

$L2_R$ = ratings for the land use of other than mineral extraction and dump sites

$L2_w$ = weights assigned to the land use of other than mineral extraction and dump sites

7.1. Depth to Water

The water table is the surface where the fluid pressure in the pores of a porous medium is equal to the atmospheric pressure (Freeze and Cherry, 1979). Depth to water in the DRASTIC method means the distance between the ground surface and the water table. Because any contaminant has to travel through the vadose zone to reach the groundwater, depth to water is one of the significant factors. As deeper water levels allow for longer travel durations, the aquifer is less likely to be contaminated as the water depth increases (Aller et al., 1987).

In this study, water levels in the wells could not be used to obtain the depth to water data because both they are in limited amounts and their current head values are not known. Therefore, the flow model of the basin, explained in detail in the previous chapter was developed in order to obtain the depth to water information. Depth to water information of the basin was obtained by subtracting the hydraulic head values obtained of the model from the topography data distributed to the basin by the kriging interpolation method. The extraction process was completed by extracting the matrix forms of the topography data and hydraulic head data in the Excel environment. Thus, depth to water values distributed over the entire basin were obtained as a point data. Then, the depth to water map of the basin was obtained from this point data using the point to raster method in the GIS environment (Figure 7.1). According to the data obtained, depth to water ranged from 0.3 meters to 1059 meters.

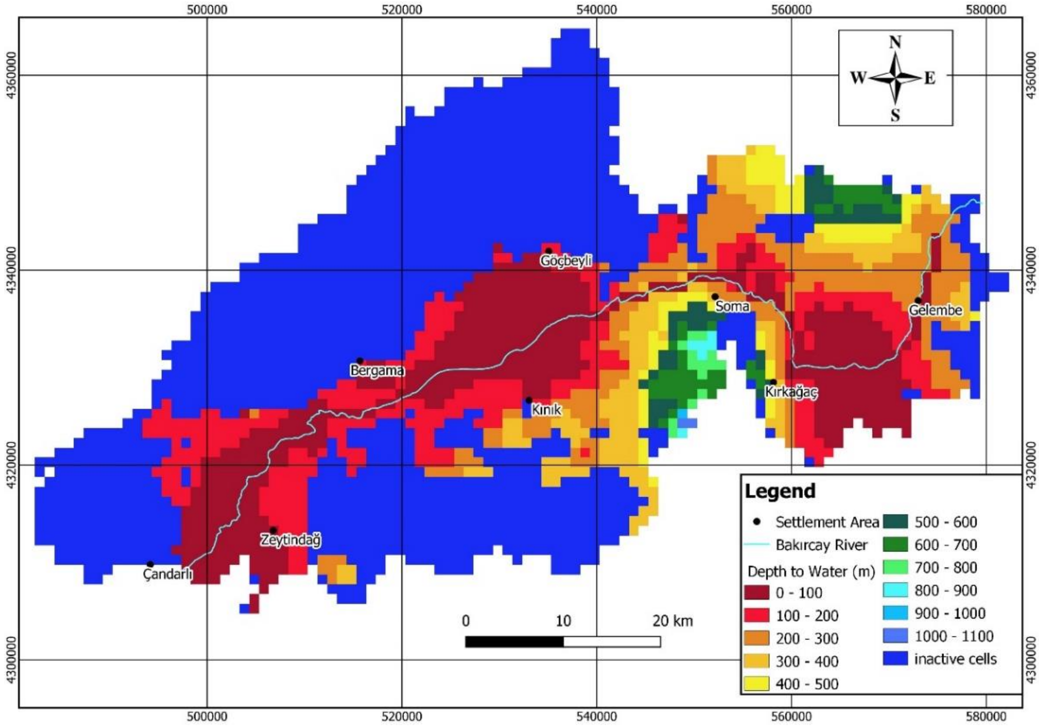


Figure 7.1 Depth to water map of the basin

Rating values were assigned to the depth to water values obtained according to the DRASTIC ranges determined by Aller et al. (1987) (Table 7.2). For the inactive regions of the model the lowest rating is adapted. The map prepared with DRASTIC rates assigned to depth to water values is given in Figure 7.2. Where depth to water increased, the DRASTIC rate decreased. A place with a rate of 1 represents the least contamination potential, while a place with a rate of 10 represents the one with the highest contamination potential. According to the Figure 7.2, high-risk areas to contamination (red color) are seen in the south of the Bergama sub-basin, three dam locations and along the Bakırçay river. When looking at the map in general, low-risk (blue color) ratings are dominant. Aside from the red and blue zones on the map, there are also points indicating medium-risk locations to contamination where the low topographic elevations exist.

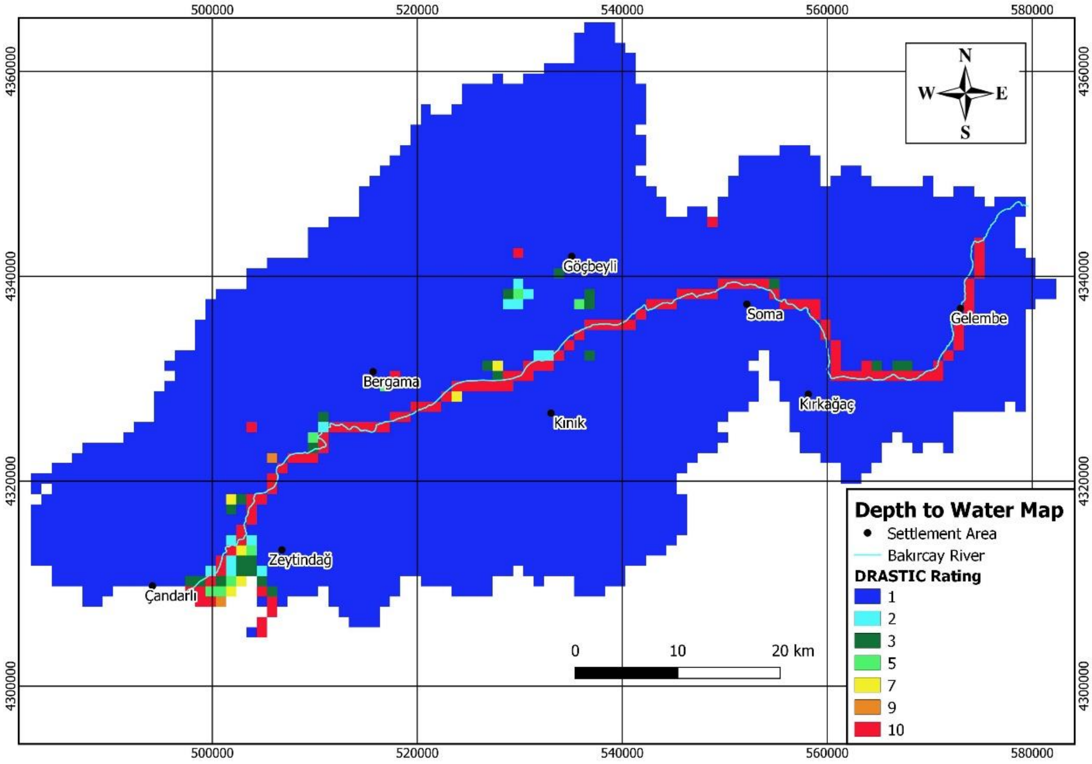


Figure 7.2 Depth to water map with DRASTIC ratings

7.2. Net Recharge

The amount of water that penetrates the ground surface and reaches the water table is referred to as net recharge. This parameter is important because recharge water can transfer a contaminant vertically to the water table and horizontally inside the aquifer. More water leaking in means more recharge chance of possibility for contaminants to be carried into the aquifer is also higher (Aller et al., 1987).

In this study, precipitation recharge values are estimated using the flow model of the basin as explained in detail in the previous chapter (see also Figure 6.6). The recharge values are assigned to the sub-basins with the help of polygons in the flow model. Recharge value is accepted as 0 for inactive cells. Thus, the lowest rating value was assigned to these parts. The recharge information in the point data form obtained from the model was converted into raster data using point to raster in the GIS environment based on the ratings given in Table 7.2. The net recharge map with the drastic rates created is shown in Figure 7.3.

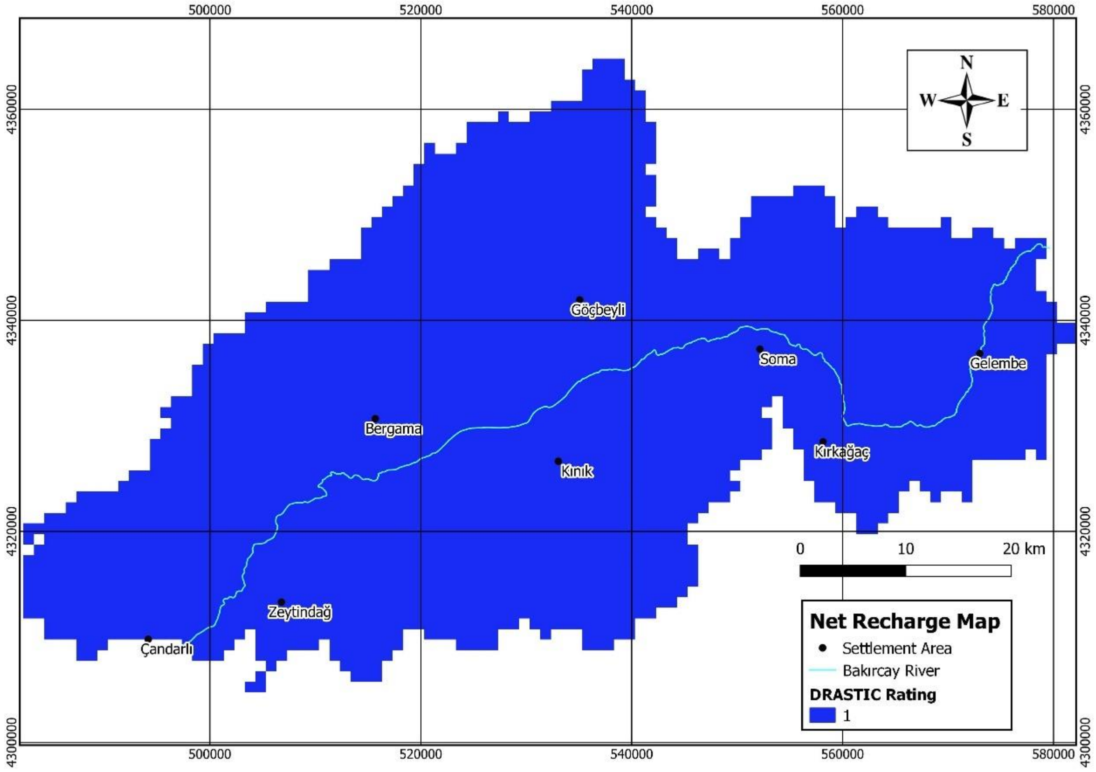


Figure 7.3 Net recharge map with DRASTIC ratings

According to this map, the value of 1 shown as blue color, which is the lowest rating value and represents the least risky contamination potential of aquifer in terms of recharge. Aquifers in whole sub-basins bear low recharge vulnerability.

7.3. Aquifer Media

The consolidated or unconsolidated material that functions as an aquifer is termed as aquifer media (Aller et al., 1987). An aquifer is a saturated permeable geologic unit capable of transmitting considerable amounts of water under common hydraulic gradients (Freeze & Cherry, 1979).

Information about the aquifer media was obtained from previous aquifer studies in the region and the geological map of the Bakırçay basin (DSI, 1976; BSNFB, 2016). According to the aquifer media information, rating values assigned to the lithological units observed in the basin using the original basic rating descriptions listed in Table 7.2 are given in Table 7.4. Then, these rating values were transferred to the GIS environment and aquifer media map of the basin was prepared (Figure 7.4).

Table 7.4 Ranges and rating values for aquifer media

Factor	Range	Rating
Aquifer Media	Metamorphic Rocks, Paleozoic Metamorphics, Volcanic rocks, Ophiolitic Melange, Granite-Granodiorite, Andesite, Basalt, Marble	3
	Conglomerate-Sandstone-Mudstone-Clayey Limestone, Flysch	4
	Neogene Limestone	6
	Mesozoic Limestone	8
	Alluvium	9

It is seen that the orange-colored areas where the alluvium unit is present in this map are the most vulnerable areas. Aquifers in the basin bear from low to high aquifer media vulnerability.

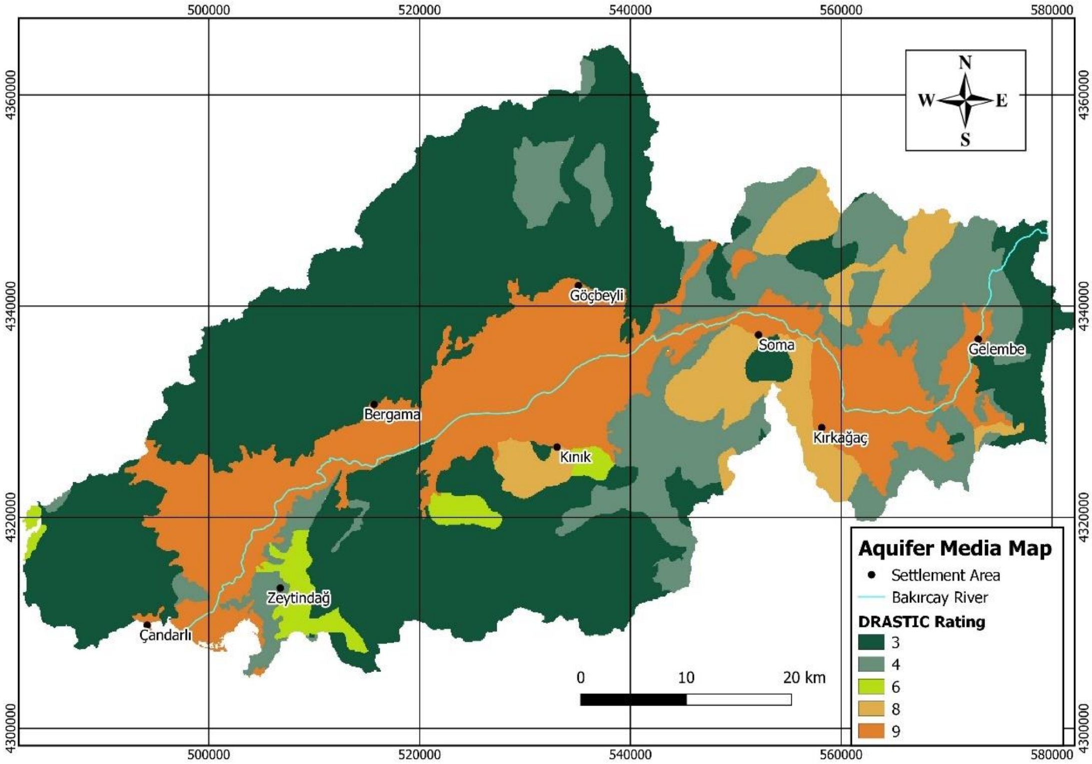


Figure 7.4 Aquifer media map with DRASTIC ratings

7.4. Soil Media

Soil media represents the uppermost weathered portion of the unsaturated zone and controls the amount of recharge that can infiltrate into the ground. Therefore, the capability of a pollutant to travel vertically into the vadose zone is influenced by soil media (Aller et al., 1987).

In coarse textured soils, contaminant enters the soil and moves more easily into larger pores. It takes less time for the water to infiltrate into the soil. In other words, infiltration rate is higher for coarse textured soils than for fine textured soils. As a result, the risk of pollution is higher for coarse textured soils than fine textured soils.

In this study, soil type data of the basin were obtained from Topraksu. The map developed according to this data in GIS environment is given in Figure 7.5. The soil groups of this original dataset were converted to the DRASTIC soil ranges (types) given in Table 7.2. Afterwards, rating values were assigned to each soil range based on the classification made by Aller et al. (1987). Then, these rating values were transferred to the GIS environment and soil media map of the basin was prepared (Figure 7.6).

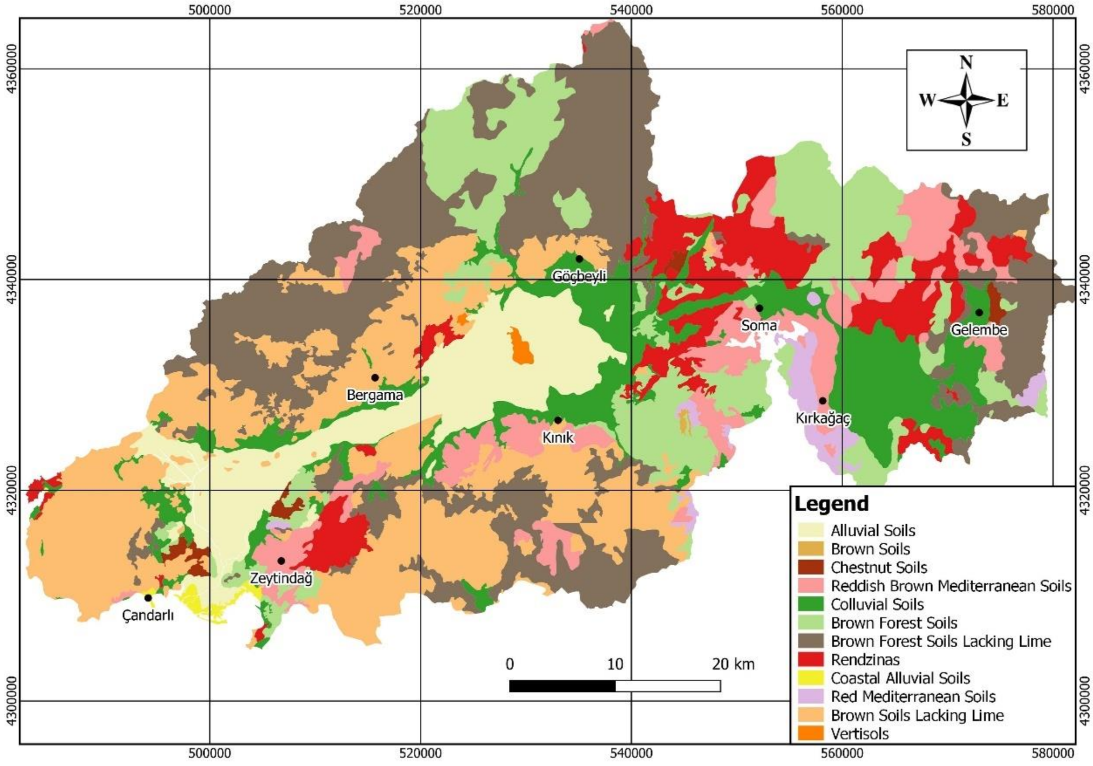


Figure 7.5 Soil map of the basin

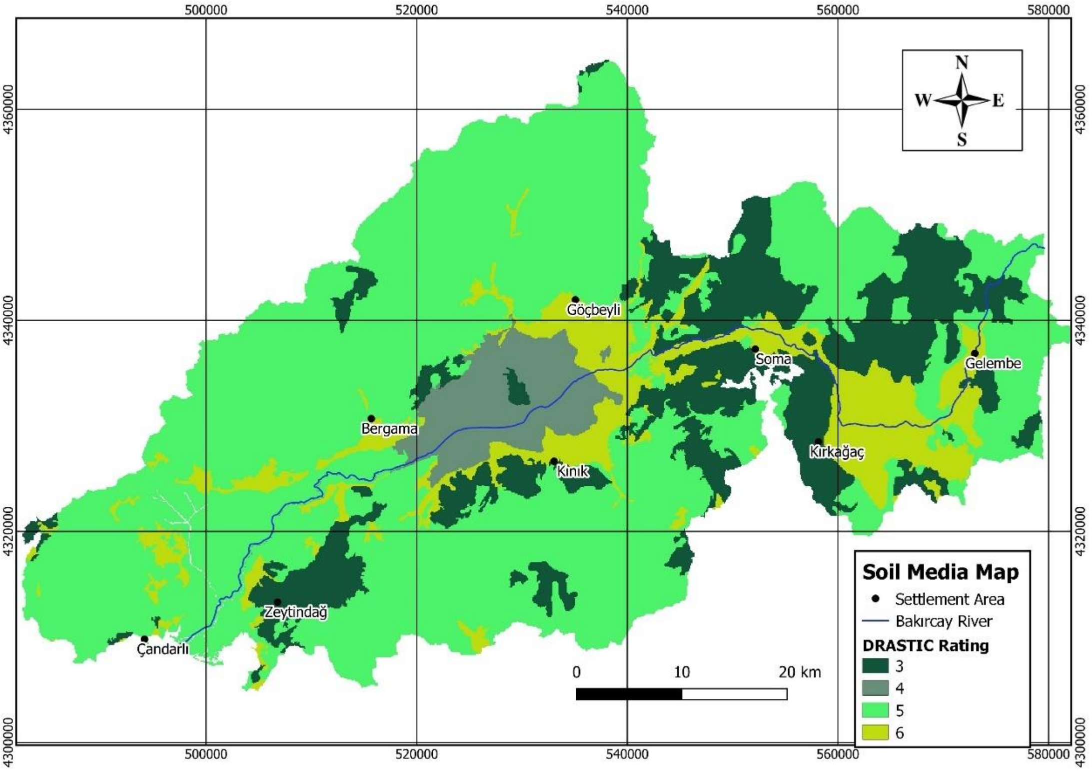


Figure 7.6 Soil media map with DRASTIC ratings

In this map, dark green areas represent low contamination vulnerability, while light green areas indicate areas with high contamination vulnerability. In the whole basin, intermediate soil media vulnerability is dominant.

7.5. Topography Slope

The slope and slope variability of the ground surface is known as topography. The possibility of a contaminant running off or remaining on the surface in one location long enough to infiltrate is controlled by topography (Aller et al., 1987).

Higher degrees of slope increase the amount of runoff. It reduces the potential for groundwater contamination by reducing the chance of contaminant infiltration. On the contrary, there is little runoff in places with low slope which have more time for infiltration, and it means contamination potential is larger.

The slope distribution map of Bakırçay Basin was prepared in GIS environment by using 1/25 000 scaled digital topographic maps (Figure 7.7). According to the slope distribution, the maximum slope is 42^0 in Bakırçay Basin. Relatively high slopes are mostly located at high altitude areas. Based on topography slope (%) ranges given in

Table 7.2, the rating values were assigned and using these rating values in the GIS environment topography slope map of the basin was prepared (Figure 7.8).

