HYDROGEOLOGICAL INVESTIGATION OF THE KAŞ - KALKAN AREA AND ITS VICINITY

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ABSTRACT

The present study comprises the hydrogeological investigation at the Kaş-Kalkan research site. The main objectives of this study, are to investigate the hydrogeological structures (features) which may affect and/or control the Karst water resources potential in such coastal region, and to obtain hydrogeological information which might be needed in the planning and implementation of water supplying projects for a near future.

In order to achieve these objectives, series of studies and works were carried out in the field and in the laboratory including (1) surface and subsurface geological studies, (2) hydrological regimen characteristics, (3) isotopic analysis of water samples (4) analysis of aerospace images covering the study area, (5) hydrogeological studies in the mainland and along Kaş-Kalkan coastline, (6) In-situ and laboratory works to determine the quality of groundwater in the research site.

Most of the lithological units at the research site, belong to the Beydağları Carbonate platform, which is considered as one of the major tectonostratigraphic units of the Teke Lycian Taurus, the western limb of the western part of the Outer Taurus Mountains.

Study of physiographical and climatic conditions of the Kaş and Kalkan towns is considered as one of the most important tools for indicating the influence of the site topography on the areal distribution of precipitation, in such coastal karstic region. The inland side of the study area is highly dissected and became rugged due to the intense faulting, folding and different rock weathering.

At the research site, there are mainly four major hydrogeological units. These units were differentiated according to their individual structural and hydrogeological characteristics, into Karstic Lower and Upper Units, Impervious Lower Unit, and the Quaternary deposits (alluvium).

Recharge of the groundwater basin is calculated depending on the volumetric determination of the water amounts (percentages) that may be infiltrated through different hydrogeologic units. The autochthonous pervious units include the Jurassic-Upper Cretaceous Beydağları limestone, Eocene Susuzdağ dolomitic limestone, and the Upper Miocene Dirgenler Conglomerates.

Comparison of the field observation, geological and lineament maps, has shown that most of the widespread karstic features were located at the northern and northwestern parts of the study area, where most of the intersection of lineaments were plotted. Eventually, the availability of the different Karstic features along the mainland faultlines, may also reflect the main groundwater flow direction through the coastal aquifer (Beydağları limestone).

Insitu and laboratory determinations of groundwater quality suggested that the groundwater of the study area, except the brackish water disharged from the coastal springs, is generally suitable for drinking and agricultural purposes.

ÖZET

Sunulan çalışma Kaş-Kalkan alanının hidrojeolojik incelemesini içermektedir. Bu çalışmanın amaçları, bu tür bir kıyı bölgesinde karst su kaynakları potansiyelini etkileyecek ve/veya denetleyecek hidrojeolojik yapıların (özelliklerin) incelenmesi ve yakın bir gelecekte su sağlama projelerinin planlanmasında ve uygulanmasında gerek duyulacak ön hidrojeolojik bilgilerin elde edilmesidir.

Bu amaçlara ulaşmak için, (1) yüzey ve yeraltı jeoloji incelemeleri, (2) hidrolojik rejim özelliklerinin ortaya konması, (3) inceleme alanını kaplayan uzay görüntülerinin analizi, (4) ana havzada ve Kaş-Kalkan kıyı şeridinde hidrojeolojik koşullar, ve (5) inceleme alanındaki yeraltısuyunun kalitesinin belirlenmesine yönelik yerinde ve laboratuvar analizlerini içeren bir dizi arazi ve laboratuvar inceleme ve çalışmaları yapılmıştır.

İnceleme alanındaki litoloji birimlerinin büyük bir bölümünü, Toros Dağlarının batı kesiminin batı kanadını oluşturan ve Teke-Likya Toroslarının ana tektonostratigrafik birimlerinden biri olarak bilinen Beydağları Karbonat Platformuna ait birimlerdir.