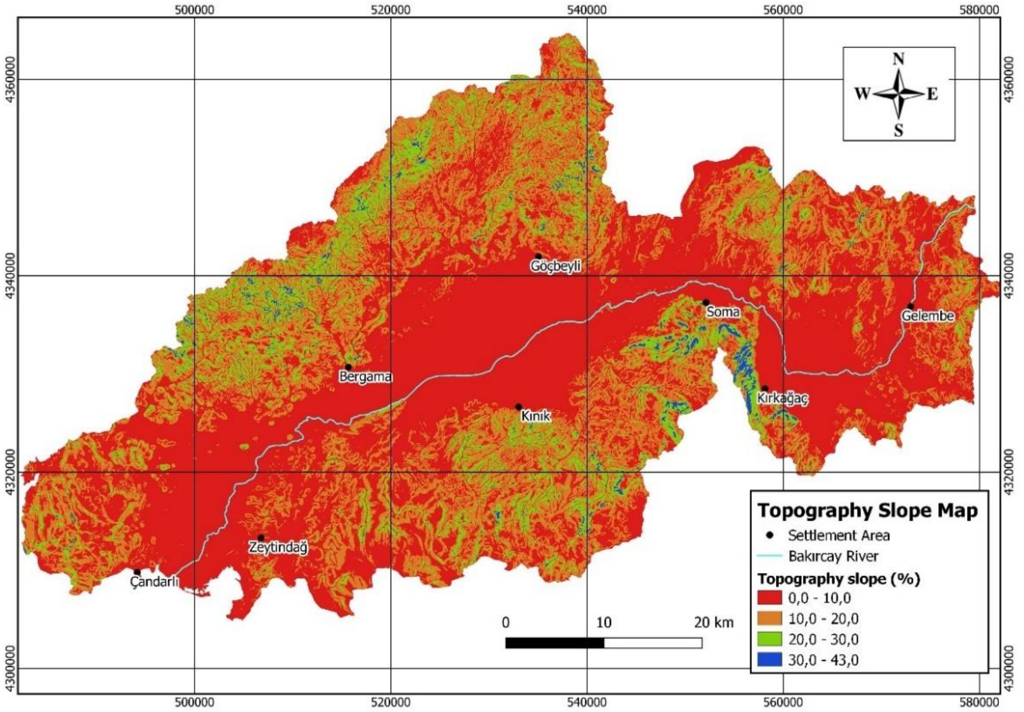


Figure 7.7 Topography slope map of the basin

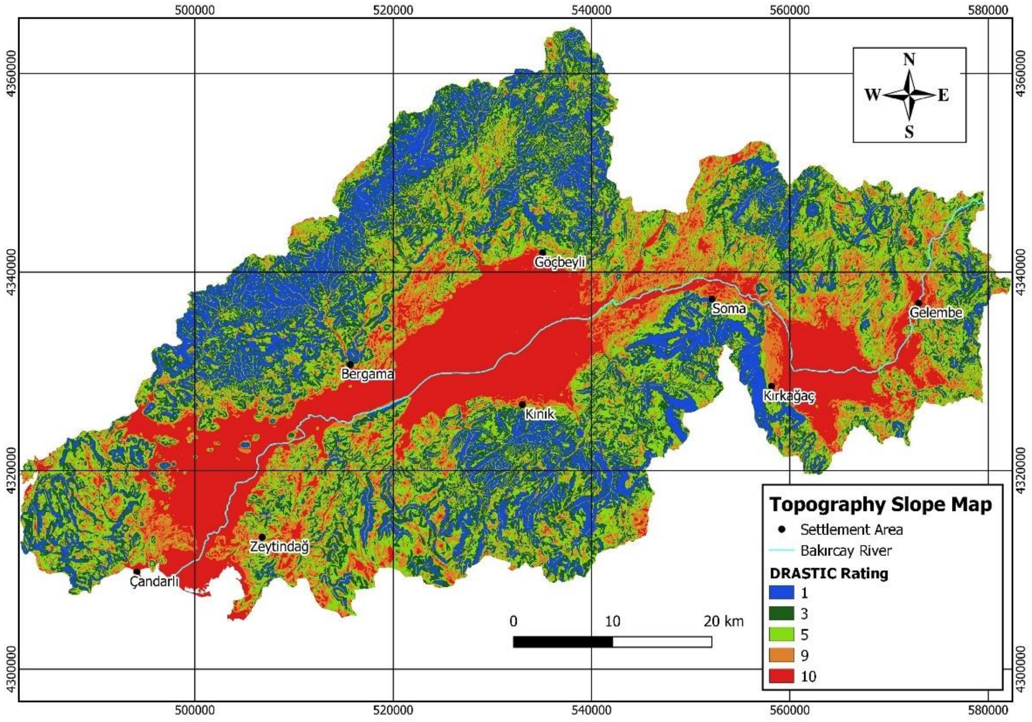


Figure 7.8 Topography slope map with DRASTIC ratings

When the rating map is examined, it is seen that the red colored areas with low slope values are located in alluvium areas which means these areas are the most vulnerable areas to contamination. When looking at the whole basin, green and blue colors are dominant, which represent low contamination potential in terms of topographic slope criteria.

7.6. Impact of Vadose Zone

The water unsaturated zone above the water table is known as the vadose zone. The attenuation characteristic of the material below the usual soil horizon and above the water table is influenced by the type of vadose zone. Within the vadose zone, biodegradation, neutralization, mechanical filtration, chemical reaction, volatilization, and dispersion are all possible processes (Aller et al., 1987). The time it takes for a pollutant to pass through the vadose zone is determined by texture of vadose zone. In unconfined aquifers, the ratings for the vadose zone are generally parallel to the aquifer media (Osborn et al., 1998).

The major aquifer type in the basin is an unconsolidated alluvium aquifer. As in aquifer media, characteristics of the vadose zone were obtained from previous aquifer studies in the region and the geological map of the Bakırçay basin. According to the aquifer media information, rating values are assigned as given in Table 7.4. Then, these rating values were transferred to the GIS environment and impact of vadose zone map was prepared. Naturally, the map is the same as that given for the aquifer media in Figure 7.4.

7.7. Hydraulic Conductivity

The capability of aquifer materials to transmit water, which regulates the pace at which groundwater flows under a particular hydraulic gradient, is known as hydraulic conductivity. The number and interconnection of empty spaces within the aquifer regulate this parameter (Aller et al., 1987). As a result, a high hydraulic conductivity indicates a significant risk of contamination.

In this study, hydraulic conductivity values are estimated using the flow model of the basin as explained in detail in the previous chapter (see also Figure 6.3). The hydraulic conductivity values obtained after model calibration vary between 0 and 10 m/day. In addition, the lowest rate value is assigned to the inactive units in the model. Rate values are assigned to these values according to the Table 7.2. These assigned values have been mapped in the GIS environment and are given in Figure 7.9.

Hydraulic conductivity of the units in the basin falls into either rating 1 or 2 according to the scale. It implies that aquifers bear low contamination vulnerability potential in terms of hydraulic conductivity values being relatively higher in the alluvium areas.

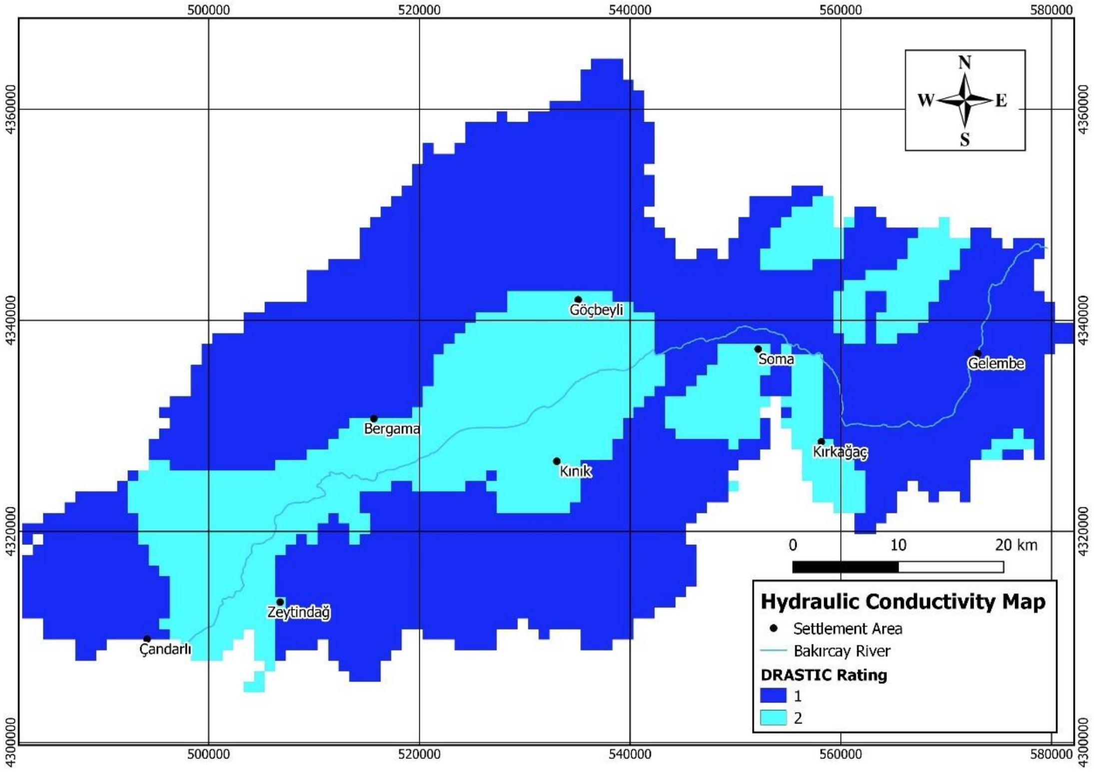


Figure 7.9 Hydraulic conductivity map with DRASTIC ratings

7.8. Land Use

Groundwater vulnerability of the most areas are influenced by land use and human activities. Also, the impact of land use on hydrogeological parameters might be significant (Shirazi et al., 2013). CORINE Land Cover (CLC) developed by the European Environment Agency (European Environment Agency, 2000) was used for land use classification for the study area. As seen on the map in Figure 4.13, there are 26 different land use classes in the basin. These land use classes were grouped among themselves and reduced to 6 groups as mineral extraction and dump site, agricultural, artificial, forest and semi natural areas, water bodies and wetlands. The map prepared based on these groups are shown in Figure 7.10.

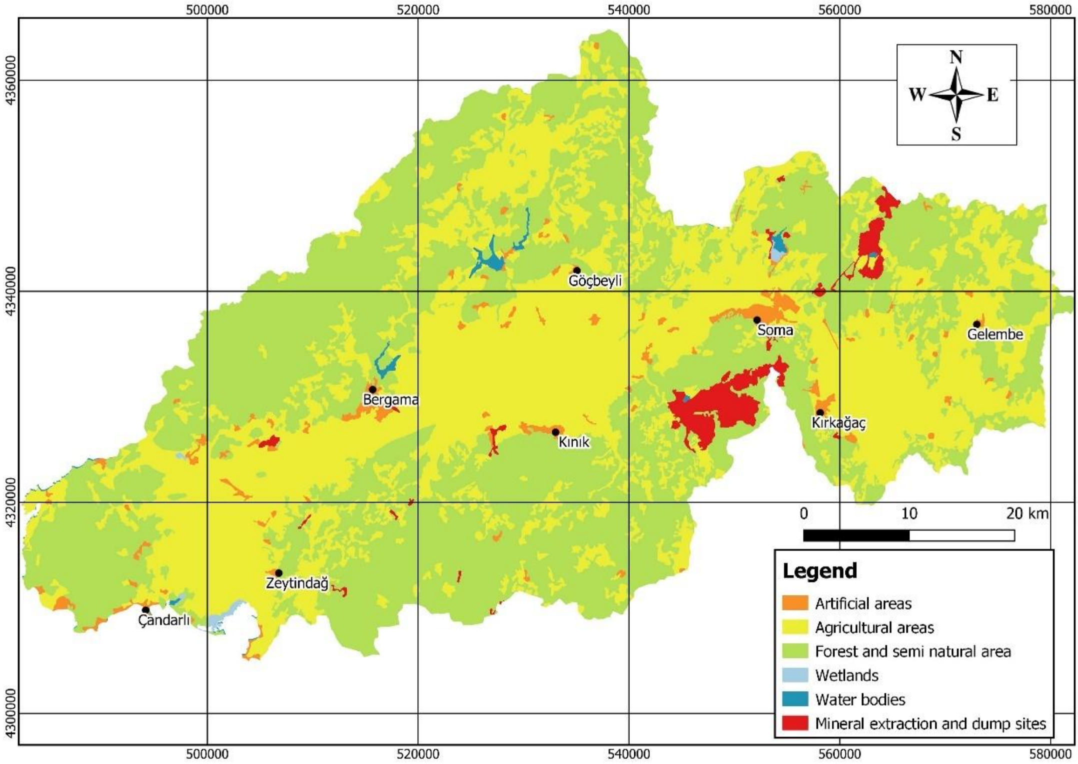


Figure 7.10 Land use map of the basin based on reduced classes

Forest and semi natural areas cover the largest part of the study area with a percentage of 52.6. Agricultural areas follow this with 42.8%. The percentages covered by artificial areas, mineral and dump sites, water bodies and wetlands are 2.2%, 1.9%, 0.4% and 0.2%, respectively.

The land use map was transformed to a raster grid with GIS tool, and rate values were assigned using Table 7.3. The final land use map with DRASTIC rating is shown Figure 7.11.

Looking at the map below, areas of high contamination risk, highlighted in red, represent mineral extraction sites and dump sites. The small red area in the southeast of Bergama is the dump site, and the other red areas are the mineral extraction sites.

Bergama-Ovacık Gold mine and coal mines around Soma are important risk areas seen on the map. Similarly, plains representing agricultural areas shown in orange are vulnerable areas to the contamination. On the other hand, the areas in the basin shown in blue corresponding to mountainous regions have the lowest contamination potential in terms of land use.

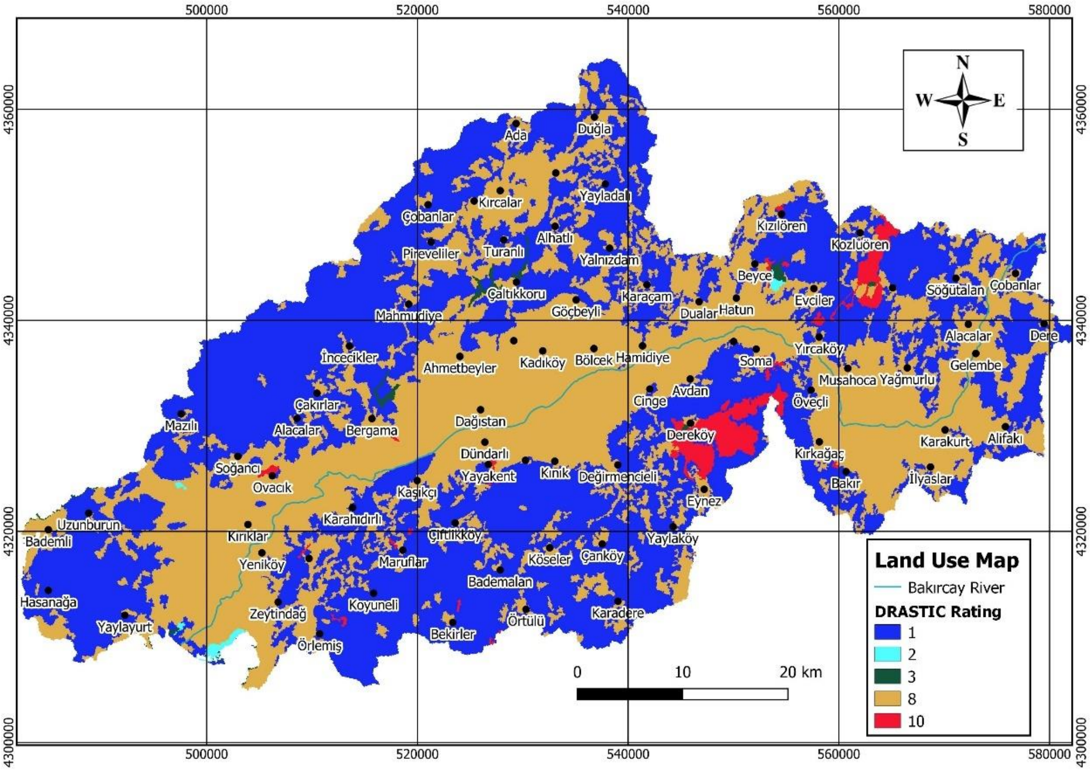


Figure 7.11 Land use map with DRASTIC ratings

7.9. Vulnerability Map with DRASTIC Index

After generating eight layers of maps, the maps were superimposed with respect to previously mentioned DRASTIC index formula using the GIS tool. Vulnerability Index is calculated as a result of this work, and it ranges from 48 to 229.

The original DRASTIC approach, published by Aller et al. (1987), does not give vulnerability categorization ranges, instead allowing the user to interpret the vulnerability index based on their own field knowledge and hydrogeological background (Gogu et al., 2003). The DRASTIC indices are divided into five groups as very low vulnerability (<70), low vulnerability (70-99), medium vulnerability (99–128), high vulnerability (128-157), and very high vulnerability (>157). The vulnerability map of these five different zones is given in Figure 7.12 below.

The vulnerability map given in Figure 7.12 should be interpreted by revealing the effect of all the parameters used. Depth to water is one of the parameters with the highest weight value in the method and its effect on the vulnerability map is therefore high. DRASTIC index values which represent medium to very high vulnerability obtained in these areas are clearly visible on the vulnerability map due to the fact that the water table is close to the surface in the south of Bergama sub-basin, around Zeytindağ, in the middle of Soma-Kınık sub-basin, in Göçbeyli region, and along Bakırçay river. Besides, three dam sites shown as red color represent very high vulnerability this is because depth to water values in these areas are very low. There is also an area of high vulnerability which is colored orange along the alluvial units with high permeability in terms of hydrogeological characteristics in the Bakırçay river bed. In addition, a low to medium vulnerability zone colored green and yellow is observed in areas where Mesozoic and Neogene aged limestone units are located. Besides, the effect of land use, another defining parameter in the study area, is clearly visible in the final vulnerability map. Mining regions that have a high rating in terms of land use become red, which represents very high vulnerability. On the other hand, the blue and green colors seen at the northern, southern, eastern, and western ends of the basin cover the entire basin. These areas are less vulnerable, largely due to the deeper water table and higher slopes which causing surface runoff.

In addition to this vulnerability map, another vulnerability map was prepared using only the original DRASTIC parameters to better illustrate the land use impact. Vulnerability Index ranges from 43 to 154. The DRASTIC indices are divided into five groups as very low vulnerability (<65), low vulnerability (65-87), medium vulnerability (87–109), high vulnerability (109-131), and very high vulnerability (>131). The vulnerability map of these five different zones is given in Figure 7.13 below. When the vulnerability map in Figure 7.12 is compared with the map in Figure 7.13, the red colors representing very high vulnerability in the mining region near

Soma changed to yellow and green (medium and low vulnerability). In addition, while the alluviums bordering the Bakırçay river turned orange (high vulnerability) to yellow (medium vulnerability), the green regions representing low vulnerability with agricultural lands at the northern, southern, eastern, and western ends of the basin turned blue (very low vulnerability). As can be seen, land use is another crucial factor in affecting the vulnerability of groundwater resources to contamination and it should be taken into consideration.

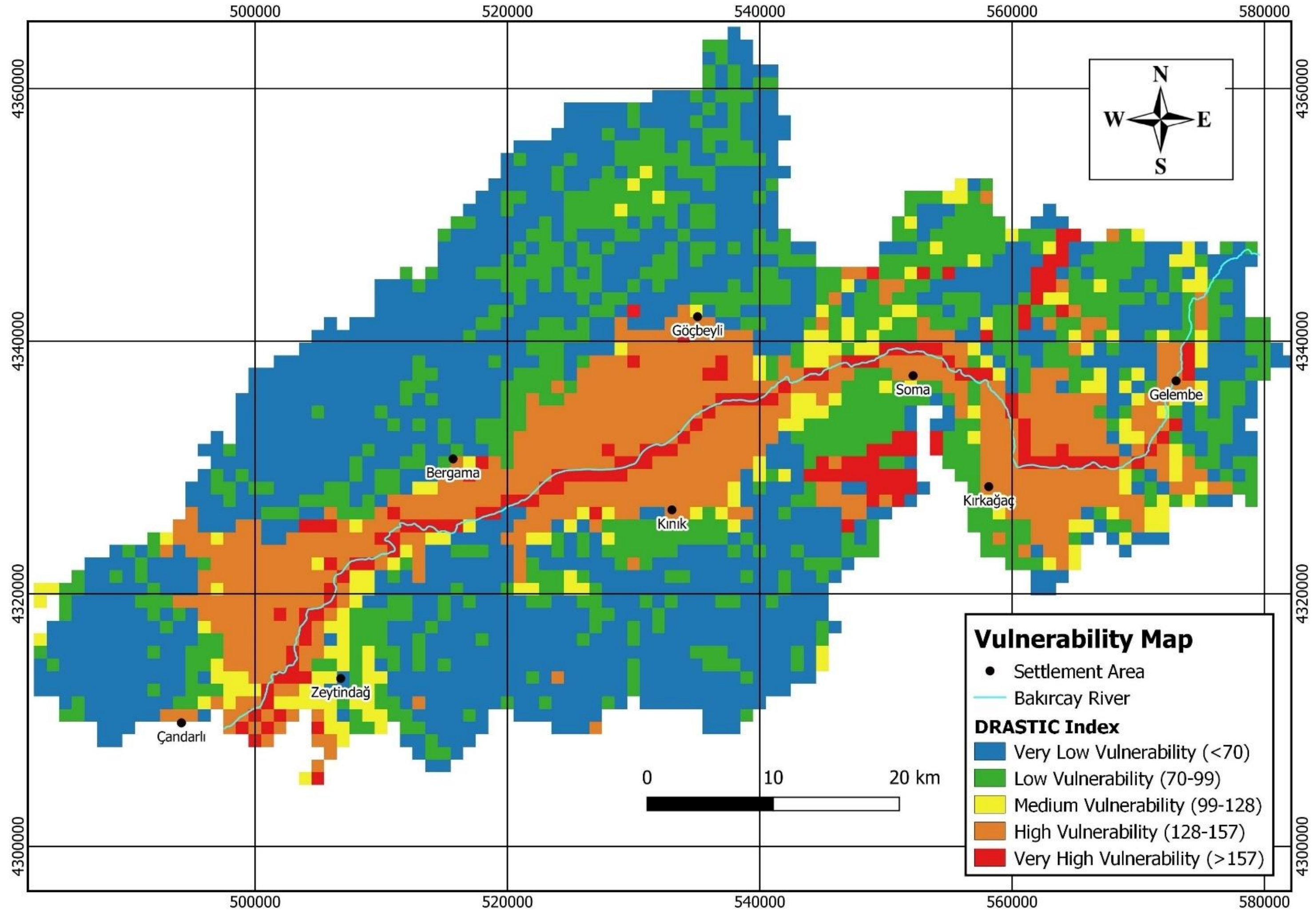


Figure 7.12 Vulnerability map of the Bakırçay basin

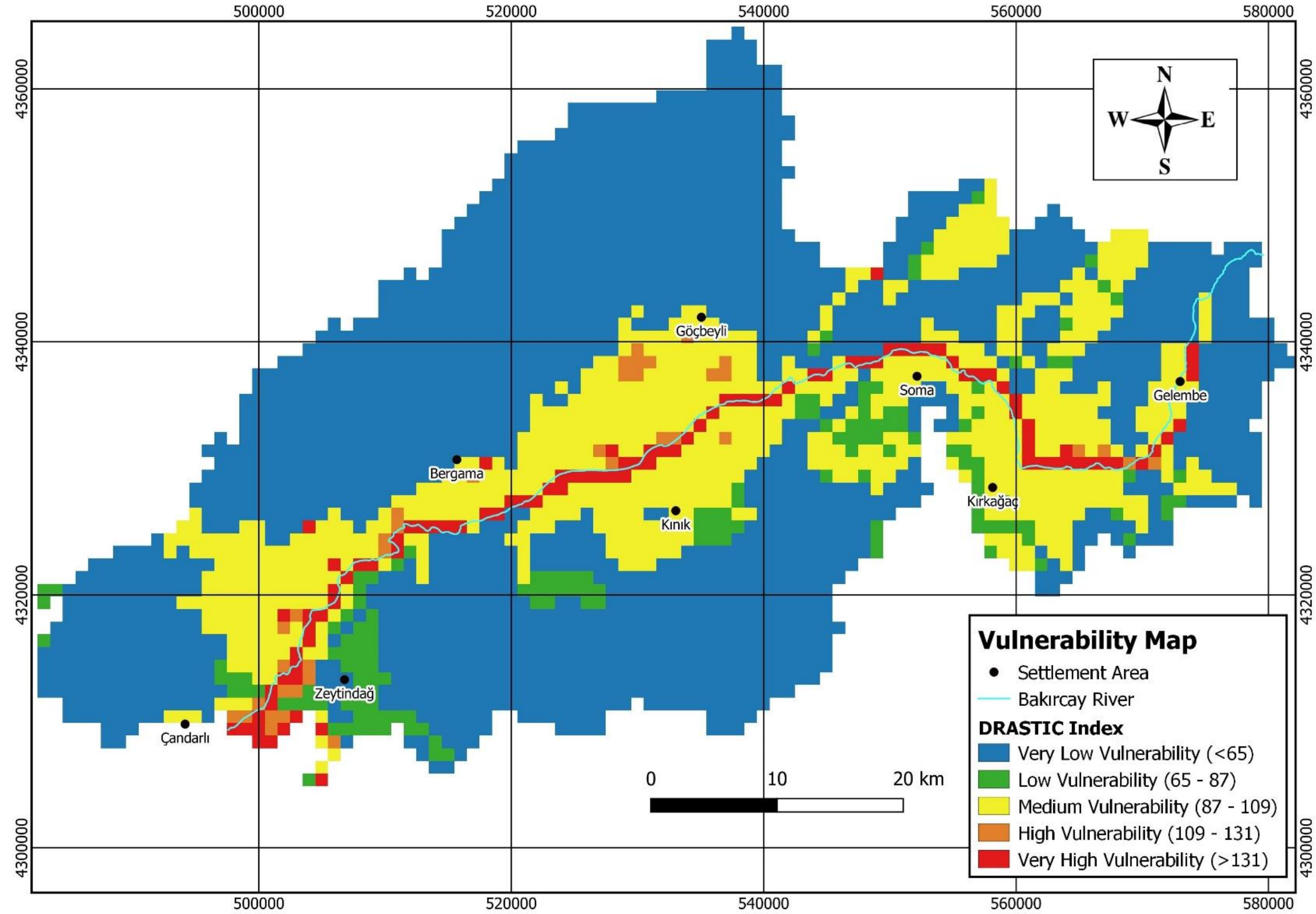


Figure 7.13 Vulnerability map of the Bakırçay basin without land use effect

CHAPTER 8

RESULTS, CONCLUSIONS AND RECOMMENDATIONS

8.1. Results and Conclusions

According to meteorological data in the 1964-2020 time period, while the annual average temperature value increased in all sub-basins, the annual average precipitation value decreased. The recharge values of the basin decreased in parallel with the reduction in precipitation. As a result, a decrease in groundwater levels was also observed according to the results of the groundwater flow model. According to model results showing changes in groundwater levels over time, the level changes for the Bergama, Soma-Kınık, and Kırkağaç sub-basins are 1.7-22.1 m, 0.5-10.1 m, and 3.8-40.2 m, respectively, for the years between 1969 and 2020.

Although, in general, the basin is associated with low-risk areas to contamination, high-risk areas exist in the south of the Bergama sub-basin, three dam locations and along the Bakırçay river.

The recharge values indicate the least risky contamination potential for the aquifers.

According to aquifer and vadose zone media map, the most vulnerable places are where alluvium unit is found in. The vulnerability of the study basin in terms of aquifer media ranges from low to high.

Considering soil map, intermediate soil medium vulnerability is the most prevalent throughout the basin.

The topographic slope evaluations indicate that alluvial areas with low slope values are the most vulnerable to contamination. The other areas indicating a minimal vulnerability.

According to the hydraulic conductivity map, hydraulic conductivity of the units in the basin is rated as 1 or 2 on the scale from 1 to 10. In terms of hydraulic conductivity values, the aquifers have a low contamination vulnerability potential.

Areas of significant contamination risk are associated with the mineral extraction and dump sites. According to land use map, the Bergama-Ovacık Gold Mine and the coal mines around Soma are the most vulnerable regions for possible contamination of the aquifers. Plains indicating agricultural regions have also relatively high vulnerability to the contamination. In terms of land use, the areas corresponding to forest and semi natural areas have the lowest contamination potential.

According to the vulnerability map obtained, Bakırçay river and alluviums in river bed, three dam location, and mining regions in the basin are the most vulnerable areas to contamination. On the other hand, the least vulnerable areas to contamination are seen at the northern, southern, eastern, and western ends of the basin covering the entire basin. According to final DRASTIC vulnerability map, 4.9% of the study area has very high, 20.2% has high, 6.2% has medium, 24.5% has low and the remaining 44.3% of the area has very low contamination vulnerability for the groundwater resources.

In addition to vulnerability map prepared by integrating land use impact into original DRASTIC parameters, another vulnerability map was prepared using only the original DRASTIC parameters to better show the land use impact. When these two vulnerability maps are compared, it is seen that the red colors representing very high vulnerability in the mining region near Soma changed to yellow and green (medium and low vulnerability). Furthermore, while the alluviums bordering the Bakırçay river turned orange (high vulnerability) to yellow (medium vulnerability), the green regions representing low vulnerability with agricultural lands at the northern, southern, eastern, and western ends of the basin turned blue (very low vulnerability).

8.2. Recommendations

It is recommended human activities in the alluvial units especially areas close to the Bakırçay river should be avoided or necessary precautions has to be taken into consideration after environmental impact investigations in small scale. Activity free protection areas along the Bakırçay river channel should be established to avoid possible contamination of the aquifers. In addition, environmental planning should be given importance in order to minimize the effects of mining and industrial activities in the basin that will cause contamination of the aquifer.

In addition to these, it has been observed that there are fewer monitoring wells in Kırkağaç sub-basin in the east of the basin compared to other sub-basins. To get more accurate groundwater level measurements, it is recommended to increase the number of wells in this area.

Finally, it should be noted that vulnerability maps are prepared to shed light on field observations by indicating the zones of vulnerable areas for management activities. These maps cannot replace field activities, they can only be used as an auxiliary tool for further research.

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APPENDICES

A. Meteorological Data and Correlation Graphs

Table A1. Meteorological Data. Blue color: predictions

Bergama Monthly Average Precipitation Values (mm)												
Station Name: Bergama												
Station Number: 17742												
Year	**Jan**	**Feb**	**March**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1964	66.70	75.90	174.00	0.80	17.90	5.20	0.40	2.40	69.10	3.50	89.80	241.70
1965	40.30	267.70	32.70	131.40	83.40	11.50	4.40	6.40	0.00	32.60	111.70	225.60
1966	205.90	29.20	141.60	34.50	23.70	10.40	0.00	62.00	84.80	5.60	98.50	242.80
1967	156.90	48.00	32.40	77.60	52.10	5.50	4.50	1.60	13.50	13.40	21.10	145.60
1968	260.00	66.40	82.20	9.40	12.70	17.50	0.00	29.70	64.40	29.30	43.20	107.50
1969	122.20	100.20	56.80	99.70	20.40	13.10	40.00	0.00	0.00	1.10	9.20	311.90
1970	99.20	207.80	81.90	83.80	41.40	17.90	0.00	0.00	0.00	51.50	49.40	118.50
1971	85.60	165.80	147.90	40.60	40.90	5.10	4.90	0.00	2.00	27.40	153.60	84.90
1972	48.90	44.30	21.30	95.00	25.60	34.50	3.90	10.00	36.00	154.30	35.50	0.20
1973	82.80	178.50	75.40	66.60	10.40	10.10	2.50	5.90	0.90	28.20	43.50	93.40
1974	20.30	80.70	107.50	27.30	16.90	1.20	0.20	12.40	10.10	23.20	149.60	164.70
1975	125.50	48.30	132.50	52.70	86.80	44.30	8.60	9.90	1.00	62.30	111.20	94.20
1976	57.00	97.40	51.20	116.80	23.00	20.20	28.10	53.50	10.90	124.90	82.70	90.80
1977	93.30	73.00	22.60	34.40	26.20	10.20	3.00	0.00	41.50	61.10	94.10	109.20
1978	145.30	167.30	98.70	112.30	34.80	0.50	0.00	0.00	109.50	54.80	67.30	23.40
1979	148.90	103.30	33.70	28.00	68.90	25.60	0.00	5.30	1.40	19.80	157.50	87.90
1980	181.40	7.30	79.90	88.30	40.40	43.40	0.30	0.00	0.30	2.40	114.30	154.90
1981	222.00	43.80	51.30	13.20	50.10	0.00	0.50	0.00	21.20	19.70	124.40	316.20
1982	73.40	60.00	53.40	84.20	76.90	0.00	2.10	0.00	0.00	69.70	46.00	138.20
1983	55.50	122.40	24.40	34.10	63.30	9.40	38.70	1.50	0.10	21.80	153.70	84.60
1984	171.70	58.60	117.80	100.90	0.30	1.30	0.40	11.60	1.40	0.00	94.70	45.20
1985	140.50	43.20	119.50	3.80	45.60	8.50	0.00	0.00	0.00	43.60	167.60	29.40
1986	229.60	125.90	14.20	66.00	2.70	13.60	0.00	0.00	14.60	33.90	35.40	240.90
1987	210.50	97.70	66.20	58.30	16.70	11.60	0.20	0.60	0.00	2.80	165.60	127.30
1988	24.70	78.20	103.20	18.90	27.40	74.40	0.00	0.00	8.30	15.10	233.50	124.00
1989	8.10	1.00	77.30	24.60	49.00	12.20	0.50	0.20	18.90	36.20	98.90	159.70
1990	1.10	28.20	15.80	62.30	7.90	12.00	0.00	0.30	3.60	26.90	15.70	216.80
1991	42.00	46.80	34.60	40.30	114.20	1.60	7.50	0.00	2.40	33.70	38.70	74.60
1992	0.00	21.60	75.50	68.20	4.20	33.00	15.70	0.00	0.00	31.10	65.20	103.90
1993	54.60	105.20	59.10	60.30	61.90	4.10	10.00	0.00	2.10	21.30	75.60	79.70
1994	72.30	48.40	34.00	41.20	29.90	9.80	0.00	0.00	0.00	86.60	74.40	86.10
1995	191.30	27.60	149.80	63.20	0.20	3.00	11.00	8.60	22.00	11.00	73.70	58.50
1996	17.00	145.10	83.20	91.00	3.70	0.30	0.00	32.80	99.40	13.10	67.80	112.00
1997	51.90	17.40	82.50	85.40	8.00	20.70	0.10	18.50	0.00	117.40	45.00	238.60
1998	130.70	79.60	80.80	18.10	110.40	28.00	22.30	0.00	60.80	115.90	170.00	88.30
1999	81.10	198.10	103.80	25.80	1.40	7.90	18.10	0.00	0.00	28.50	103.70	105.10
2000	53.80	86.00	64.20	70.30	5.30	0.00	0.00	0.40	0.00	90.80	66.10	24.60
2001	53.50	109.40	5.10	42.20	32.70	0.00	23.40	0.30	16.20	0.50	176.30	183.50
2002	52.20	56.50	81.20	69.60	3.70	3.10	11.40	9.00	30.00	53.40	179.30	109.90
2003	105.90	103.00	21.80	77.40	16.40	0.00	0.00	0.10	13.50	111.70	9.20	42.30
2004	177.10	33.20	13.10	36.20	16.70	32.50	0.00	0.00	0.20	0.00	92.60	88.10
2005	103.10	161.70	89.50	34.40	29.40	31.40	5.10	34.40	32.60	9.10	171.40	93.10
2006	47.50	100.10	108.40	18.50	11.00	23.50	4.10	0.00	39.70	67.30	11.60	8.10
2007	26.30	42.00	46.50	28.30	18.30	18.50	0.00	0.00	0.50	52.60	97.10	144.10
2008	38.00	8.90	72.90	42.10	12.00	1.10	0.00	0.90	37.40	14.00	57.00	78.30
2009	197.10	206.40	147.10	101.10	54.40	42.90	10.60	0.00	26.50	40.50	135.40	166.90
2010	116.50	245.60	32.00	53.80	15.40	33.90	8.60	0.00	19.60	240.20	86.50	172.40
2011	43.40	57.20	10.00	72.00	33.60	1.80	0.20	0.00	9.40	0.00	0.60	81.20
2012	0.00	0.00	21.40	105.00	71.00	14.20	0.20	0.00	8.40	66.40	54.80	275.40
2013	211.20	111.80	81.80	50.60	13.80	22.60	0.00	0.00	20.40	96.20	134.80	9.40
2014	87.20	6.40	50.80	127.00	10.60	45.40	1.40	25.00	32.20	48.40	29.80	179.60
2015	127.20	80.40	98.70	35.60	18.30	20.60	0.20	0.00	14.30	105.50	58.60	0.20
2016	180.20	54.00	53.40	12.40	61.40	21.80	0.00	0.00	2.00	6.80	129.60	10.80
2017	208.60	50.80	75.20	36.20	56.20	14.20	14.00	2.60	0.20	50.80	61.00	128.60
2018	62.40	109.00	79.60	11.60	17.80	42.80	43.20	0.00	15.60	17.20	75.40	87.40
2019	225.80	87.20	23.60	83.00	5.60	4.40	29.60	2.00	7.40	84.40	65.20	64.20
2020	33.20	80.80	37.40	37.60	53.20	12.80	0.00	0.40	0.00	62.00	0.20	109.20

Soma Monthly Average Precipitation Values (mm)

Station Name: Soma

Station Number: 4575

Year	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1964	28.40	74.40	155.20	0.00	52.50	2.00	0.00	2.10	64.20	1.10	68.40	223.60
1965	28.50	294.60	41.60	120.70	99.30	0.90	2.30	9.20	0.00	27.70	119.10	164.70
1966	163.80	48.80	139.40	37.20	41.90	21.10	1.20	39.60	63.80	4.40	59.80	197.80
1967	151.30	35.50	38.30	74.30	15.80	6.90	0.00	0.00	5.90	25.60	15.30	106.10
1968	241.90	80.90	67.70	15.70	22.20	12.70	0.00	32.50	54.30	15.90	39.60	95.60
1969	153.00	97.00	49.00	58.40	63.30	25.10	83.00	0.00	0.00	0.30	13.50	277.90
1970	83.90	145.70	63.60	60.20	19.30	19.00	0.00	0.00	0.30	46.40	66.00	97.80
1971	81.00	135.40	125.80	44.50	7.40	23.20	5.70	0.00	7.50	37.30	87.20	79.70
1972	34.20	40.40	30.00	93.80	23.00	16.30	64.40	12.70	25.90	92.70	41.40	0.00
1973	70.90	186.20	74.00	77.50	10.80	8.80	0.00	4.50	2.70	23.40	76.50	96.10
1974	23.80	104.90	83.80	28.50	34.50	2.30	0.00	67.00	3.40	11.70	90.70	125.50
1975	115.30	43.90	80.40	40.30	107.60	63.20	0.00	1.10	7.00	30.60	137.80	78.70
1976	65.10	51.30	31.20	105.90	50.20	22.30	27.70	7.80	6.30	119.60	59.00	86.50
1977	74.30	51.90	62.20	46.40	4.90	2.00	0.80	0.00	25.80	74.70	59.00	82.30
1978	150.00	125.80	76.80	114.80	50.00	3.10	0.00	0.00	146.60	55.40	95.90	33.00
1979	151.90	79.40	26.90	36.10	50.50	11.30	10.50	11.60	2.50	45.00	96.10	90.80
1980	162.10	20.70	96.60	79.90	45.60	59.80	0.00	0.00	0.00	4.30	95.40	163.80
1981	199.90	46.90	51.30	10.80	77.40	6.40	2.90	0.00	22.70	24.70	131.80	238.88
1982	78.42	64.94	55.94	78.41	98.85	5.43	2.55	3.22	1.87	59.56	46.48	116.08
1983	64.13	118.87	33.19	40.29	82.38	12.28	45.09	3.88	1.96	26.28	114.68	79.10
1984	156.88	63.73	106.44	91.11	6.07	6.37	0.57	8.33	3.25	11.14	77.32	51.92
1985	131.98	50.42	107.77	17.25	60.94	11.63	0.11	3.22	1.87	41.43	123.48	41.02
1986	203.10	121.89	25.20	64.56	8.98	15.35	0.11	3.22	16.30	34.69	39.77	186.93
1987	187.85	97.52	65.97	58.70	25.94	13.89	0.34	3.49	1.87	13.08	122.21	108.56
1988	39.55	80.67	94.99	28.73	38.90	59.69	0.11	3.22	10.07	21.63	165.21	106.29
1989	26.30	13.95	74.68	33.07	65.06	14.33	0.69	3.31	20.56	36.29	79.98	130.92
1990	20.71	37.46	26.45	61.75	15.28	14.18	0.11	3.35	5.43	29.83	27.29	170.31
1991	53.36	53.53	41.19	45.01	144.03	6.59	8.82	3.22	4.24	34.55	41.86	72.20
1992	19.83	31.76	73.27	66.23	10.80	29.50	18.35	3.22	1.87	32.74	58.64	92.42
1993	63.41	104.00	60.41	60.23	80.68	8.42	11.73	3.22	3.94	25.94	65.22	75.72
1994	77.54	54.92	40.72	45.70	41.93	12.57	0.11	3.22	1.87	71.30	64.46	80.14
1995	172.53	36.94	131.53	62.43	5.95	7.61	12.89	7.01	23.62	18.78	64.02	61.10
1996	33.40	138.49	79.31	83.58	10.19	5.65	0.11	17.65	100.17	20.24	60.28	98.01
1997	61.26	28.13	78.76	79.32	15.40	20.53	0.22	11.36	1.87	92.70	45.85	185.35
1998	154.80	62.80	97.60	48.60	219.90	8.90	21.00	0.00	31.80	102.80	141.30	108.40
1999	80.90	265.30	106.30	47.60	0.00	1.00	0.00	15.40	2.10	59.90	79.30	110.30
2000	68.00	90.80	97.30	74.40	1.00	1.60	0.00	0.00	0.00	40.80	61.40	31.00
2001	62.70	87.90	20.20	99.00	39.30	0.00	0.00	4.00	25.50	1.00	149.80	176.90
2002	61.50	20.10	93.20	95.20	2.50	2.70	3.00	3.80	76.50	34.70	123.60	103.30
2003	69.60	137.70	25.00	85.10	9.20	0.00	0.00	0.00	15.00	45.20	34.70	70.00
2004	193.80	39.80	18.50	29.10	40.10	9.70	0.00	2.50	3.00	1.20	63.90	53.00
2005	88.70	137.30	64.80	46.90	34.50	34.10	16.80	0.00	4.80	10.50	133.50	77.00
2006	57.70	90.50	84.60	10.70	4.60	8.50	2.20	0.00	61.90	79.60	29.50	11.00
2007	32.80	45.50	39.90	23.20	49.70	29.80	0.00	0.00	2.50	111.00	107.20	93.60
2008	54.60	20.80	71.50	54.00	74.70	36.50	0.00	1.00	34.90	22.60	51.40	76.60
2009	182.60	190.40	164.00	87.10	54.80	10.50	0.00	2.00	81.00	33.00	88.20	144.10
2010	139.20	231.10	48.90	53.40	32.90	45.00	2.50	1.30	22.40	211.20	31.90	184.30
2011	80.10	81.50	36.70	76.50	90.20	50.90	0.00	0.00	28.30	90.20	1.00	117.30
2012	112.70	144.40	25.00	76.60	75.30	3.20	0.00	3.22	10.17	0.00	8.70	95.90
2013	167.40	90.00	92.60	36.80	5.80	4.90	0.00	0.00	1.00	72.30	81.50	10.40
2014	50.60	6.20	36.70	99.10	59.90	61.50	0.00	9.90	30.60	49.30	51.80	103.50
2015	104.80	82.57	55.00	42.40	49.00	45.90	2.20	8.20	58.50	74.60	78.50	1.20
2016	106.30	40.80	134.50	26.00	50.10	42.40	3.70	0.00	21.10	7.10	89.80	12.30
2017	167.70	68.40	36.00	18.40	34.50	28.70	3.80	4.50	29.70	46.50	39.00	73.40
2018	49.00	88.60	75.60	9.40	22.10	48.90	7.90	2.80	4.30	21.60	73.80	58.90
2019	246.70	68.00	30.60	57.30	26.20	33.10	25.00	0.00	5.20	37.50	18.90	43.10
2020	24.40	68.40	15.40	33.70	82.10	72.60	1.50	0.00	0.10	27.20	10.60	60.10