Kaş ve Kalkan yörelerinin fizyografik ve iklimsel açıdan incelenmesi, bu tür bir kıyı karst bölgesinde topoğrafyanın, yağışın alansal dağılımına etkisinin belirlenmesinde yararlanılabilecek çok önemli bir araç olarak ele alınmıştır.

İnceleme alanının iç kesimleri, faylanma, kıvrımlanma ve farklı kayaç bozunmalarından ötürü ileri derecede paralanmış bir görüntüye sahiptir.

İnceleme alanında, dört ana hidrojeolojik birim bulunmaktadır. Bu birimler, yapısal ve hidrojeolojik özelliklerine göre Karstik Alt ve Üst Birimler, Geçirimsiz Alt Birim ve Kuvaterner Çökeller (alüvyon) olarak ayırdedilmişlerdir.

Yeraltısuyu havzasının beslenimi, başlıca, farklı hidrojeolojik birimlerde süzülen suların hacimsel veya yüzde olarak belirlenmesi şeklinde hesaplanmıştır.

Jura-Üst Kretase yaşlı Beydağları kireçtaşı, Eosen yaşlı Susuzdağ dolomitik kireçtaşı ve Üst Miyosen yaşlı Dirgenler çakıltaşlarını Otokton geçirimli birimler oluştururlar.

Arazi gözlemleri ile jeoloji ve çizgisellik haritalarının karşılaştırılması sonucunda, karstik yapıların en yaygın olarak inceleme alanının kuzey ve kuzeybatısında yeraldığı görülmüştür. Burada, fayların kesiştiği bir çok nokta işaretlenmiştir. Buna göre, iç kesimlerdeki fay hatları boyunca farklı karstik yapıların bulunması, aynı zamanda, kıyı akiferine (Beydağları kireçtaşı) doğru oluşan yeraltısuyu akım yönünü de göstermektedir.

Yerinde ve laboratuvarda yapılan yeraltısuyu kalitesi incelemelerinde, inceleme alanındaki yeraltısuyunun kıyı yakınındaki denizsuyu biraz tuzlu olan kaynaklar hariç genellikle içme ve sulama açısından uygun olduğunu göstermektedir.

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1. INTRODUCTION

1.1. Purpose and Scope

The widespread extended karstic regions along the Mediterreanean Coast of Turkey appear to be more sensitive to the environmental changes than do other rock terranes. This is related to the karst dynamic and the tendency of carbonate rocks to develop local and deep zones of high permeability which causes sometimes many problems in addition to its distinctions in such coastal regions.

One of the major problems in coastal karst areas is the loss of fresh groundwater discharging into the sea before it can be used. This phenomenon has been observed along the coastline of Kaş-Kalkan towns on the Mediterranean coast of Turkey (Fig. 1).

The present study comprises detailed hydrogeological investigation at the Kaş-Kalkan region. The main objectives of the study, are to investigate the geological and hydrogeological structures (features) which affect and/or control the karst water resources potential in such coastal region, and to obtain hydrogeological information which might be needed in the planning and application of water supplying projects for a near future.

In order to achieve these objectives, series of studies and works had been carried out in the field and in the laboratory including (1) surface and subsurface geological studies, (2) hydrological and hydrogeological regimen characteristics, (3) isotopic analysis of water samples (4) analysis of aerospace photographs covering the study area, (5) hydrogeological conditions in the mainland and along Kaş-Kalkan coastline, (6) in-situ and laboratory works to determine the quality of groundwater in the study area.