Table A1 continued

Kınık Monthly Average Precipitation Values (mm)

Station Name: Kınık

Station Number: 4747

Year	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1964	43.40	86.50	142.20	10.90	24.50	26.40	0.00	1.90	63.40	0.60	50.80	179.90
1965	28.50	235.10	37.70	100.00	82.20	6.30	10.20	0.50	0.00	32.40	114.80	146.00
1966	174.80	44.70	139.10	31.60	16.20	6.90	0.00	44.00	25.90	2.90	64.10	193.30
1967	124.80	43.40	34.00	65.90	9.50	3.00	0.00	0.00	0.00	15.70	19.90	114.70
1968	178.20	62.60	61.60	12.90	9.50	8.00	0.00	21.70	84.70	15.30	48.00	77.30
1969	120.80	100.80	46.00	43.70	20.60	17.50	49.90	0.00	0.00	2.50	11.40	271.30
1970	67.80	155.30	70.60	41.60	27.20	8.50	0.00	0.00	0.00	68.10	56.20	90.70
1971	86.90	133.80	147.00	34.80	3.30	14.30	3.40	0.00	6.70	48.20	86.30	89.00
1972	38.70	47.10	28.60	83.30	23.30	83.30	0.00	24.60	39.90	139.80	39.60	0.00
1973	57.80	145.50	60.50	68.00	5.50	5.30	25.10	0.60	1.00	32.70	43.10	89.10
1974	8.80	55.60	75.30	28.10	23.70	0.00	0.00	6.60	17.40	14.00	105.80	113.10
1975	124.60	38.80	63.80	48.70	66.20	29.10	0.00	2.70	1.50	24.90	87.60	70.00
1976	40.40	35.40	43.20	100.70	34.80	25.00	21.30	22.00	5.40	122.50	51.70	78.00
1977	73.30	41.90	37.70	37.90	11.20	26.50	2.00	0.00	36.60	62.70	67.70	78.70
1978	141.60	120.40	73.00	105.10	37.50	3.30	0.00	0.00	131.20	45.40	75.50	28.10
1979	113.50	74.90	26.40	23.10	30.00	4.60	54.30	0.00	0.00	27.50	81.30	71.40
1980	144.90	12.10	94.50	61.10	14.90	32.40	0.00	0.00	0.60	4.40	80.30	137.90
1981	171.60	40.60	44.20	17.60	58.70	0.00	0.60	0.00	12.80	32.20	102.50	310.10
1982	79.30	48.30	57.40	85.00	68.00	0.00	8.50	0.00	0.00	69.90	31.80	98.10
1983	47.30	88.20	8.90	33.20	96.90	9.00	78.40	2.70	0.10	24.60	167.90	80.10
1984	138.60	60.30	88.90	115.00	0.10	1.50	2.30	0.50	2.50	0.00	70.40	20.40
1985	113.53	35.68	82.70	4.30	18.30	12.90	0.10	0.00	0.00	46.50	115.70	30.60
1986	149.20	106.60	40.90	45.90	6.10	47.70	1.80	0.00	4.80	29.90	37.50	168.10
1987	170.90	62.20	46.30	75.00	14.00	22.10	0.00	0.00	0.00	16.60	144.00	83.70
1988	18.60	74.90	102.40	16.50	15.60	19.00	0.00	0.00	0.00	33.00	114.10	102.90
1989	6.80	1.00	77.50	17.30	41.30	23.00	0.00	0.00	12.10	29.40	74.10	166.70
1990	4.30	37.90	13.60	71.90	5.30	11.10	0.00	1.80	5.90	23.20	13.20	176.30
1991	30.10	26.20	22.40	52.90	86.40	1.50	4.40	0.00	3.50	41.10	24.40	78.70
1992	0.50	28.80	53.50	22.40	3.30	29.80	5.40	0.00	0.00	48.70	56.00	103.30
1993	51.70	84.90	58.20	56.40	45.70	10.80	15.10	0.00	15.10	15.10	55.90	75.40
1994	53.70	44.40	19.80	31.50	21.70	9.70	0.00	0.00	0.00	63.20	71.30	78.60
1995	184.10	7.90	132.10	60.40	3.60	7.40	1.30	10.90	55.60	6.20	89.20	47.10
1996	12.20	101.60	79.30	48.40	7.20	0.00	0.00	6.50	100.00	8.50	39.90	49.90
1997	61.60	0.50	81.50	118.60	6.00	1.00	0.00	0.00	0.48	101.00	44.10	201.00
1998	116.50	54.20	82.90	29.80	117.80	21.74	12.60	0.00	58.57	104.10	117.25	71.72
1999	67.41	156.22	87.57	26.96	0.00	11.60	22.92	0.00	0.48	28.87	77.78	85.56
2000	46.21	68.98	56.79	60.66	3.22	7.61	1.32	0.19	0.48	82.50	55.39	19.26
2001	45.98	87.19	10.86	39.38	26.46	7.61	29.25	0.14	15.96	4.77	121.00	150.13
2002	44.97	46.03	70.00	60.13	1.86	9.17	14.93	4.85	29.14	50.30	122.78	89.51
2003	86.67	82.21	23.84	66.03	12.63	7.61	1.32	0.03	13.38	100.49	21.52	33.84
2004	141.95	27.89	17.08	34.84	12.89	24.02	1.32	0.00	0.67	4.34	71.17	71.56
2005	84.49	127.89	76.46	33.48	23.66	23.46	7.41	18.59	31.63	12.17	118.08	75.68
2006	41.32	79.96	91.14	21.44	8.05	19.47	6.22	0.00	38.41	62.27	22.95	5.67
2007	24.86	34.74	43.04	28.86	14.25	16.95	1.32	0.00	0.95	49.62	73.85	117.68
2008	33.94	8.98	63.55	39.31	8.90	8.16	1.32	0.46	36.21	16.39	49.98	63.49
2009	157.48	162.68	121.22	83.98	44.86	29.27	13.97	0.00	25.80	39.20	96.65	136.46
2010	94.90	193.18	31.77	48.16	11.79	24.72	11.59	0.00	19.20	211.10	67.54	140.99
2011	38.14	46.57	14.67	61.95	27.22	8.52	1.56	0.00	9.46	4.34	16.40	65.88
2012	4.44	2.06	23.53	86.93	58.94	14.78	1.56	0.00	8.50	61.49	48.67	225.82
2013	168.43	89.06	70.47	45.74	10.43	19.02	1.32	0.00	19.97	87.15	96.29	6.74
2014	72.15	7.04	46.38	103.59	7.71	30.53	2.99	13.51	31.24	46.00	33.78	146.92
2015	103.21	64.62	83.61	34.38	14.25	18.01	1.56	0.00	14.14	95.15	50.93	0.00
2016	144.36	44.08	48.40	16.82	50.80	18.61	1.32	0.00	2.39	10.19	78.50	18.60
2017	173.20	48.20	47.20	14.40	51.40	87.40	0.40	0.80	0.20	32.80	46.00	83.80
2018	57.20	104.40	69.60	13.40	36.00	52.60	50.80	1.00	10.80	18.20	72.80	83.00
2019	218.80	87.20	35.20	80.40	11.20	64.80	31.80	0.20	7.60	54.20	22.00	54.40
2020	44.20	83.80	27.80	38.80	85.40	44.60	0.00	0.00	0.00	46.00	4.80	62.40

Table A1 continued

Kırkağaç Monthly Average Precipitation Values (mm)

Station Name: Kırkağaç

Station Number: 4749

Year	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1964	49.93	95.59	175.79	21.74	73.85	23.72	21.74	23.82	85.46	22.83	89.63	243.68
1965	50.03	314.16	63.03	141.54	120.30	22.63	24.02	30.87	21.74	49.23	139.96	185.22
1966	184.32	70.18	160.11	58.66	63.33	42.68	22.93	61.04	85.06	26.10	81.09	218.07
1967	171.92	56.97	59.75	95.49	37.42	28.59	21.74	21.74	27.59	47.15	36.92	127.05
1968	261.85	102.04	88.94	37.32	43.77	34.34	21.74	54.00	75.64	37.52	61.04	116.63
1969	173.60	118.02	70.37	79.70	84.57	46.65	104.12	21.74	21.74	22.03	35.14	297.58
1970	105.02	166.36	84.87	81.49	40.89	40.60	21.74	21.74	22.03	67.79	87.25	118.81
1971	102.14	156.14	146.61	65.91	29.08	44.77	27.39	21.74	29.18	58.76	108.29	100.85
1972	55.68	61.84	51.52	114.84	44.57	37.92	85.66	34.34	47.45	113.75	62.83	21.74
1973	92.11	206.56	95.19	98.66	32.46	30.47	21.74	26.20	24.42	44.96	97.67	117.13
1974	45.36	125.86	104.92	50.03	55.98	24.02	21.74	88.24	25.11	33.35	111.77	146.31
1975	136.18	65.31	101.54	61.74	128.54	84.47	21.74	22.83	28.69	52.11	158.52	99.85
1976	86.36	72.66	52.71	126.85	71.57	43.87	49.23	29.48	27.99	140.45	80.30	107.60
1977	95.49	73.25	83.48	67.79	26.60	23.72	22.53	21.74	47.35	95.88	80.30	103.43
1978	170.63	146.61	97.97	135.69	71.37	24.81	21.74	21.74	167.25	76.73	116.93	54.49
1979	172.51	100.55	48.44	57.57	71.86	32.95	32.16	33.25	24.22	66.40	117.13	111.87
1980	182.64	42.28	117.62	101.05	67.00	81.09	21.74	21.74	21.74	26.01	116.43	184.32
1981	220.16	68.29	72.66	32.46	98.56	28.09	24.62	21.74	44.27	46.25	152.56	258.85
1982	99.58	86.20	77.26	99.56	119.86	27.12	24.27	24.94	23.59	80.86	67.87	136.96
1983	85.39	139.73	54.69	61.73	103.51	33.93	66.49	25.59	23.69	47.83	135.56	100.26
1984	177.46	85.00	127.39	112.17	27.77	28.06	22.31	30.00	24.96	32.79	98.48	73.27
1985	152.74	71.79	128.71	38.86	82.23	33.28	21.84	24.94	23.59	62.86	144.30	62.45
1986	224.30	134.40	50.50	30.90	1.00	12.30	8.70	17.20	21.60	206.20	61.21	207.29
1987	208.20	118.54	87.22	80.01	47.48	35.52	22.07	25.20	23.59	34.72	143.04	129.50
1988	60.99	101.81	116.02	50.26	60.35	80.99	21.84	24.94	31.74	43.21	185.72	127.24
1989	47.84	35.59	95.86	54.56	86.31	35.96	22.42	25.02	42.14	57.76	101.12	151.68
1990	42.29	58.92	47.99	83.03	36.90	35.81	21.84	25.07	27.12	51.34	48.83	190.79
1991	74.70	74.88	62.63	66.42	164.70	28.28	30.50	24.94	25.94	56.03	63.29	93.41
1992	41.42	53.26	94.46	87.48	32.45	51.02	39.96	24.94	23.59	54.24	79.94	113.47
1993	84.68	124.97	81.70	81.52	101.82	30.09	33.38	24.94	25.65	47.48	86.48	96.90
1994	98.71	76.25	62.16	67.09	63.35	34.22	21.84	24.94	23.59	92.51	85.72	101.28
1995	192.99	58.41	152.30	83.71	27.65	29.30	34.53	28.69	45.19	40.38	85.28	82.38
1996	54.89	159.20	100.46	104.70	31.85	27.34	21.84	39.26	121.17	41.83	81.57	119.02
1997	82.54	49.66	99.91	100.47	37.02	42.11	21.96	33.02	23.59	113.75	67.24	205.71
1998	175.39	84.07	118.61	69.98	240.01	30.57	42.58	21.74	53.30	123.78	161.99	129.33
1999	102.04	285.07	127.25	68.98	21.74	22.73	21.74	37.02	23.82	81.19	100.45	131.22
2000	89.23	111.87	118.32	95.59	22.73	23.33	21.74	21.74	21.74	62.24	82.68	52.51
2001	83.97	108.99	41.79	120.00	60.75	21.74	21.74	25.71	47.05	22.73	170.43	197.33
2002	82.78	41.69	114.25	116.23	24.22	24.42	24.71	25.51	97.67	56.18	144.42	124.27
2003	90.82	158.42	46.55	106.21	30.87	21.74	21.74	21.74	36.63	66.60	56.18	91.22
2004	214.10	61.24	40.10	50.62	61.54	31.37	21.74	24.22	24.71	22.93	85.16	74.34
2005	109.78	158.02	86.06	68.29	55.98	55.58	38.41	21.74	26.50	32.16	154.25	98.17
2006	79.01	111.57	105.71	32.36	26.30	30.17	23.92	21.74	83.18	100.75	51.02	32.66
2007	54.29	66.90	61.34	44.77	71.07	51.32	21.74	21.74	24.22	131.92	128.14	114.64
2008	75.93	42.38	92.71	75.34	95.88	57.97	21.74	22.73	56.38	44.17	72.76	97.77
2009	202.99	210.73	184.52	108.19	76.13	32.16	21.74	23.72	102.14	54.49	109.28	164.77
2010	159.91	251.13	70.28	74.74	54.39	66.40	24.22	23.03	43.97	231.37	53.40	204.67
2011	101.24	102.63	58.17	97.67	111.27	72.26	21.74	21.74	49.83	111.27	22.73	138.17
2012	133.60	165.07	46.55	97.77	96.48	24.91	21.74	24.94	31.83	21.74	30.37	116.93
2013	187.90	111.07	113.65	58.26	27.49	26.60	21.74	21.74	22.73	93.50	102.63	32.06
2014	71.96	27.89	58.17	120.10	81.19	82.78	21.74	31.56	52.11	70.67	73.15	124.47
2015	125.76	103.70	76.33	63.82	70.37	67.30	23.92	29.88	79.80	95.78	99.66	22.93
2016	127.25	62.24	155.24	47.54	71.47	63.82	25.41	21.74	42.68	28.78	110.87	33.95
2017	188.20	89.63	57.47	40.00	55.98	50.22	25.51	26.20	51.22	3.60	35.50	61.30
2018	55.70	91.70	74.20	7.70	27.70	62.10	2.80	3.50	3.50	20.10	73.30	79.00
2019	285.20	97.20	27.50	74.10	10.90	17.90	16.40	0.00	7.20	36.00	16.70	41.50
2020	26.10	72.20	21.00	30.50	91.30	41.70	9.20	0.00	0.00	42.30	7.30	84.70

Table A1 continued

Bergama Monthly Average Temperature Values (°C)

Station Name: Bergama

Station Number: 17742

Year	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1964	3.40	5.90	9.40	14.00	18.40	24.50	25.90	25.00	21.10	18.50	12.20	10.40
1965	7.30	5.60	9.80	12.80	17.80	24.20	26.40	24.00	23.50	15.60	13.00	10.40
1966	7.80	10.80	9.90	15.20	18.40	23.50	26.90	26.70	21.10	20.00	15.40	9.00
1967	5.30	4.40	8.10	13.80	19.10	22.60	25.90	26.60	21.80	17.50	11.30	9.20
1968	5.10	8.10	8.50	15.00	22.40	23.70	26.10	24.10	20.70	15.50	12.00	8.10
1969	4.60	8.90	8.00	11.30	19.80	23.50	23.60	25.20	22.50	15.60	13.00	10.10
1970	8.70	10.20	10.90	15.60	17.80	23.90	26.80	26.20	22.00	15.50	12.00	7.80
1971	10.00	6.90	9.80	13.00	19.70	23.80	24.80	26.20	21.70	14.90	11.90	7.20
1972	5.40	7.00	9.30	16.10	19.70	24.60	26.40	26.00	22.50	15.10	11.80	6.90
1973	5.90	9.50	8.50	13.40	19.80	23.10	27.10	24.60	22.80	17.20	10.10	8.80
1974	3.70	8.20	9.90	13.00	18.80	24.10	25.90	25.20	22.20	19.30	12.00	7.20
1975	6.10	5.30	12.00	15.00	19.20	23.70	26.50	25.10	23.00	17.00	11.20	6.30
1976	6.20	5.10	8.30	13.50	18.90	22.70	25.00	22.70	20.50	17.10	12.40	8.40
1977	7.10	10.60	9.60	14.10	20.10	24.40	26.70	26.20	21.20	14.30	13.90	6.90
1978	6.50	9.70	10.80	13.60	19.10	24.50	26.40	24.70	19.80	16.60	10.70	9.20
1979	7.20	8.40	11.70	13.50	19.40	25.20	25.80	25.30	22.50	17.10	12.00	8.70
1980	5.10	6.10	8.70	12.80	18.10	23.10	26.60	25.40	20.90	18.40	14.10	9.00
1981	5.70	7.00	11.60	14.90	17.60	25.60	25.10	25.50	22.50	19.40	9.70	11.70
1982	7.20	5.10	8.60	13.70	18.50	24.30	24.80	25.70	23.90	17.40	11.30	9.30
1983	5.30	5.70	10.00	16.20	19.80	22.50	26.20	24.40	21.60	15.60	11.00	8.90
1984	7.90	8.30	9.20	12.30	20.40	23.40	25.30	24.30	23.40	18.70	12.50	7.30
1985	8.90	3.50	9.40	15.80	21.30	24.00	25.80	26.60	22.20	15.10	13.40	9.30
1986	9.00	9.00	9.30	16.80	18.90	24.50	26.40	27.30	23.20	16.30	9.80	7.30
1987	7.50	8.10	5.60	12.30	17.70	24.10	27.80	25.60	23.70	16.10	11.70	7.90
1988	8.10	7.30	9.60	13.80	19.80	24.40	28.30	26.80	22.40	16.20	8.70	7.90
1989	5.00	8.20	11.80	17.70	18.60	23.40	25.90	26.50	22.60	15.70	10.70	7.60
1990	5.30	7.90	11.60	14.90	19.20	23.80	26.90	26.00	21.80	17.70	14.70	9.60
1991	6.60	7.30	11.00	13.80	17.10	24.50	26.30	26.30	22.00	17.40	12.40	4.80
1992	4.90	4.30	8.90	14.30	18.20	24.00	25.20	27.40	21.60	20.10	10.90	5.60
1993	5.50	4.70	8.90	13.70	18.20	24.00	26.00	26.30	22.40	19.50	10.30	10.30
1994	8.80	7.70	10.10	16.30	20.40	23.60	27.30	27.80	26.30	20.00	10.70	7.00
1995	7.90	9.40	10.20	13.50	19.70	26.60	26.80	26.20	22.80	15.90	8.80	9.60
1996	5.20	7.70	7.40	12.70	21.90	24.90	26.90	26.40	21.10	15.60	13.20	11.10
1997	8.10	6.90	8.00	10.60	20.60	25.10	27.30	24.50	20.70	16.30	12.60	8.50
1998	7.20	8.70	7.70	16.00	18.80	24.80	28.00	27.80	22.00	17.90	13.10	7.80
1999	8.30	7.80	10.80	15.60	20.80	25.60	28.20	27.60	23.50	18.50	12.60	11.10
2000	3.90	7.20	9.60	16.20	20.10	25.10	28.90	26.70	22.90	16.80	14.00	9.40
2001	8.80	8.90	14.30	15.10	20.00	25.20	29.00	28.10	23.50	18.30	11.20	6.20
2002	5.60	10.80	11.40	14.00	20.10	25.60	28.70	27.10	22.50	17.40	12.90	6.50
2003	9.60	3.70	7.30	12.20	21.90	26.80	28.20	28.00	22.00	18.40	12.40	8.50
2004	6.20	6.80	10.90	14.60	19.50	25.00	27.00	26.80	22.90	19.80	12.40	9.10
2005	8.40	6.90	9.90	15.10	20.50	23.70	28.00	27.00	22.90	16.00	11.10	9.30
2006	5.00	7.60	10.60	15.70	20.20	24.60	26.50	28.30	22.50	18.00	10.50	7.60
2007	8.10	8.30	10.40	14.00	21.40	26.70	28.50	27.35	21.20	18.00	10.30	6.80
2008	4.80	6.80	12.30	15.40	16.70	25.40	24.90	26.10	22.30	14.60	13.90	9.00
2009	8.30	8.20	10.00	14.40	20.10	24.80	27.70	26.30	22.10	19.30	12.47	10.60
2010	7.90	10.40	10.90	15.10	21.10	24.30	27.60	29.40	23.20	16.30	15.80	10.10
2011	6.90	7.60	9.60	12.20	18.40	23.90	28.00	26.40	24.40	15.10	9.20	8.30
2012	4.50	5.30	9.50	14.91	19.50	26.40	29.50	28.20	23.90	20.30	14.50	8.40
2013	7.40	9.40	12.30	15.70	21.90	24.70	26.90	27.80	22.70	15.80	13.00	6.20
2014	9.80	9.60	11.30	15.50	19.30	23.80	27.10	27.70	22.50	17.70	12.20	9.80
2015	6.60	7.90	10.30	13.00	21.00	23.50	27.50	28.40	24.80	18.00	14.30	7.90
2016	6.40	12.00	11.90	17.70	19.20	26.00	27.80	28.00	23.20	17.60	12.20	4.80
2017	4.10	8.30	11.80	14.90	19.90	25.10	27.50	27.10	23.70	17.00	11.70	9.50
2018	7.40	10.20	13.50	18.30	22.40	24.90	28.10	28.40	24.00	18.40	13.80	7.10
2019	7.00	8.30	11.30	14.30	20.90	26.40	27.00	28.10	23.80	19.60	15.70	9.50
2020	6.90	9.00	11.70	14.20	20.40	23.60	27.90	28.10	25.60	19.90	13.00	11.00

Table A1 continued

Soma Monthly Average Temperature Values (°C)

Station Name: Soma

Station Number: 4575

Year	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1964	2.52	4.94	8.67	13.45	17.94	23.55	25.30	24.37	20.34	17.61	11.31	9.68
1965	6.50	4.60	9.10	12.50	17.40	24.10	25.80	23.40	22.60	14.40	12.50	9.90
1966	7.30	10.30	9.30	15.20	18.30	22.70	26.30	26.30	20.80	19.60	15.00	8.60
1967	5.10	3.70	8.30	14.10	19.00	22.40	25.40	26.00	21.70	16.70	10.70	8.90
1968	4.60	7.60	8.40	15.50	22.20	23.30	26.20	24.20	20.60	15.00	11.60	8.00
1969	4.40	8.70	8.10	12.40	20.20	24.20	23.40	24.70	21.40	15.50	12.30	9.60
1970	8.20	9.90	10.50	15.90	17.70	23.60	26.20	25.20	20.70	14.60	11.30	7.20
1971	9.20	6.40	9.30	12.70	19.50	23.20	24.10	25.10	20.90	13.80	11.10	6.20
1972	4.30	6.10	8.80	16.00	19.40	23.60	25.90	25.00	21.50	14.40	10.70	5.90
1973	4.90	8.70	7.60	13.00	19.40	22.40	26.50	23.50	22.20	16.40	9.10	8.10
1974	2.40	7.30	9.00	12.50	18.40	23.60	25.50	24.30	21.20	18.90	11.30	6.40
1975	4.80	4.70	11.50	15.10	18.70	23.10	25.70	24.90	22.00	15.90	10.50	5.20
1976	5.40	4.10	7.40	13.30	18.10	21.90	24.60	22.10	20.00	16.50	11.50	7.70
1977	6.20	10.10	8.80	13.50	19.80	24.30	26.10	25.90	20.70	13.20	13.50	6.20
1978	5.70	9.40	10.10	12.90	18.90	24.10	25.80	23.70	19.00	15.70	9.70	8.40
1979	6.90	7.70	11.30	13.10	18.80	24.90	25.00	25.00	21.80	16.30	11.40	8.30
1980	4.50	5.40	8.10	12.40	17.70	22.50	25.90	24.90	20.00	17.90	13.20	8.40
1981	5.20	6.10	11.00	14.50	16.80	24.60	24.20	24.80	21.10	18.49	9.20	11.07
1982	6.25	4.11	7.86	13.60	18.00	23.80	24.00	25.40	23.50	16.60	10.80	9.10
1983	5.70	5.50	9.28	15.46	19.00	22.31	25.50	23.88	20.76	14.78	10.11	8.07
1984	6.93	7.44	8.47	11.90	19.46	22.86	24.91	23.79	22.26	17.80	11.61	6.36
1985	7.92	2.44	8.67	15.09	20.14	23.24	25.23	25.67	21.26	14.30	12.51	8.50
1986	8.01	8.16	8.57	16.01	18.32	23.55	25.63	26.24	22.09	15.47	8.91	6.36
1987	6.54	7.23	4.81	11.90	17.40	23.30	26.54	24.85	22.51	15.27	10.81	7.00
1988	7.13	6.40	8.88	13.27	19.00	23.48	26.87	25.83	21.42	15.37	7.82	7.00
1989	4.09	7.33	11.11	16.83	18.09	22.86	25.30	25.59	21.59	14.88	9.81	6.68
1990	4.38	7.02	10.91	14.27	18.54	23.11	25.95	25.18	20.92	16.83	13.81	8.82
1991	5.66	6.40	10.30	13.27	16.94	23.55	25.56	25.42	21.09	16.54	11.51	3.68
1992	3.99	3.28	8.17	13.72	17.78	23.24	24.84	26.32	20.76	19.17	10.01	4.53
1993	4.58	3.69	8.17	13.17	17.78	23.24	25.36	25.42	21.42	18.58	9.41	9.57
1994	7.82	6.81	9.39	15.55	19.46	22.99	26.21	26.65	24.67	19.07	9.81	6.03
1995	6.93	8.58	9.49	12.99	18.93	24.85	25.89	25.34	21.76	15.08	7.92	8.82
1996	4.29	6.81	6.64	12.26	20.60	23.79	25.95	25.51	20.34	14.78	12.31	10.43
1997	7.13	5.98	7.25	10.34	19.61	23.92	26.21	23.96	18.70	14.90	11.71	7.50
1998	5.60	7.20	6.20	14.60	17.30	23.00	26.10	26.10	20.80	17.00	11.70	6.40
1999	7.00	6.40	9.50	14.91	19.60	23.90	27.00	25.80	22.20	17.00	11.30	9.40
2000	2.30	5.90	8.50	15.10	18.90	23.00	27.40	25.20	21.80	15.40	12.80	7.80
2001	7.50	7.30	13.50	13.60	18.10	23.60	27.10	26.60	21.80	16.90	10.00	4.70
2002	3.90	9.30	10.10	12.60	18.40	23.50	27.20	25.70	20.70	16.00	11.40	4.90
2003	8.30	2.30	5.60	10.50	20.10	24.50	25.90	26.40	20.40	16.90	10.50	6.80
2004	4.80	5.60	9.80	13.40	17.70	23.50	26.00	25.40	22.00	18.70	11.20	8.00
2005	6.70	5.90	9.00	14.00	19.10	22.70	26.40	26.40	22.10	14.90	10.00	8.50
2006	3.40	6.00	9.50	14.70	19.00	23.50	24.80	27.50	21.00	16.60	9.40	6.60
2007	7.40	7.40	10.00	12.80	20.20	25.50	27.50	27.20	21.90	17.00	9.80	5.60
2008	3.70	5.70	12.20	14.80	18.30	24.10	26.00	26.80	21.00	16.40	12.80	7.70
2009	6.40	6.90	8.90	13.00	18.80	23.60	26.50	24.90	20.70	17.90	11.50	9.70
2010	7.00	9.50	9.80	13.90	19.80	23.10	26.40	28.40	22.30	15.00	15.30	9.30
2011	5.90	6.50	8.50	11.10	17.10	22.50	26.90	24.80	22.80	13.80	7.70	7.50
2012	3.50	4.20	9.70	14.30	18.00	25.10	27.40	26.97	22.67	20.90	12.30	7.60
2013	6.80	8.90	11.70	15.20	21.60	23.70	25.50	26.60	22.20	15.00	12.70	5.60
2014	9.20	9.20	10.80	15.00	18.30	22.70	26.30	26.90	21.70	17.00	12.40	9.80
2015	3.40	7.02	13.30	12.40	20.40	22.30	26.80	27.70	24.20	17.40	13.40	6.40
2016	5.70	11.30	11.20	17.10	18.80	25.50	27.30	27.50	22.50	17.00	11.60	4.10
2017	3.50	8.00	11.00	14.40	19.00	24.50	26.90	26.30	24.00	16.20	11.10	9.40
2018	6.80	9.70	13.10	17.60	21.60	24.40	27.60	27.90	23.30	17.50	13.00	6.30
2019	6.50	7.50	10.70	13.60	20.40	25.40	26.10	26.90	22.80	18.70	14.60	8.30
2020	5.70	8.20	10.80	13.40	19.70	22.90	26.90	27.10	24.90	19.20	11.50	10.20

Table A1 continued

Kınık Monthly Average Temperature Values (°C)

Station Name: Kınık

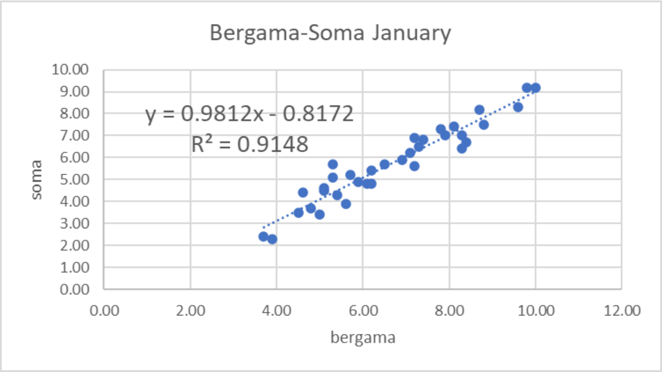
Station Number: 4747

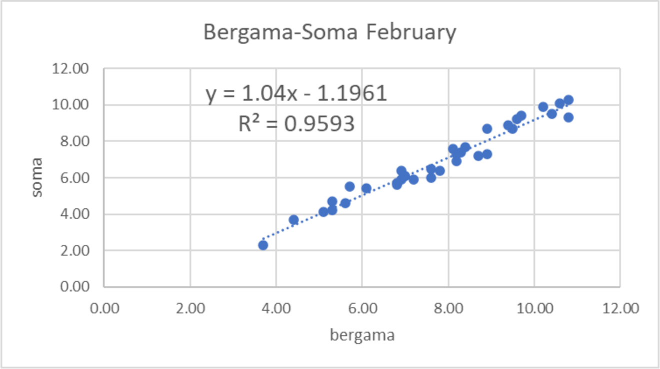
Year	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1964	3.13	5.68	9.15	13.61	17.96	24.23	25.62	24.77	20.85	18.30	11.96	10.29
1965	7.07	5.37	9.53	12.38	17.38	24.05	26.03	23.83	23.28	15.30	12.75	10.29
1966	7.58	10.69	9.63	14.83	17.96	23.65	26.44	26.35	20.85	19.86	15.09	8.74
1967	5.05	4.14	7.91	13.40	18.64	23.13	25.62	26.26	21.56	17.27	11.09	8.96
1968	4.85	7.93	8.29	14.63	21.85	23.76	25.78	23.93	20.45	15.20	11.77	7.74
1969	4.35	8.75	7.82	10.85	19.32	23.65	23.73	24.95	22.27	15.30	12.75	9.96
1970	8.49	10.08	10.58	15.24	17.38	23.88	26.36	25.88	21.76	15.20	11.77	7.41
1971	9.80	6.70	9.53	12.58	19.23	23.82	24.72	25.88	21.46	14.58	11.67	6.75
1972	5.15	6.80	9.06	15.75	19.23	24.28	26.03	25.70	22.27	14.79	11.57	6.42
1973	5.66	9.36	8.29	12.99	19.32	23.41	26.61	24.39	22.57	16.96	9.91	8.52
1974	3.44	8.03	9.63	12.58	18.35	23.99	25.62	24.95	21.96	19.13	11.77	6.75
1975	5.86	5.07	11.63	14.63	18.74	23.76	26.11	24.86	22.77	16.75	10.99	5.75
1976	5.96	4.86	8.10	13.09	18.45	23.18	24.88	22.62	20.24	16.86	12.16	8.08
1977	6.87	10.49	9.34	13.71	19.61	24.17	26.28	25.88	20.95	13.96	13.62	6.42
1978	6.27	9.57	10.48	13.20	18.64	24.23	26.03	24.49	19.54	16.34	10.50	8.96
1979	6.97	8.24	11.34	13.09	18.93	24.63	25.54	25.05	22.27	16.86	11.77	8.41
1980	4.85	5.88	8.48	12.38	17.67	23.41	26.20	25.14	20.65	18.20	13.82	8.74
1981	5.46	6.80	11.25	14.52	17.18	24.86	24.96	25.23	22.27	19.24	9.52	11.73
1982	6.97	4.86	8.39	13.30	18.06	24.11	24.72	25.42	23.68	17.17	11.09	9.07
1983	5.05	5.47	9.72	15.85	19.32	23.07	25.87	24.21	21.36	15.30	10.79	8.63
1984	7.68	8.13	8.96	11.87	19.91	23.59	25.13	24.11	23.18	18.51	12.26	6.86
1985	8.69	3.22	9.00	15.80	21.40	24.90	26.30	27.10	23.10	15.30	13.40	9.00
1986	8.80	8.70	8.90	16.40	18.30	24.30	26.20	27.10	23.40	16.00	9.70	7.20
1987	7.10	7.90	5.50	12.30	17.90	24.00	27.80	25.90	23.90	16.00	11.70	7.50
1988	8.20	7.40	9.30	13.20	19.50	24.50	27.80	26.50	22.10	15.60	8.50	7.60
1989	4.80	7.90	11.20	17.40	17.70	22.80	25.00	26.00	21.50	15.00	10.30	4.80
1990	4.90	7.40	11.30	14.60	19.20	23.80	26.80	25.80	21.80	17.60	14.00	9.30
1991	6.10	6.90	10.50	13.30	16.80	23.90	25.70	26.00	21.60	17.40	12.00	4.30
1992	4.50	3.90	8.70	13.90	17.60	23.60	24.70	26.60	21.00	19.70	10.60	5.50
1993	5.50	4.60	8.80	13.00	18.00	24.60	26.20	26.40	22.50	20.00	10.40	10.60
1994	8.70	7.80	10.30	16.70	20.50	23.70	26.70	27.10	25.60	19.50	10.40	6.90
1995	7.70	9.70	10.10	13.00	18.50	25.50	25.90	25.70	22.80	15.10	8.50	9.80
1996	5.40	7.60	7.20	12.50	21.50	24.20	26.40	25.40	20.50	15.40	13.30	11.10
1997	8.10	6.80	7.90	10.00	19.10	24.20	26.70	23.80	20.00	16.10	12.30	8.40
1998	6.30	8.20	7.40	14.70	17.90	24.40	26.60	27.38	21.76	17.68	12.84	7.41
1999	8.08	7.62	10.48	15.24	20.30	24.86	27.51	27.19	23.28	18.30	12.36	11.06
2000	3.64	7.01	9.34	15.85	19.61	24.57	28.09	26.35	22.67	16.54	13.72	9.18
2001	8.59	8.75	13.82	14.73	19.52	24.63	28.17	27.65	23.28	18.10	10.99	5.64
2002	5.36	10.69	11.06	13.61	19.61	24.86	27.92	26.72	22.27	17.17	12.65	5.97
2003	9.40	3.43	7.15	11.77	21.37	25.56	27.51	27.56	21.76	18.20	12.16	8.19
2004	5.96	6.60	10.58	14.22	19.03	24.52	26.52	26.44	22.67	19.65	12.16	8.85
2005	8.19	6.70	9.63	14.73	20.00	23.76	27.35	26.63	22.67	15.72	10.89	9.07
2006	4.75	7.42	10.29	15.34	19.71	24.28	26.11	27.84	22.27	17.79	10.31	7.19
2007	7.88	8.13	10.10	13.61	20.88	25.50	27.76	26.95	20.95	17.79	10.11	6.31
2008	4.55	6.60	11.91	15.04	16.31	24.75	24.80	25.79	22.07	14.27	13.62	8.74
2009	8.08	8.03	9.72	14.01	19.61	24.40	27.10	25.98	21.86	19.13	12.22	10.51
2010	7.68	10.28	10.58	14.73	20.59	24.11	27.02	28.87	22.98	16.03	15.48	9.96
2011	6.67	7.42	9.34	11.77	17.96	23.88	27.35	26.07	24.19	14.79	9.04	7.96
2012	4.24	5.07	9.25	14.53	19.03	25.33	28.58	27.75	23.68	20.17	14.21	8.08
2013	7.17	9.26	11.91	15.34	21.37	24.34	26.44	27.38	22.47	15.51	12.75	5.64
2014	9.60	9.46	10.96	15.14	18.84	23.82	26.61	27.28	22.27	17.48	11.96	9.62
2015	6.37	7.72	10.01	12.58	20.49	23.65	26.94	27.93	24.59	17.79	14.01	7.52
2016	6.16	11.92	11.53	17.39	18.74	25.09	27.18	27.56	22.98	17.37	12.10	4.20
2017	3.80	7.90	11.50	14.60	19.40	24.90	27.30	27.20	23.80	17.00	11.20	9.20
2018	6.80	9.70	13.00	17.60	21.70	24.60	28.00	27.90	23.70	17.80	13.50	6.50
2019	6.60	7.70	10.60	13.80	20.40	25.70	26.40	27.30	23.20	19.30	14.90	8.80
2020	6.10	8.30	11.00	13.40	19.80	23.00	27.30	27.70	25.00	16.50	12.50	10.90

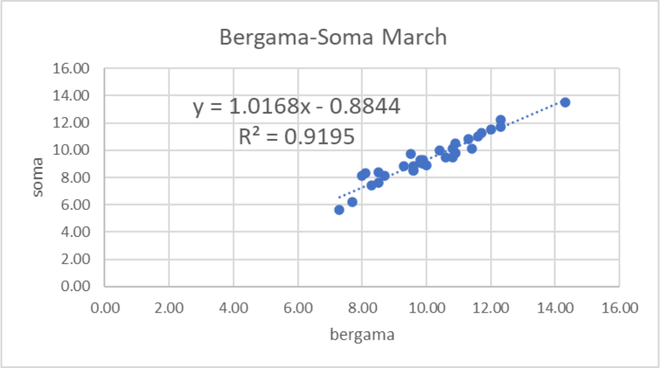
Table A1 continued

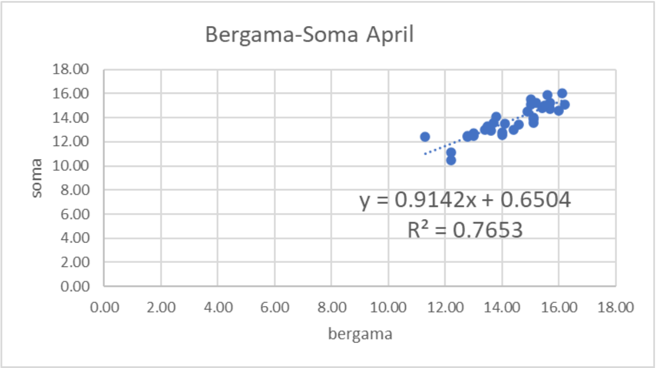
Kırkağaç Monthly Average Temperature Values (°C)												
Station Name: Kırkağaç												
Station Number: 4749												
Year	**Jan**	**Feb**	**March**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1964	2.46	4.93	8.73	13.60	18.17	23.89	25.67	24.72	20.62	17.84	11.42	9.76
1965	6.52	4.58	9.17	12.63	17.62	24.45	26.18	23.74	22.92	14.57	12.63	9.98
1966	7.33	10.39	9.37	15.38	18.54	23.02	26.69	26.69	21.09	19.87	15.18	8.66
1967	5.09	3.67	8.35	14.26	19.26	22.72	25.78	26.39	22.01	16.91	10.80	8.96
1968	4.58	7.64	8.45	15.69	22.52	23.64	26.59	24.55	20.89	15.18	11.72	8.05
1969	4.38	8.76	8.15	12.53	20.48	24.55	23.74	25.06	21.70	15.69	12.43	9.68
1970	8.25	9.98	10.59	16.10	17.93	23.94	26.59	25.57	20.99	14.77	11.41	7.23
1971	9.27	6.42	9.37	12.84	19.76	23.53	24.45	25.47	21.19	13.96	11.21	6.21
1972	4.28	6.11	8.86	16.20	19.66	23.94	26.29	25.37	21.80	14.57	10.80	5.91
1973	4.89	8.76	7.64	13.14	19.66	22.72	26.90	23.84	22.52	16.61	9.17	8.15
1974	2.34	7.33	9.07	12.63	18.64	23.94	25.88	24.66	21.50	19.15	11.41	6.42
1975	4.79	4.68	11.61	15.28	18.95	23.43	26.08	25.27	22.31	16.10	10.59	5.19
1976	5.40	4.07	7.44	13.45	18.34	22.21	24.96	22.41	20.27	16.71	11.61	7.74
1977	6.21	10.19	8.86	13.65	20.07	24.66	26.49	26.29	20.99	13.35	13.65	6.21
1978	5.70	9.47	10.19	13.04	19.15	24.45	26.18	24.04	19.26	15.89	9.78	8.45
1979	6.93	7.74	11.41	13.24	19.05	25.27	25.37	25.37	22.11	16.50	11.51	8.35
1980	4.48	5.40	8.15	12.53	17.93	22.82	26.29	25.27	20.27	18.13	13.35	8.45
1981	5.19	6.11	11.10	14.67	17.01	24.96	24.55	25.16	21.39	18.73	9.27	11.18
1982	6.26	4.08	7.90	13.75	18.24	24.15	24.35	25.78	23.84	16.81	10.90	9.17
1983	5.70	5.50	9.35	15.65	19.26	22.62	25.87	24.22	21.04	14.96	10.20	8.12
1984	6.96	7.47	8.53	12.02	19.72	23.19	25.27	24.14	22.57	18.04	11.73	6.37
1985	7.96	2.39	8.73	15.28	20.42	23.57	25.61	26.05	21.55	14.46	12.64	8.55
1986	8.10	8.30	8.70	16.00	18.00	23.70	25.90	27.00	22.80	15.70	8.80	6.60
1987	6.56	7.26	4.80	12.02	17.63	23.63	26.94	25.22	22.83	15.46	10.91	7.03
1988	7.16	6.41	8.94	13.41	19.26	23.82	27.27	26.22	21.72	15.55	7.86	7.03
1989	4.06	7.37	11.22	17.05	18.33	23.19	25.67	25.97	21.89	15.06	9.90	6.70
1990	4.36	7.05	11.01	14.44	18.79	23.45	26.34	25.55	21.21	17.04	13.97	8.88
1991	5.66	6.41	10.39	13.41	17.16	23.89	25.94	25.80	21.38	16.75	11.63	3.64
1992	3.96	3.23	8.22	13.88	18.01	23.57	25.21	26.71	21.04	19.43	10.10	4.51
1993	4.56	3.66	8.22	13.32	18.01	23.57	25.74	25.80	21.72	18.83	9.49	9.65
1994	7.86	6.84	9.46	15.74	19.72	23.32	26.60	27.05	25.04	19.33	9.90	6.04
1995	6.96	8.64	9.56	13.13	19.18	25.22	26.27	25.72	22.06	15.26	7.96	8.88
1996	4.26	6.84	6.66	12.39	20.89	24.14	26.34	25.88	20.62	14.96	12.44	10.52
1997	7.16	5.99	7.28	10.43	19.88	24.27	26.60	24.31	18.95	15.08	11.83	7.54
1998	5.60	7.23	6.21	14.77	17.52	23.33	26.49	26.49	21.09	17.22	11.82	6.42
1999	7.03	6.42	9.58	15.09	19.87	24.25	27.41	26.18	22.52	17.22	11.41	9.47
2000	2.24	5.91	8.56	15.28	19.15	23.33	27.81	25.57	22.11	15.59	12.94	7.84
2001	7.54	7.33	13.65	13.75	18.34	23.94	27.51	27.00	22.11	17.12	10.08	4.68
2002	3.87	9.37	10.19	12.73	18.64	23.84	27.61	26.08	20.99	16.20	11.51	4.89
2003	8.35	2.24	5.60	10.59	20.38	24.86	26.29	26.79	20.68	17.12	10.59	6.82
2004	4.79	5.60	9.88	13.55	17.93	23.84	26.39	25.78	22.31	18.95	11.31	8.05
2005	6.72	5.91	9.07	14.16	19.36	23.02	26.79	26.79	22.41	15.08	10.08	8.56
2006	3.36	6.01	9.58	14.87	19.26	23.84	25.16	27.92	21.29	16.81	9.47	6.62
2007	7.44	7.44	10.08	12.94	20.48	25.88	27.92	27.61	22.21	17.22	9.88	5.60
2008	3.67	5.70	12.33	14.98	18.54	24.45	26.39	27.20	21.29	16.61	12.94	7.74
2009	6.42	6.93	8.96	13.14	19.05	23.94	26.90	25.27	20.99	18.13	11.61	9.78
2010	7.03	9.58	9.88	14.06	20.07	23.43	26.79	28.83	22.62	15.18	15.49	9.37
2011	5.91	6.52	8.56	11.21	17.32	22.82	27.30	25.16	23.13	13.96	7.74	7.54
2012	3.46	4.18	9.78	14.47	18.24	25.47	27.81	27.38	23.00	21.19	12.43	7.64
2013	6.82	8.96	11.82	15.38	21.90	24.04	25.88	27.00	22.52	15.18	12.84	5.60
2014	9.27	9.27	10.90	15.18	18.54	23.02	26.69	27.30	22.01	17.22	12.53	9.88
2015	3.36	7.05	13.45	12.53	20.68	22.62	27.20	28.12	24.55	17.62	13.55	6.42
2016	5.70	11.41	11.31	17.32	19.05	25.88	27.71	27.92	22.82	17.22	11.72	4.07
2017	3.46	8.05	11.10	14.57	19.26	24.86	27.30	26.69	24.35	14.30	10.80	9.00
2018	6.20	9.30	12.70	16.90	21.00	23.40	26.00	26.80	22.20	16.70	13.10	8.80
2019	6.50	7.20	9.90	13.10	19.60	24.70	24.50	26.00	21.80	17.70	15.00	7.40
2020	4.90	7.50	10.30	13.10	19.10	22.00	26.00	25.90	24.20	18.10	10.40	9.20