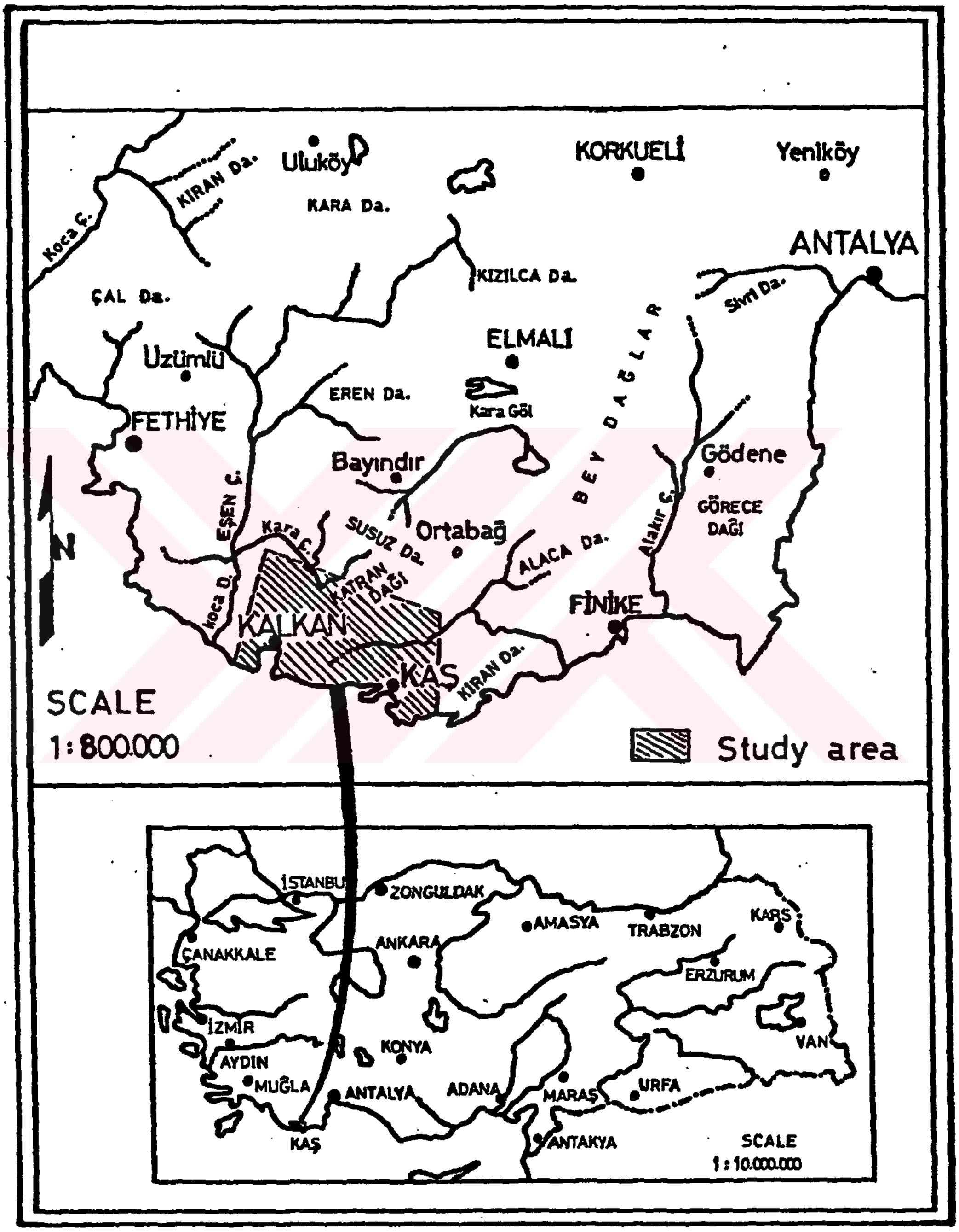


Figure 1.1. Location map of the study area.

1.2. Location and Accessibility

The study area is located at about 170 km southwest of Antalya city on the Mediterranean coast of Turkey. Kalkan is a district of Kaş, located about 26 km to the west of Kaş and 80 km. southeast of Fethiye (Fig. 1.1). Kaş-Kalkan countryseats are located near the provincial highway which runs along the coast to Antalya and Fethiye. This makes the study area accessible.