Table A1 continued

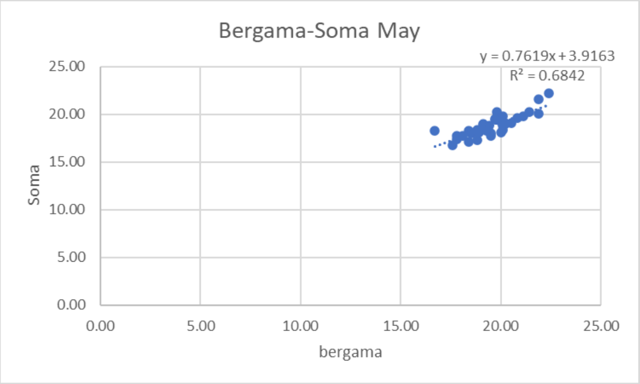


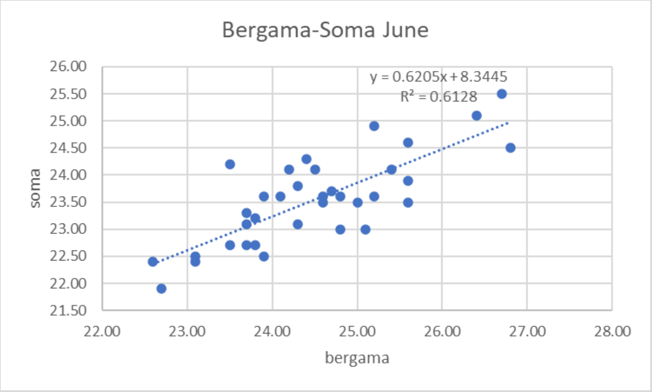


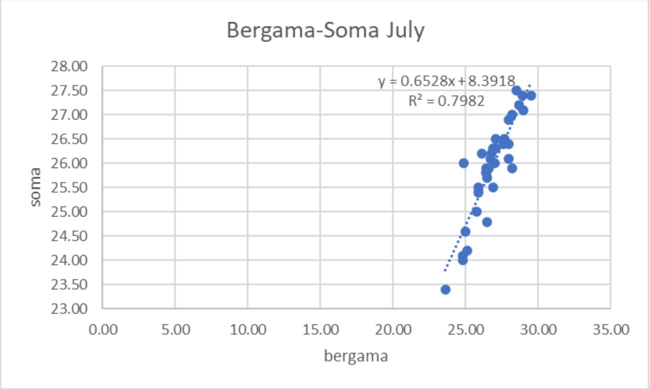




FigureA1. Temperature correlation graphs between Bergama and Soma stations







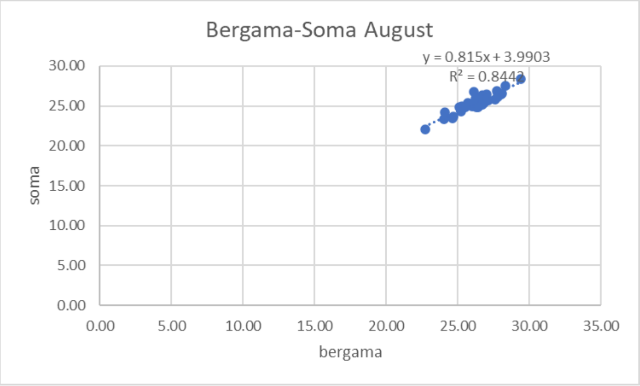
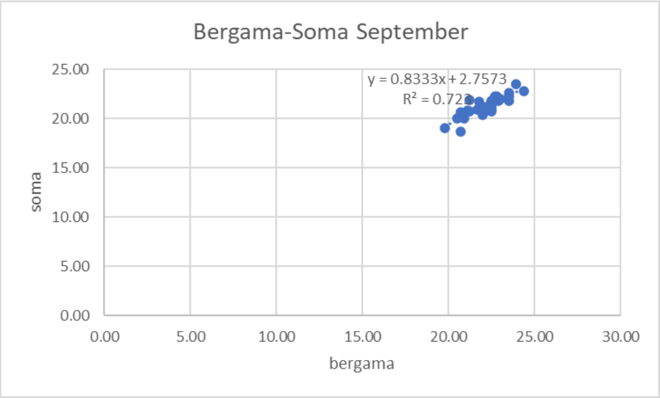
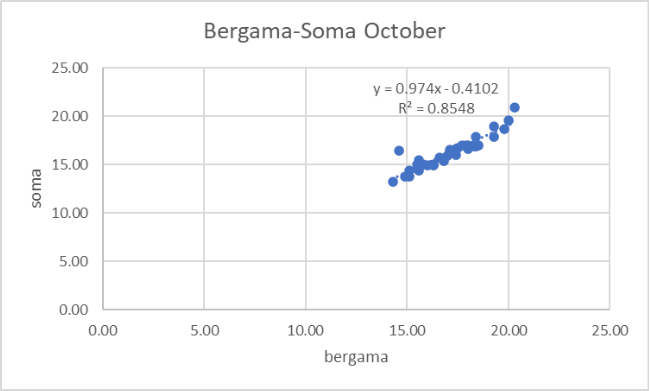
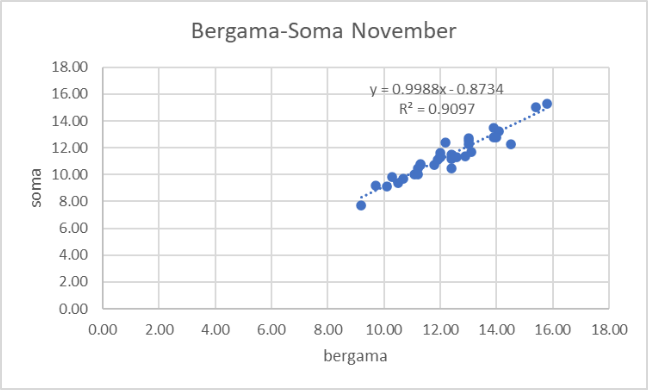


Figure A1 continued







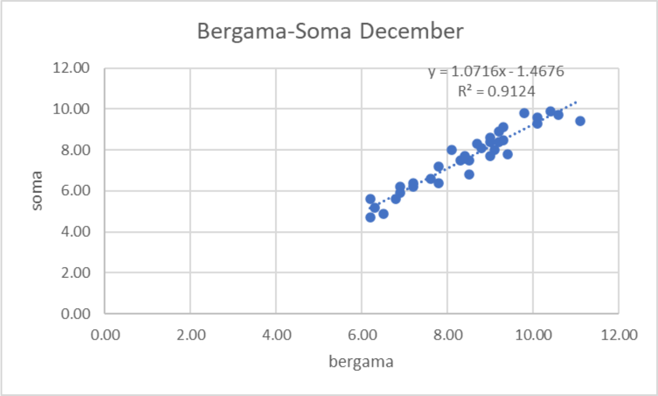


Figure A1 continued

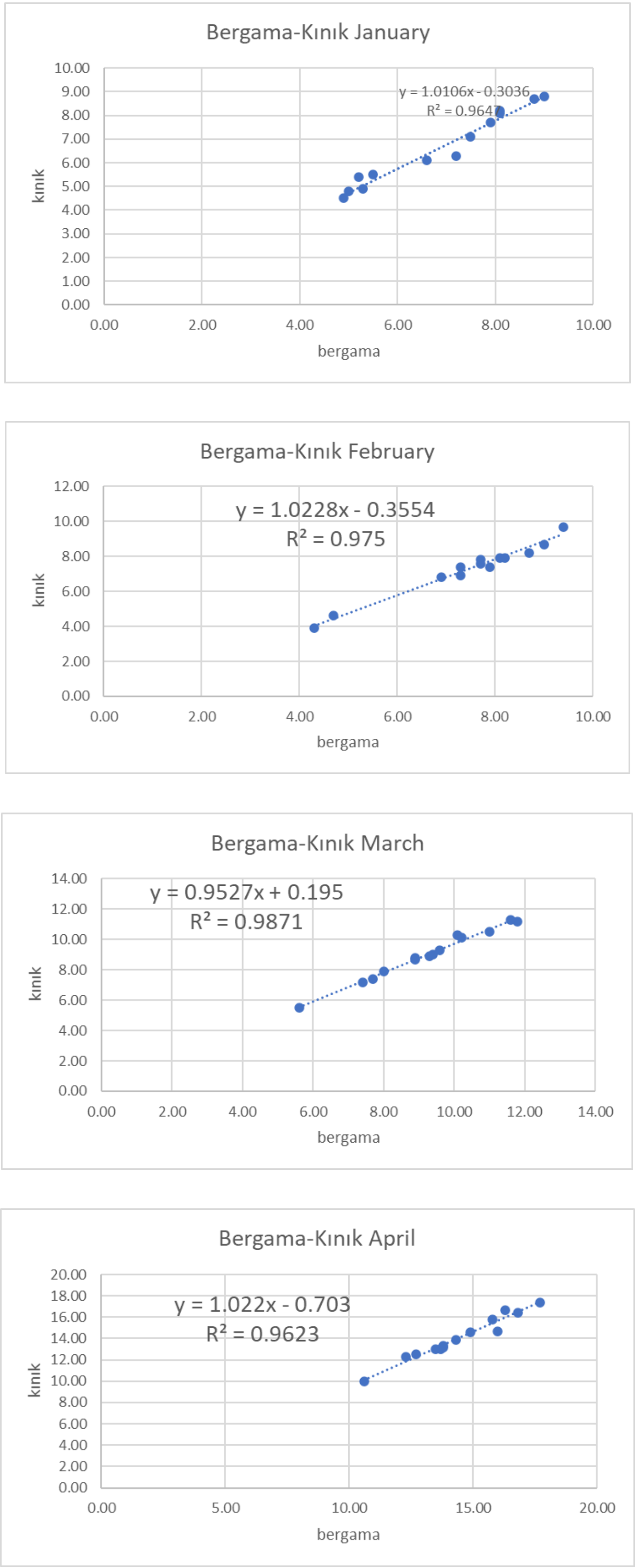
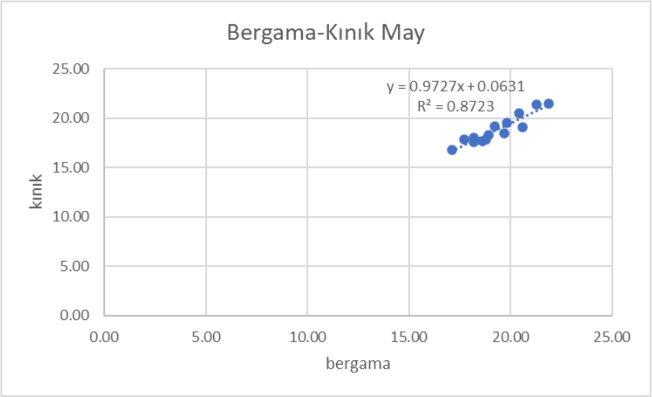
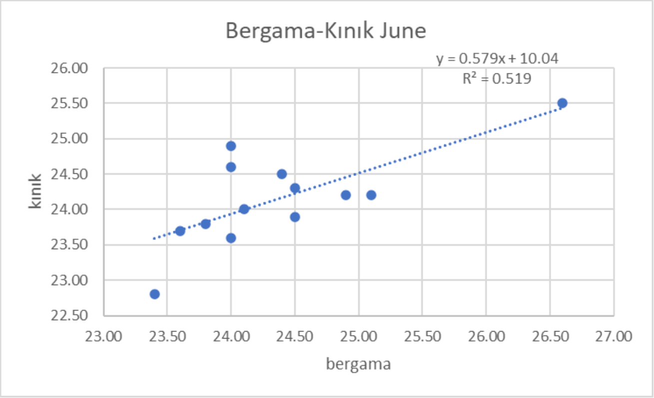
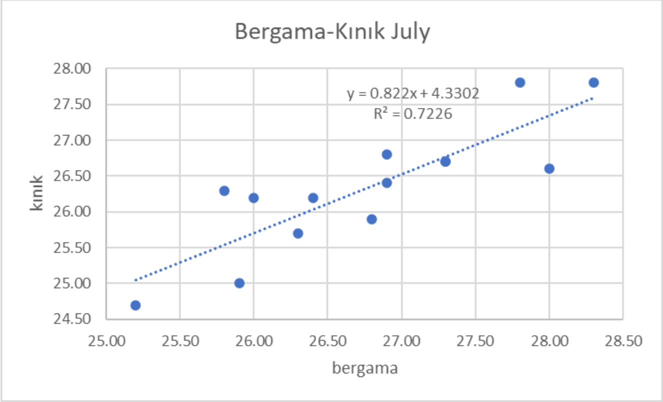
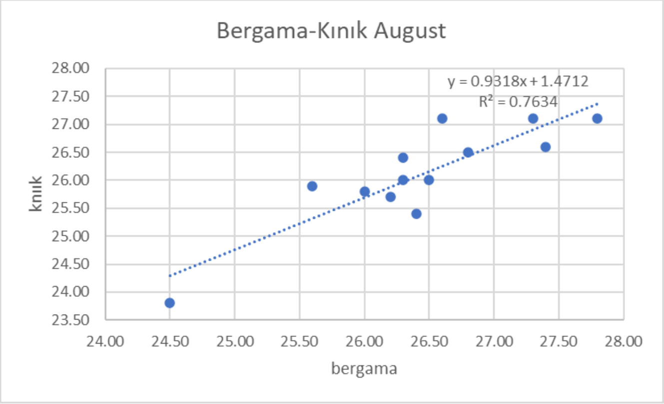


Figure A2. Temperature correlation graphs between Bergama and Kınık stations









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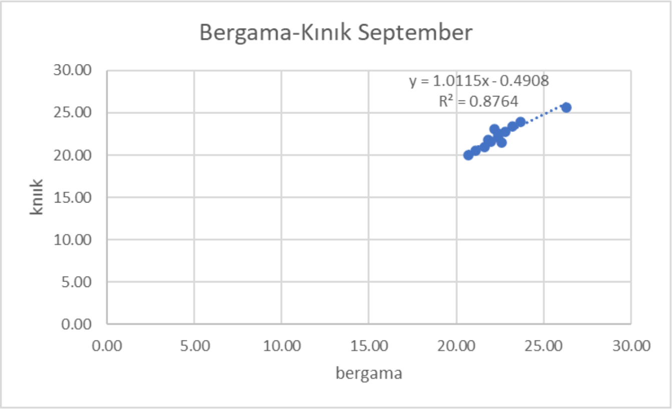

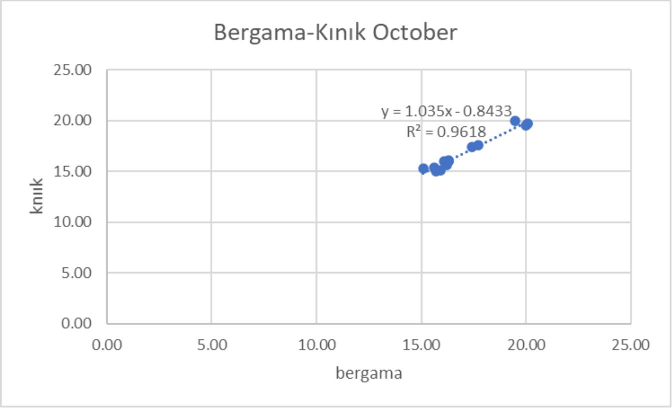

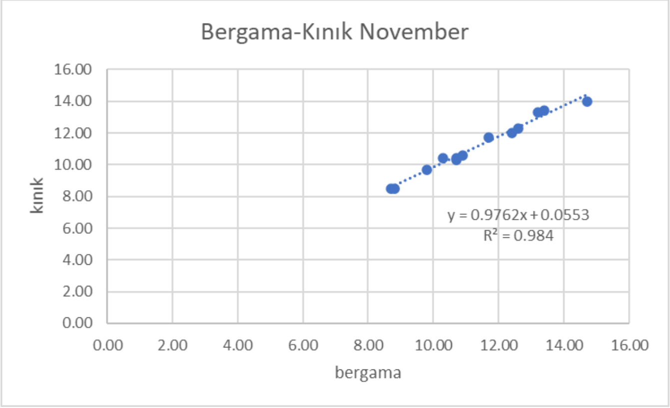

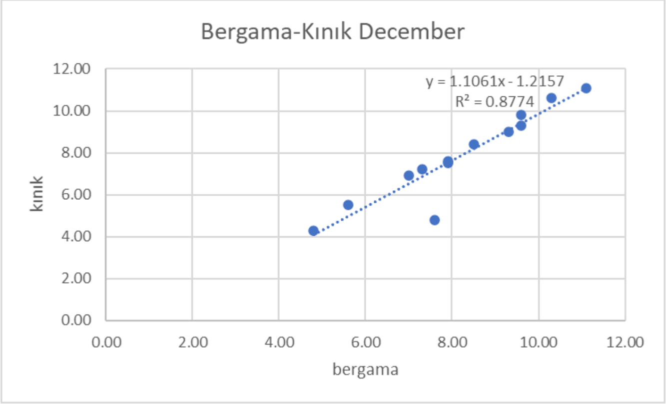

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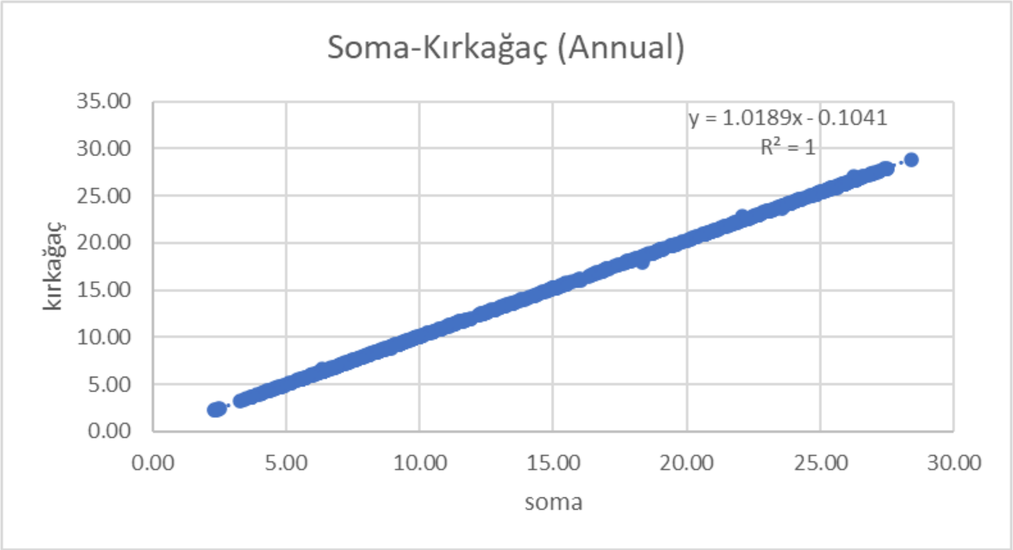


Figure A3. Temperature correlation graphs between Soma and Kırkağaç stations

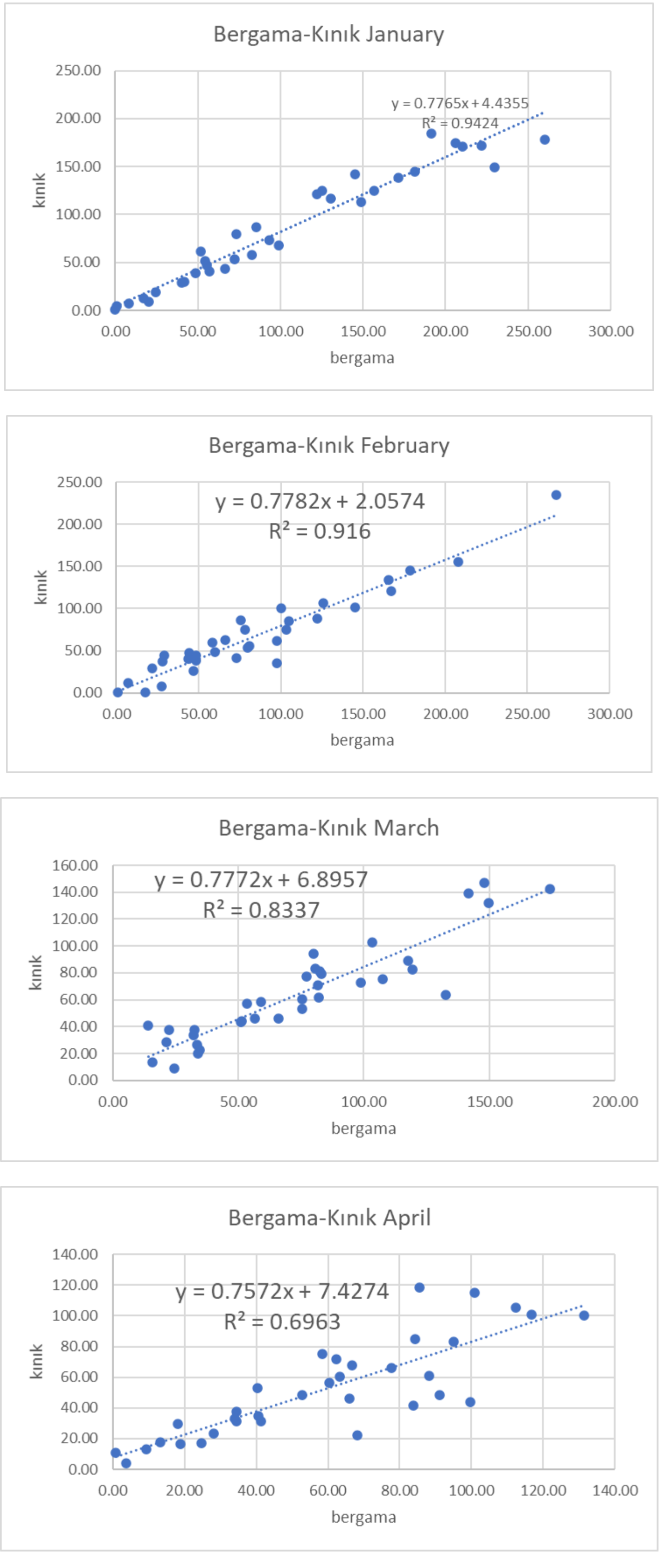


Figure A4. Precipitation correlation graphs between Bergama and Kınık stations

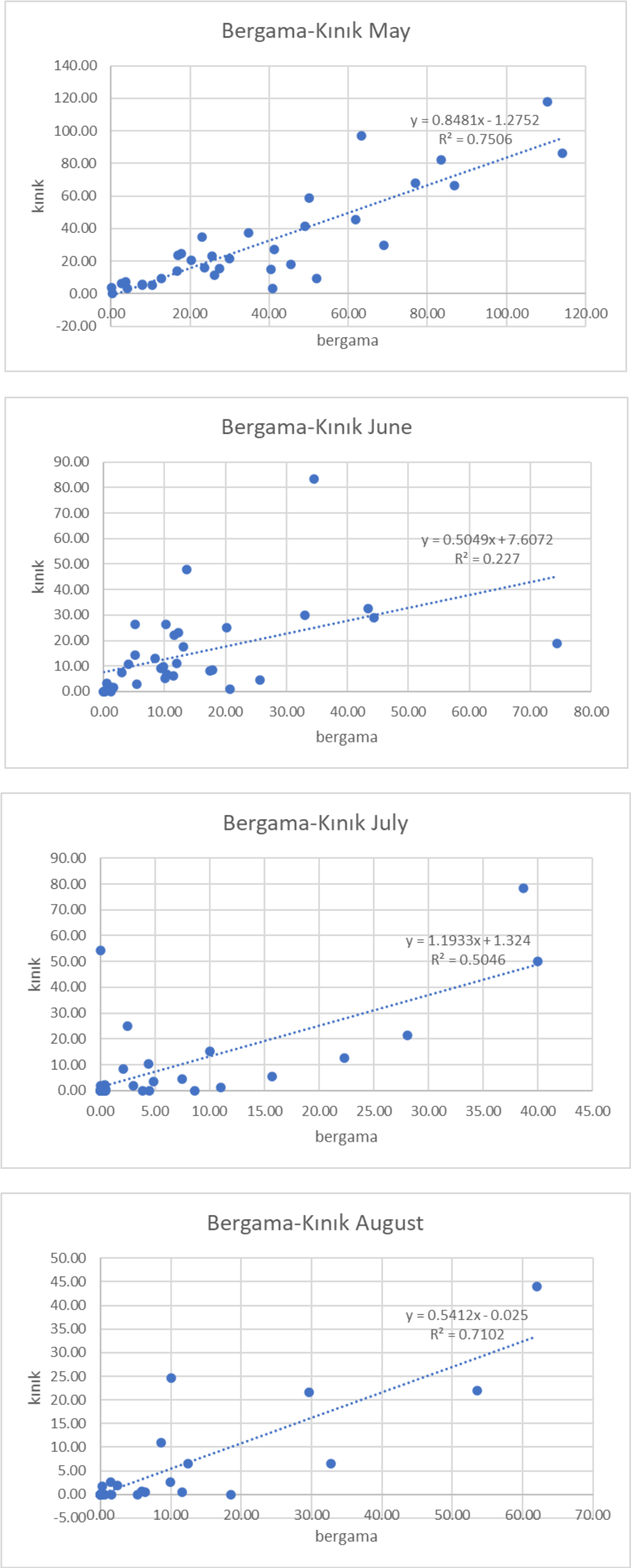
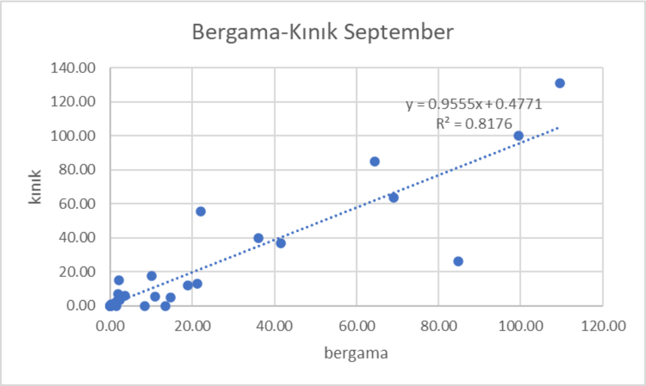
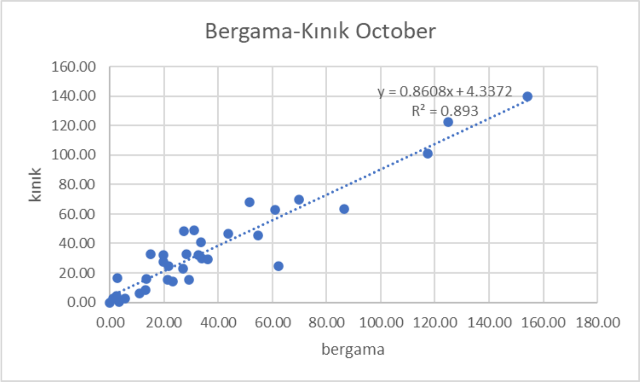
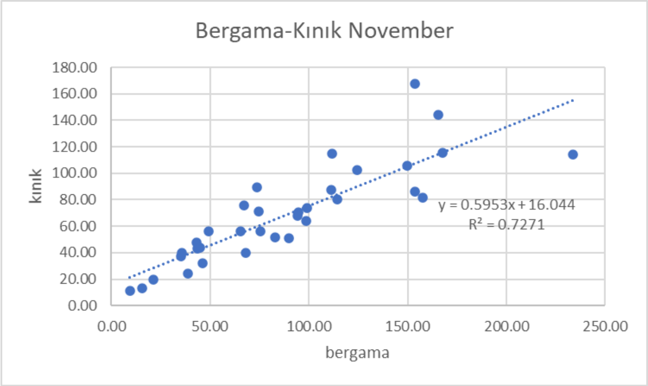
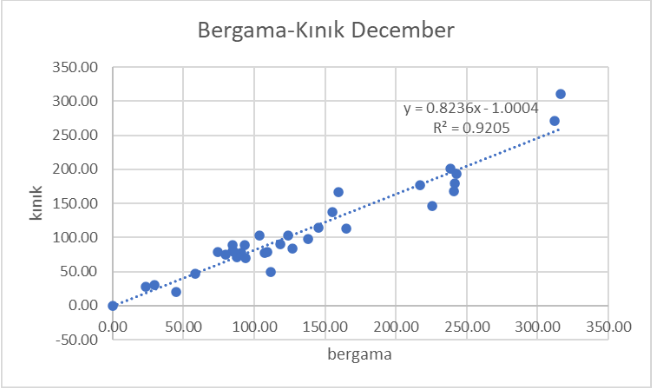


Figure A4 continued









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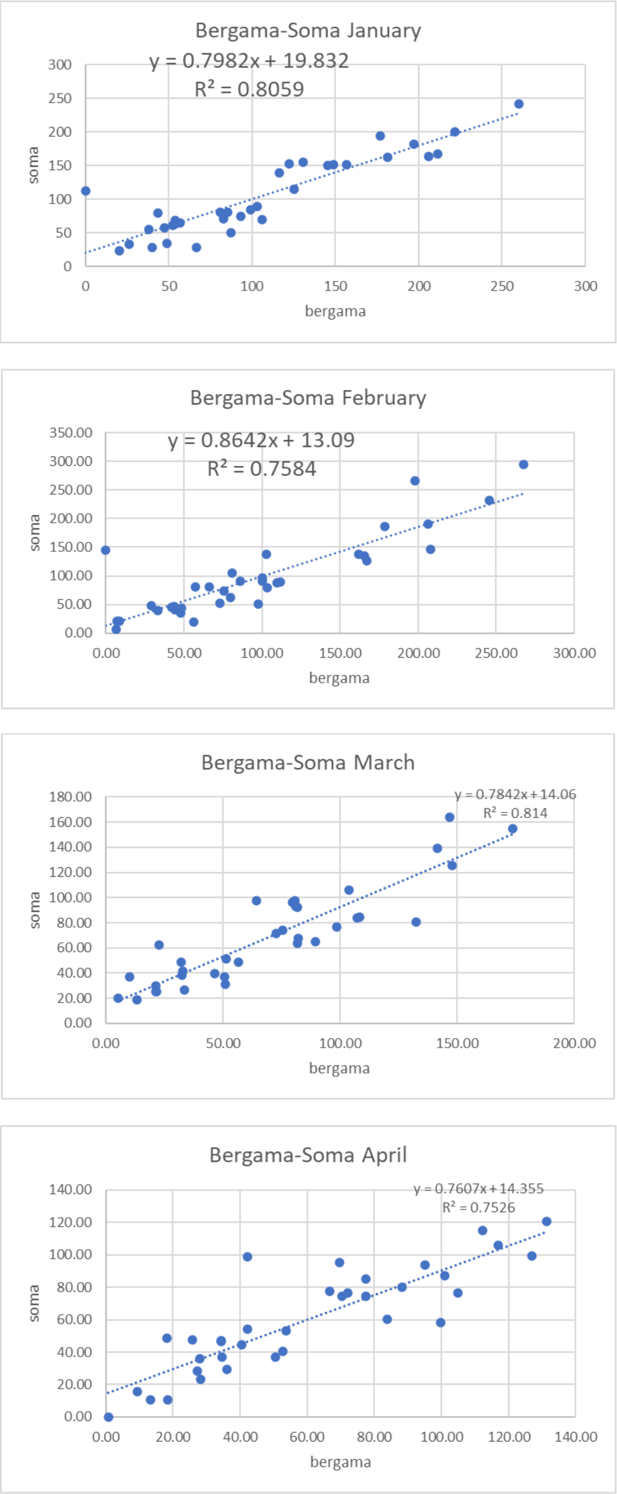
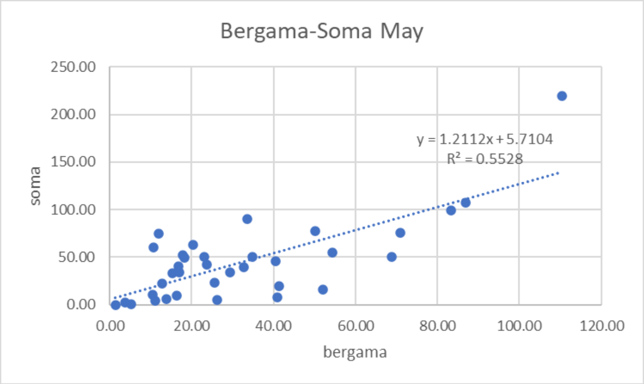
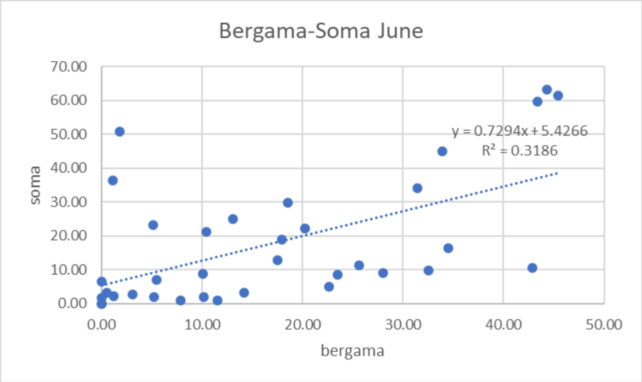
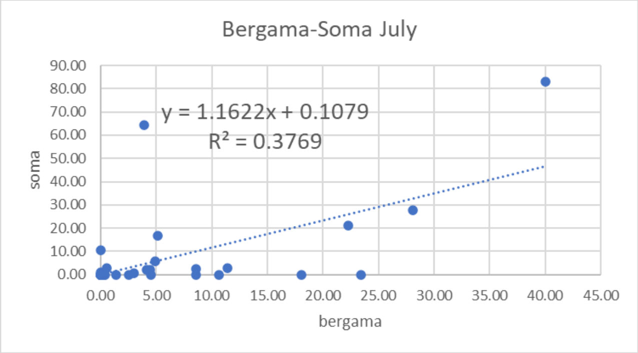


Figure A5. Precipitation correlation graphs between Bergama and Soma stations







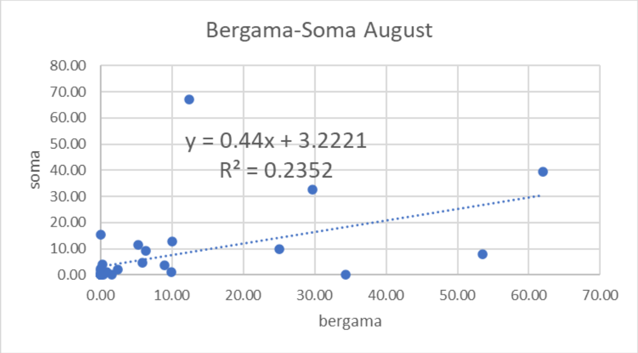
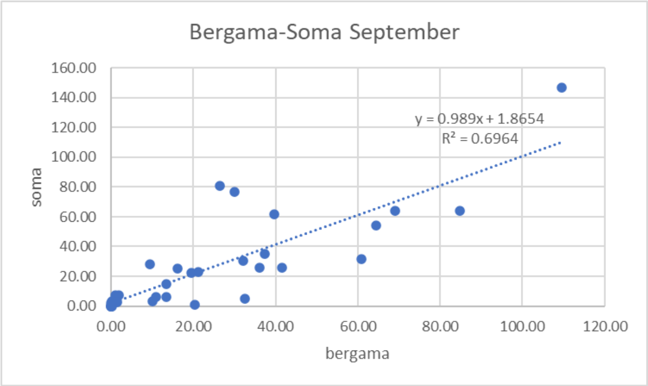
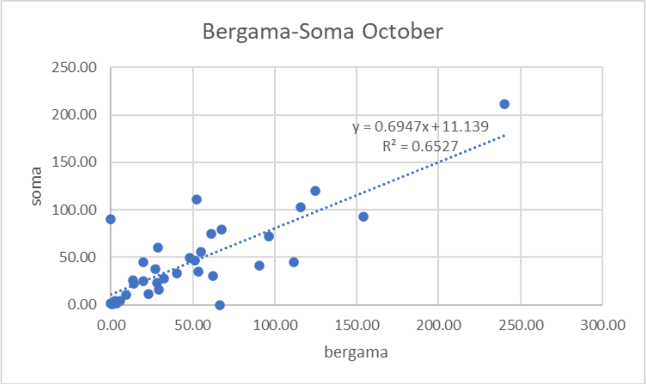
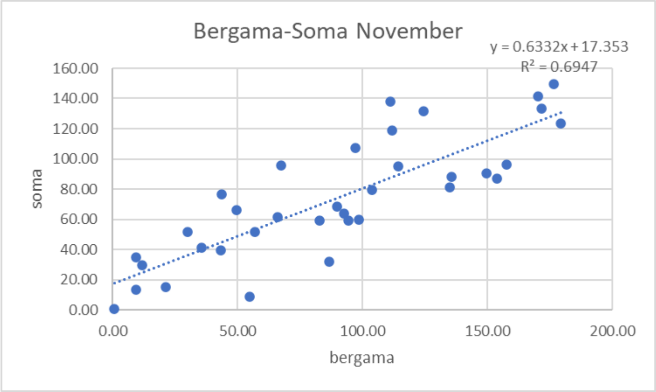
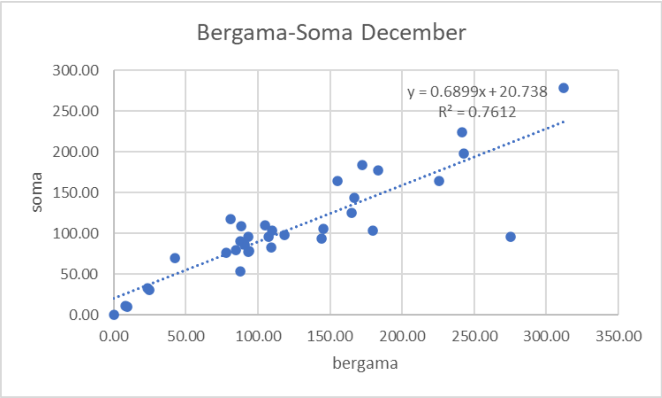


Figure A5 continued









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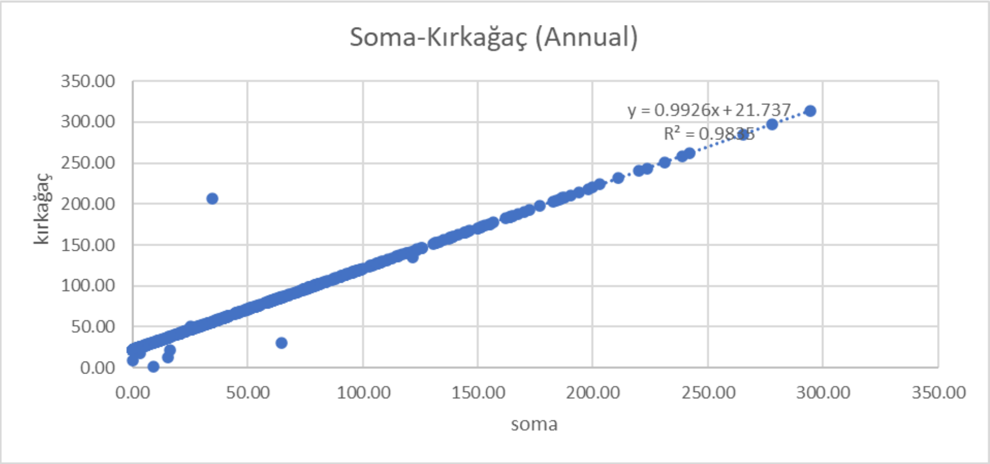