Mediterranean climate, indescribable nature beauty, numerous peaceful bays, and historical sites make Kaş-Kalkan the ideal place for touristic activities and fishing. Therefore, the essential income is tourism. Farming is the major occupation at the small villages which are located near Kaş and Kalkan towns.

1.3. Previous Studies

The study area is located at the southwestern part of the Central Autochthonous Unit (Beydağlari Carbonate Platform), which is considered as one of the major tectonostratigraphic units of the Teke Lycian Taurus. This had been subjected to numerous previous geological investigations.

-Brunn et al., 1971, indicated that the Taurus Belts belongs to the southern sector of the Alpine-Mediterranean chain, comprising the longest major tectonic belt of Turkey.

-Demirtaşlı (1981), differentiated the western and central parts of the Taurus Belts into two distinct units; the Inner Taurus Belts at the north and outer Taurus Belt at the south (Fig.1.2). The Inner Taurus Belt starts from the west, covering the southern edge of the Menderes massif and mainly composed of slightly metamorphozed limestones. The non- metamorphic carbonates and the clastic of the outer Taurus Belt are thrust over either the wild flysch and/or the metamorphic rocks of the Inner Taurus.

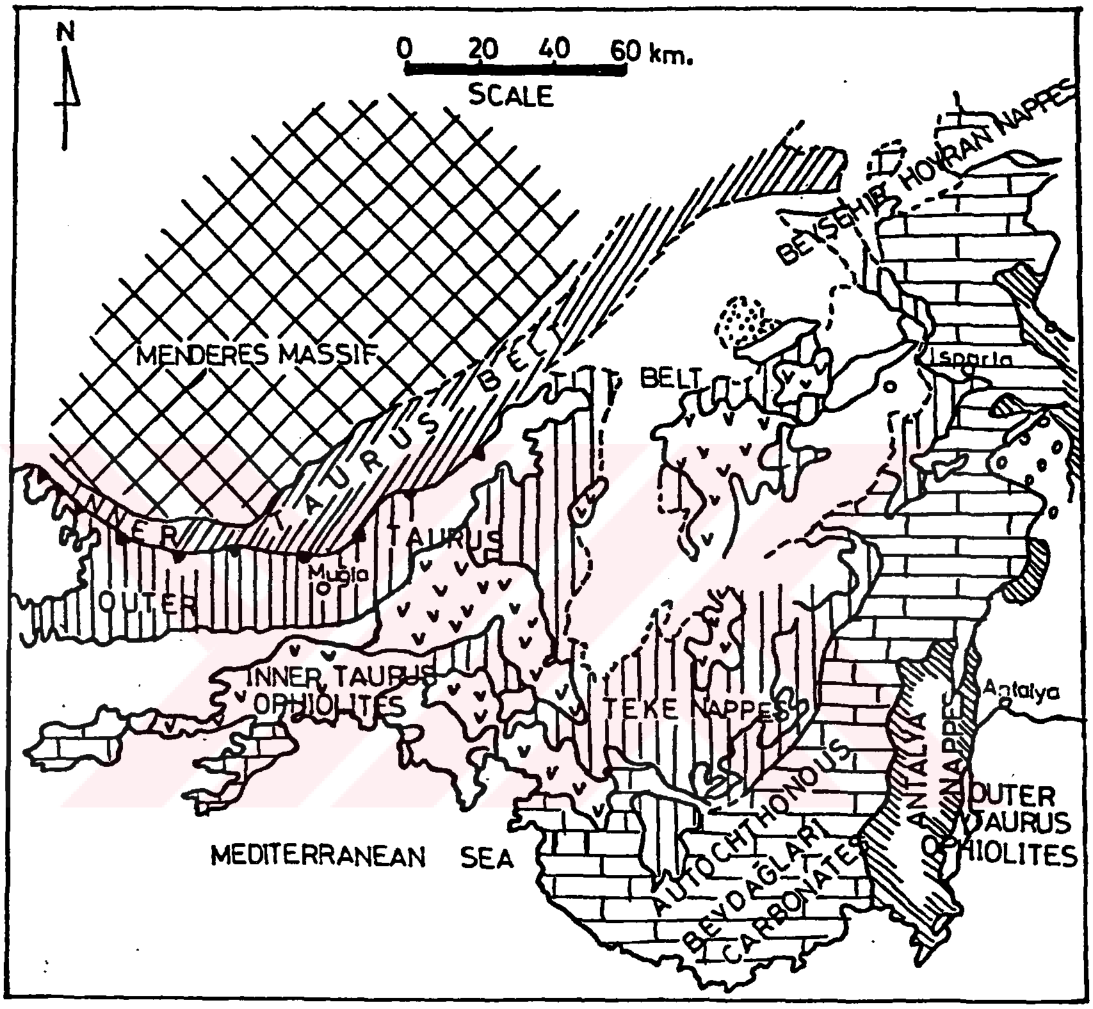


Figure 1.2. Major Tectonic Structures of the Teke Lycian Taurus (after Demirtaşlı, 1981)

The western part of the Outher Taurus forms an arcuate belt divided into two limbs on either side of the Gulf of Antalya. The western limb which trends in the northeast-southwest direction, is defined as "the Teke (Lycian) Taurus". The Teke Lycian Taurus consists of a Central Autochthonous unit, the Beydağları carbonate platform, and in the other sides of which lie two Allochtonous units, the "Teke Nappes" to the west and the "Antalya Nappes" to the east.