Figure A6. Precipitation correlation graphs between Soma and Kırkağaç stations

B. Water Budget Components for Each Sub-Basin

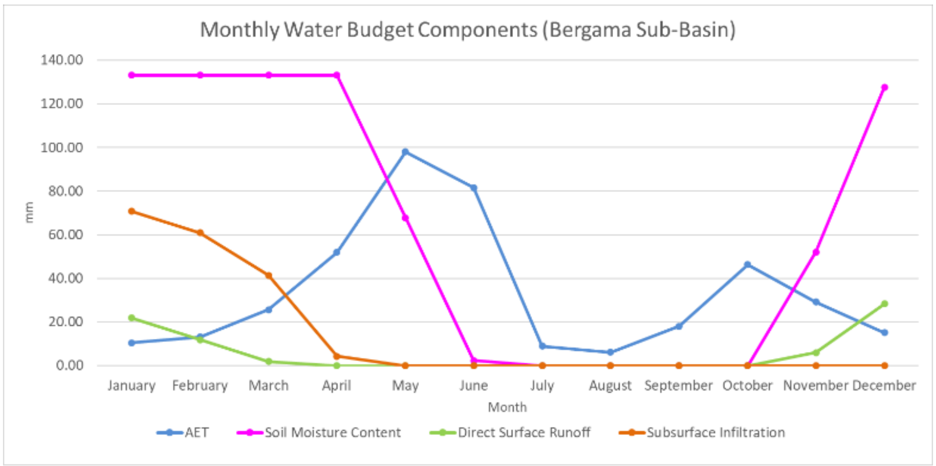


Figure B1 Monthly water budget components for Bergama sub-basin

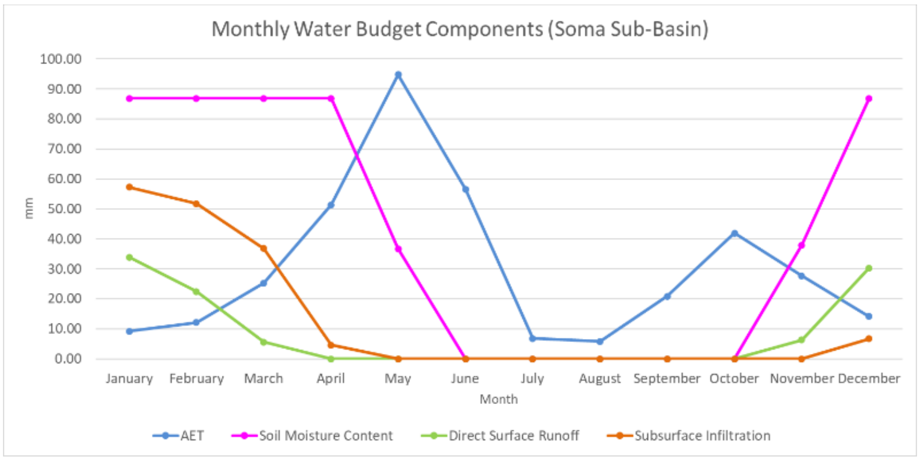


Figure B2 Monthly water budget components for Soma sub-basin

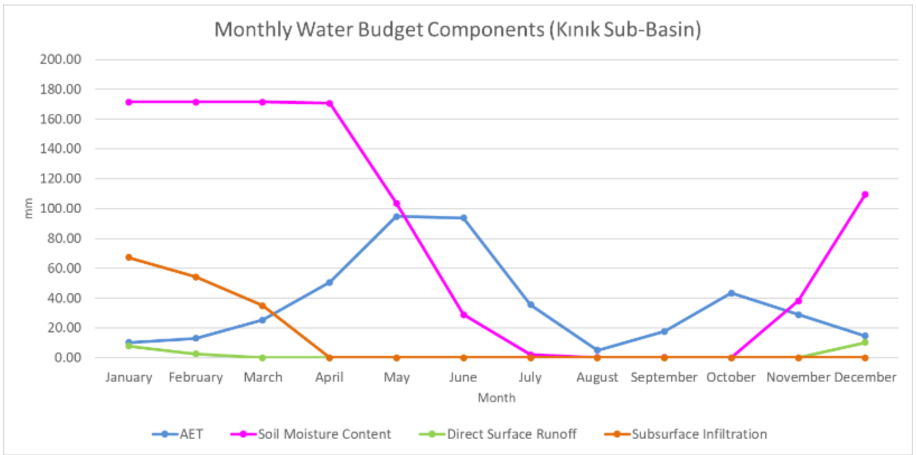


Figure B3 Monthly water budget components for Kınık sub-basin

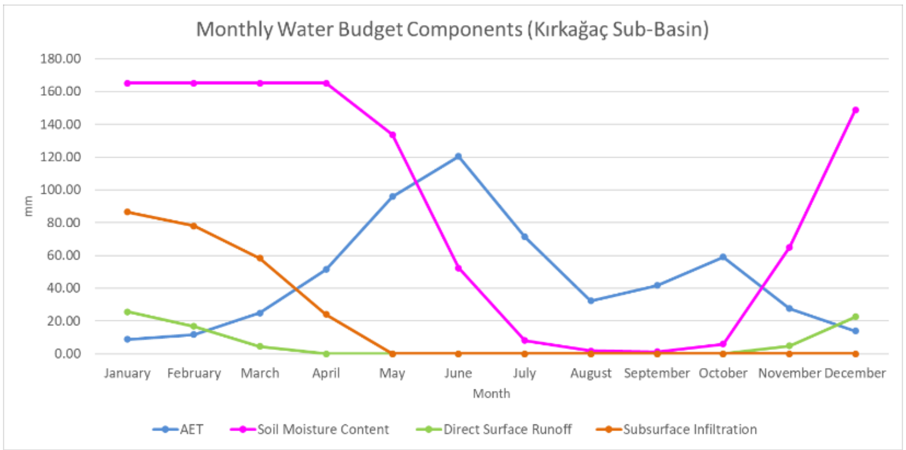


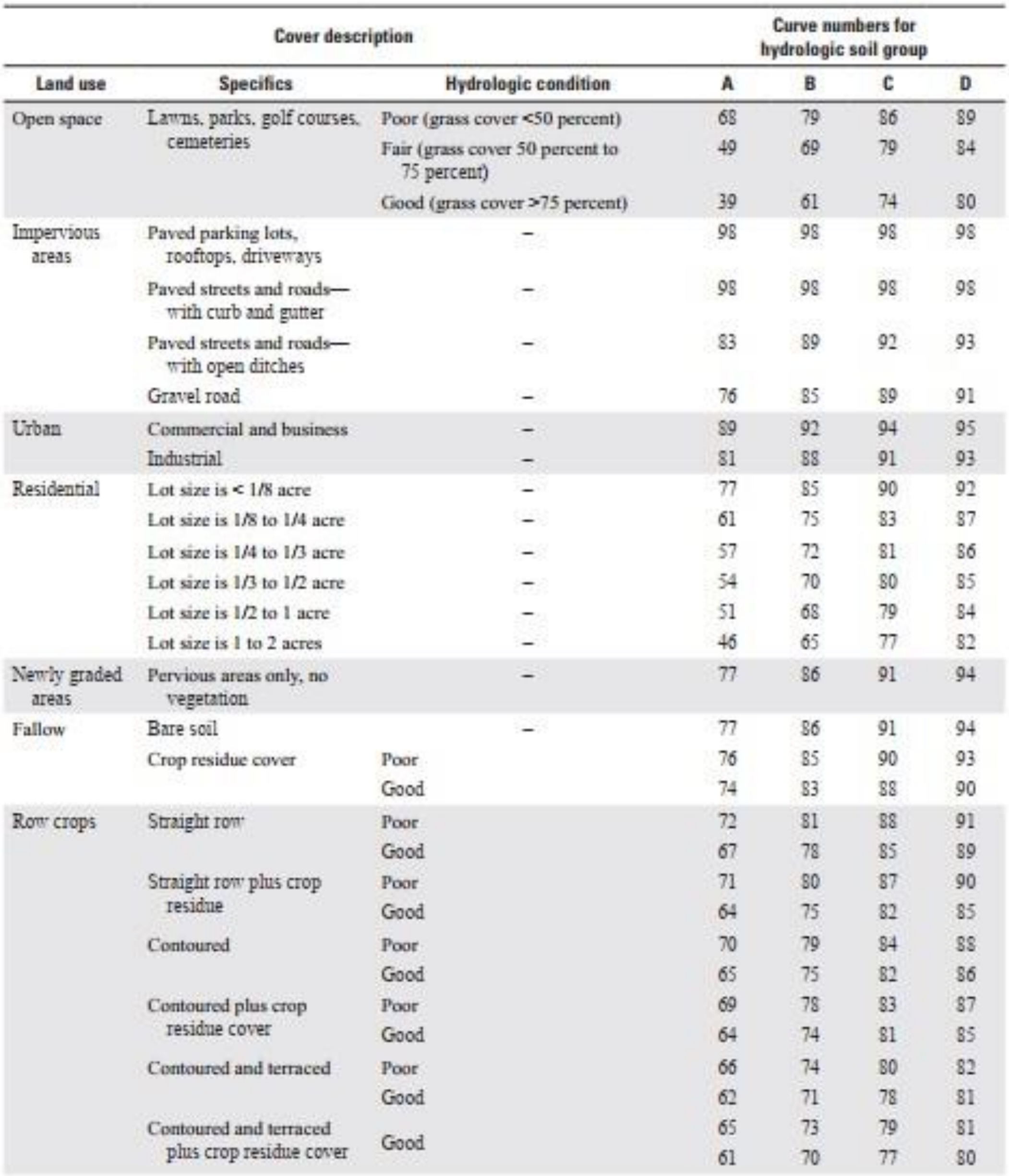
Figure B4 Monthly water budget components for Kırkağaç sub-basin

C. Recommended Curve Numbers for Select Land Uses and Hydrologic Soil Groups

Table C1 CN Values for Land Use Classes and Hydrological Soil Groups modified from Cronshey et al., 1986

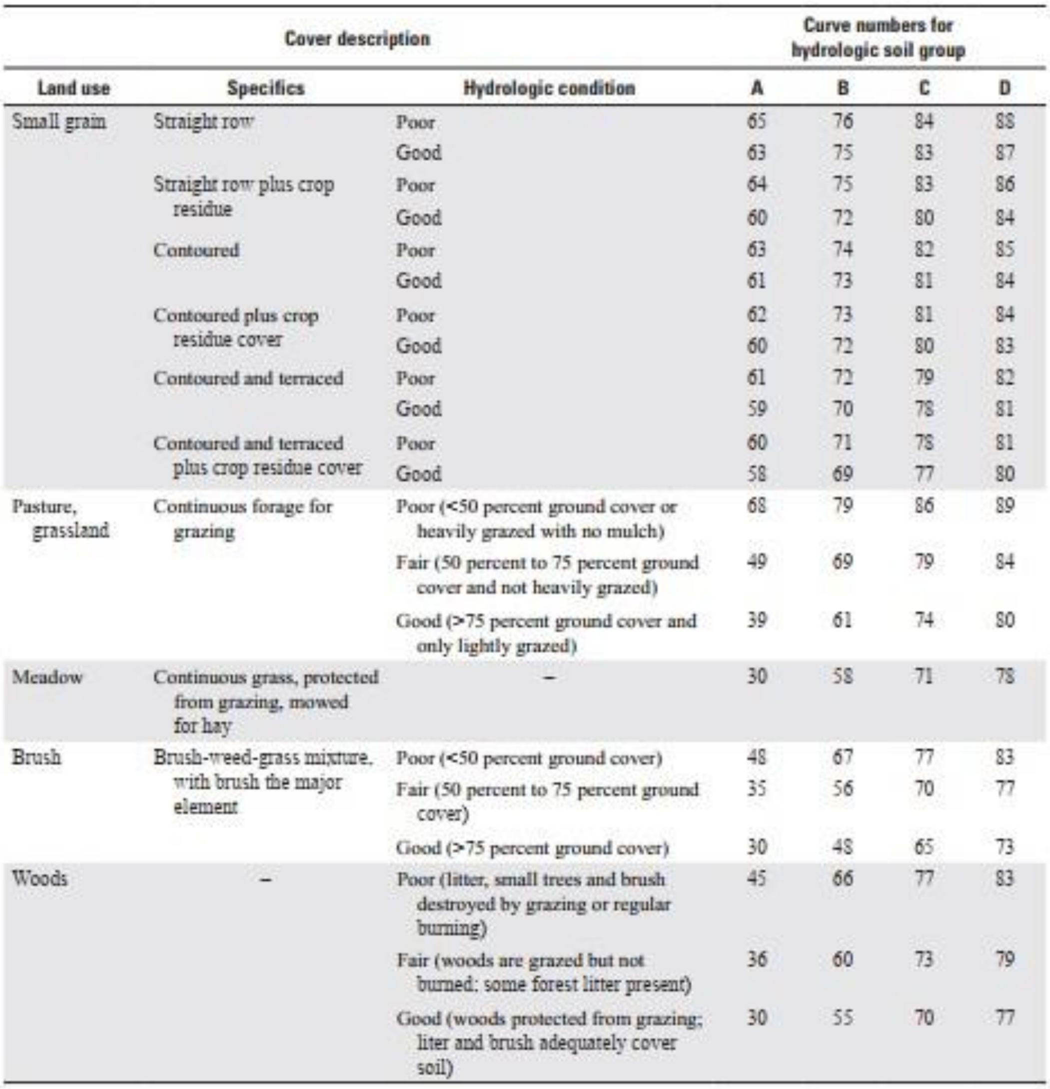
CLC Code	**Land Use Classes**		**CN for Hydrological Soil Groups (HSG)**			
			A	**B**	**C**	**D**
112	Artificial surfaces	Discontinuous urban fabric	77	85	90	92
121		Industrial or commercial units	85	90	92.5	94
131		Mineral extraction sites	81	88	91	93
132		Dump sites	81	88	91	93
133		Construction sites	77	86	91	94
142		Sport and leisure facilities	49	69	79	84
211	Agricultural areas	Non-irrigated arable land	60	72	80	84
212		Permanently irrigated land	30	58	71	78
222		Fruit trees and berry plantations	43	65	76	82
223		Olive groves	43	65	76	82
231		Pastures	30	58	71	78
242		Complex cultivation patterns	59	74	82	86
243		Land principally occupied by agriculture, with significant areas of natural vegetation	64	75	82	85
311	Forest and semi natural areas	Broad-leaved forest	30	55	70	77
312		Coniferous forest	30	55	70	77
313		Mixed forest	30	55	70	77
321		Natural grasslands	39	61	74	80
323		Sclerophyllous vegetation	45	66	77	83
324		Transitional woodland-shrub	35	56	70	77
333		Sparsely vegetated areas	74	83	88	90
331		Beaches, dunes, sands	55	72	81	86

Table C2 CN Values for Land Use Classes and Hydrological Soil Groups after Cronshey et al., 1986



Cover description			Curve numbers for hydrologic soil group			
Land use	**Specifics**	**Hydrologic condition**	**A**	**B**	**C**	**D**
Open space	Lawns, parks, golf courses, cemeteries	Poor (grass cover <50 percent)	68	79	86	89
		Fair (grass cover 50 percent to 75 percent)	49	69	79	84
		Good (grass cover >75 percent)	39	61	74	80
Impervious areas	Paved parking lots, rooftops, driveways	–	98	98	98	98
	Paved streets and roads—with curb and gutter	–	98	98	98	98
	Paved streets and roads—with open ditches	–	83	89	92	93
	Gravel road	–	76	85	89	91
Urban	Commercial and business	–	89	92	94	95
	Industrial	–	81	88	91	93
Residential	Lot size is < 1/8 acre	–	77	85	90	92
	Lot size is 1/8 to 1/4 acre	–	61	75	83	87
	Lot size is 1/4 to 1/3 acre	–	57	72	81	86
	Lot size is 1/3 to 1/2 acre	–	54	70	80	85
	Lot size is 1/2 to 1 acre	–	51	68	79	84
	Lot size is 1 to 2 acres	–	46	65	77	82
Newly graded areas	Pervious areas only, no vegetation	–	77	86	91	94
Fallow	Bare soil	–	77	86	91	94
	Crop residue cover	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row	Poor	72	81	88	91
		Good	67	78	85	89
	Straight row plus crop residue	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured plus crop residue cover	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured and terraced	Poor	66	74	80	82
		Good	62	71	78	81
	Contoured and terraced plus crop residue cover	Good	65	73	79	81
			61	70	77	80

Table C3 CN Values for Land Use Classes and Hydrological Soil Groups after Cronshey et al., 1986



Cover description			Curve numbers for hydrologic soil group			
Land use	**Specifics**	**Hydrologic condition**	**A**	**B**	**C**	**D**
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Straight row plus crop residue	Poor	64	75	83	86
		Good	60	72	80	84
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured plus crop residue cover	Poor	62	73	81	84
		Good	60	72	80	83
	Contoured and terraced	Poor	61	72	79	82
		Good	59	70	78	81
	Contoured and terraced plus crop residue cover	Poor	60	71	78	81
		Good	58	69	77	80
Pasture, grassland	Continuous forage for grazing	Poor (<50 percent ground cover or heavily grazed with no mulch)	68	79	86	89
		Fair (50 percent to 75 percent ground cover and not heavily grazed)	49	69	79	84
		Good (>75 percent ground cover and only lightly grazed)	39	61	74	80
Meadow	Continuous grass, protected from grazing, mowed for hay	–	30	58	71	78
Brush	Brush-weed-grass mixture, with brush the major element	Poor (<50 percent ground cover)	48	67	77	83
		Fair (50 percent to 75 percent ground cover)	35	56	70	77
		Good (>75 percent ground cover)	30	48	65	73
Woods	–	Poor (litter, small trees and brush destroyed by grazing or regular burning)	45	66	77	83
		Fair (woods are grazed but not burned; some forest litter present)	36	60	73	79
		Good (woods protected from grazing; liter and brush adequately cover soil)	30	55	70	77

D. Observation well data

Table D1 Data on drilled DSI wells (DSI, 1976; BSNFB, 2016)

Data on Drilled DSI Wells (DSI, 1976 and BSNFB, 2016)								
Well No	**Coordinate**		**Construction Year**	**Date of Measurement**	**Ground Attitude (m)**	**Static Level (m)**	**Transmissivity (m^2/day)**	**Alluvium Thickness (m)**
	X	**Y**						
112	563454	4331442	1961	Nov /1969	133	0.40	-	100
113	536513	4332387	1961	Oct / 1969	55	8.25	-	150
114	533751	4328051	1961	Oct / 1969	58	3.25	525.00	140
115	532242	4331644	1961	Oct / 1969	42	2.10	-	150
116	527348	4331150	1961	Oct / 1969	38	0.30	-	150
117	510777	4326296	1961	Nov /1969	28	10.50	-	42
118	516795	4329740	1961	Nov /1969	48	6.90	-	81
119	553972	4338984	1961	Nov /1969	135	4.00	-	50
120	559579	4330306	1961	-	159	-	-	0.15
2605	533414	4340479	1961	Dec / 1961	61	3.00	-	50
2606	506074	4322930	1961	Dec / 1962	15	-	-	58
2609	535956	4337264	1962	Jan / 1962	54	4.90	-	90
2610	510286	4324223	1961	Dec / 1961	16	3.75	-	31
2612	537438	4330232	1961	Dec / 1961	85	6.28	-	170
2690	564478	4333040	1962	May / 1962	177	1.35	-	10
2691	566526	4331280	1962	May / 1962	162	0.75	-	50
2912	563378	4326691	1962	May / 1962	181	0.00	-	55
2913	565776	4333934	1962	May / 1962	192	2.30	-	75
2915/B	523324	4328581	1962	June / 1962	34	3.43	-	130
2916	503415	4314047	1962	June / 1962	7.5	0.80	-	40
2917/B	501906	4318772	1962	June / 1962	12	2.25	-	104
989	529144	4338073	1959	Sept / 1959	51	7.80	-	100
990	536684	4337973	1959	Sept / 1959	58	7.50	-	112
992	529732	4338575	1959	Sept / 1959	52	8.20	-	106
11199	516602	4328873	1968	Aug / 1968	-	14.80	4.51	70
13198	539935	4333204	1969	Oct / 1969	-	21.23	8.40	90
26912	571150	4331150	1979	-	-	1.17	510.67	93
60319	561862	4325600	-	-	-	11.48	26.17	76
59110	563850	4331325	2006	-	-	9.98	35.21	140
59794	560740	4333055	2008	-	-	14.34	32.76	150
36723	540500	4335824	1987	-	-	4.94	192.21	54
36423	539806	4332795	1987	-	-	32.00	5.48	50
41969	505923	4324180	1991	-	-	13.22	751.36	86
51028	504734	4325503	1996	-	-	0.50	249.9	29

Table D2. Data on drilled master plan wells (BSNFB, 2016)

Data on Drilled Master Plan Wells (BSNFB, 2016)							
Well No	**Well Location**	**Coordinate**		**Date of Measurement**		**Static Level (m)**	
		X	**Y**				
62	Ovacık Village	505673	4324486	Sept / 2015	Apr / 2016	22.05	15.43
69	Bademli	485575	4320217	Sept / 2015	Apr / 2016	0.00	artesian
70	Katıralan	489952	4317823	Sept / 2015	Apr / 2016	4.08	1.32
71	Çandarlı	492756	4310786	Sept / 2015	Apr / 2016	20.73	18.47
72	Denizköy	484962	4311195	Sept / 2015	Apr / 2016	15.70	8.22
73	Çandarlı	500326	4312345	Sept / 2015	Apr / 2016	23.50	15.3
83	Yeniköy	506075	4318650	Sept / 2015	Apr / 2016	17.83	7.49
84	Yeniköy	501818	4317719	Sept / 2015	Apr / 2016	16.80	8.62
85	Kırıklar	498090	4321309	Sept / 2015	Apr / 2016	24.76	7.16
86	Bergama	510963	4326595	Sept / 2015	Apr / 2016	7.61	4.17
87	Bergama	517390	4329908	Sept / 2015	Apr / 2016	13.72	10.50
88	İhsamsaray	518938	4328321	Sept / 2015	Apr / 2016	5.97	5.05
89	Yayakent	524920	4327821	Sept / 2015	Apr / 2016	8.04	4.36
90	Kırıklı	521405	4333739	Sept / 2015	Apr / 2016	2.77	2.20
91	Ayaskent	528432	4336760	Sept / 2015	Apr / 2016	10.78	6.25
92	Alibeyli	532638	4341379	Sept / 2015	Apr / 2016	14.04	7.52
93	Bölceg	536031	4338363	Sept / 2015	Apr / 2016	18.10	8.80
94	Cumalı	537665	4333032	Sept / 2015	Apr / 2016	16.05	15.56
95	Değirmencieli Village	538812	4326797	Sept / 2015	Apr / 2016	dry	0.52
96	Kınık	531411	4333182	Sept / 2015	Apr / 2016	8.24	2.80
97	Kınık	532527	4328447	Sept / 2015	Apr / 2016	5.65	1.70
98	Paşaköy	524946	4340193	Sept / 2015	Apr / 2016	39.01	19.43
104	Soma	549910	4338255	Sept / 2015	Apr / 2016	2.70	1.84
105	Kırkağaç	561333	4330887	Sept / 2015	Apr / 2016	9.78	9.78
106	Siledik Village	566831	4333708	Sept / 2015	Apr / 2016	48.32	42.20
107	Alacalar Village	572876	4338437	Sept / 2015	Apr / 2016	4.85	2.15