-Şenel and Serdaroğlu (1989), studied in detailed the litho-stratigraphical caharacteristics of the Autochthonous Beydağları carbonate platforms in Kaş-Kalkan region and its vicinity.

-Detailed studies in the tecto-genetic classification and hydro-geological properties of the karst regions in the southern part of Turkey, were performed by Günay and Eroskay, 1979.

-Relevant previous geophysical, hydrogeological and hydrochemical studies of Kaş-Kalkan were initiated by D.S.I. (1983) for investigating the possibilty of intercepting the coastal and submarine springs for beneficial uses.

2. GEOLOGY

2.1. Introduction

The investigation area is located at the southwestern part of the Central Autochthonous Unit, the Beydağları carbonate platform, which forms one of the major tectonostratigraphic units of the Teke Lycian Taurus, the western limb of the western part of the Outer Taurus mountains. This also includes two allochthonous units; the "Teke Nappes" to the west and the "Antalya Nappes" to the east. These tectonostratigraphic units were emplaced during the late Mesozoic and early Tertiary orogenic events (Delaune-Meyere, et al., 1977) which caused the unconformity between the different lithological units existing in the study area.

As seen in Figure 2.1, the study area comprises the sedimentary rocks from the Jurassic-Upper Cretaceous to Quaternary which were deposited in a stable environment. The youngest unit includes the consolidated and unconsolidated deposits of the Quaternary age. The Jurassic-Upper Cretaceous limestone of the Beydağları Formation which exists along the coastline and at higher altitudes, is the oldest autochthonous unit in the study area. Generally, the autochthonous lithological units of the study area include Beydağları, Gedikbaşı, Susuzdağ (Garipçe fm.), Sinekçi and Kasaba (Dirgenler) formations. Whereas, the allochthonous units include the Kaymaklı and Kozağacı formations, and the post tectonic unit of the Çamal formation (Fig. 2.2).

2.2. Autochthonous Units

2.2.1. Beydağları formation

The Beydağları formation (Jkb) of Jurassic-Upper Cretaceous age exists along the coastline of Kaş-Kalkan, in the northeastern part of Kalkan and in the eastern part of the Kaş, at higher elevations. It

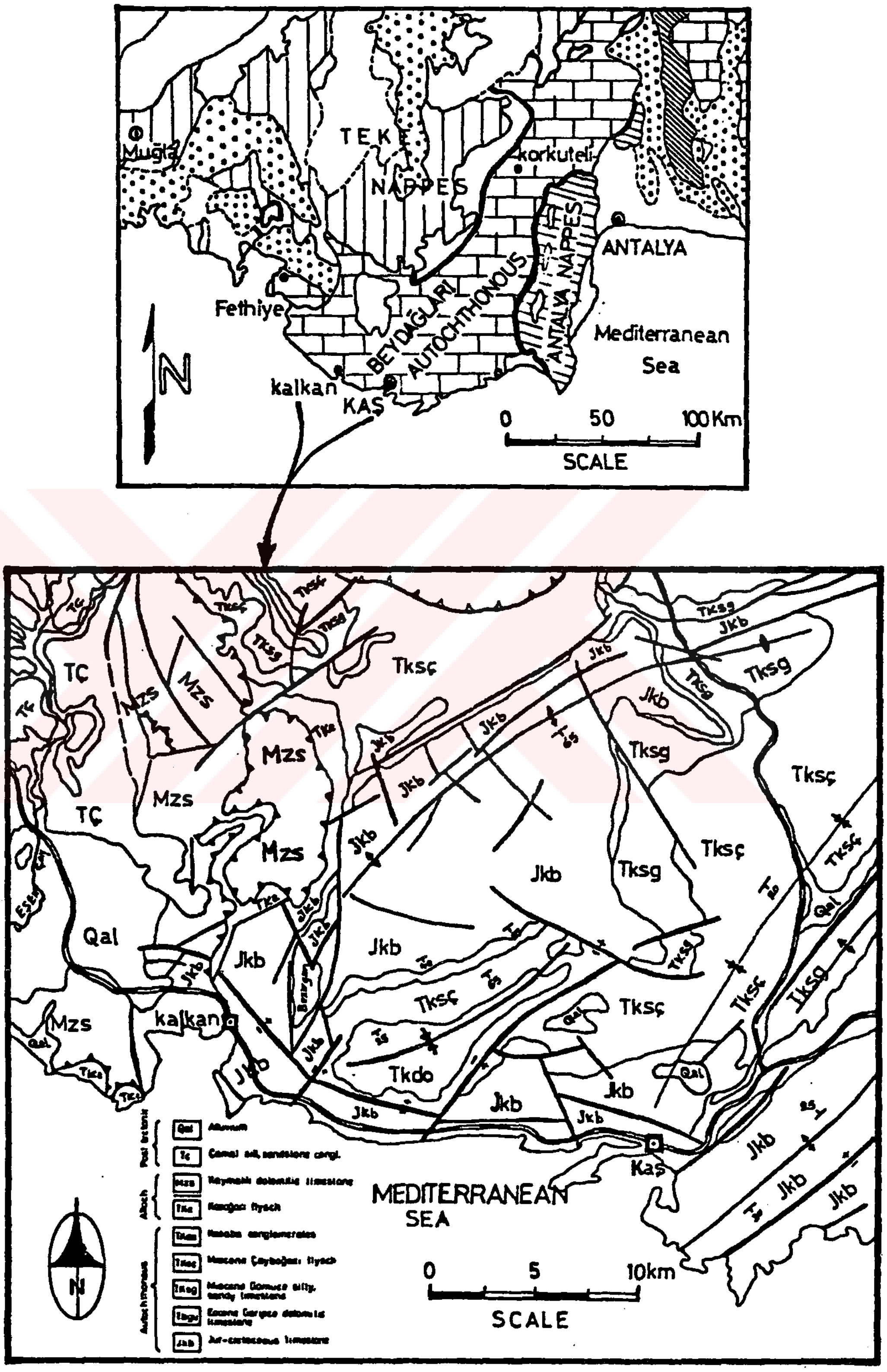


Figure 2.1. Geological map of the study area (after Şenel, 1989).

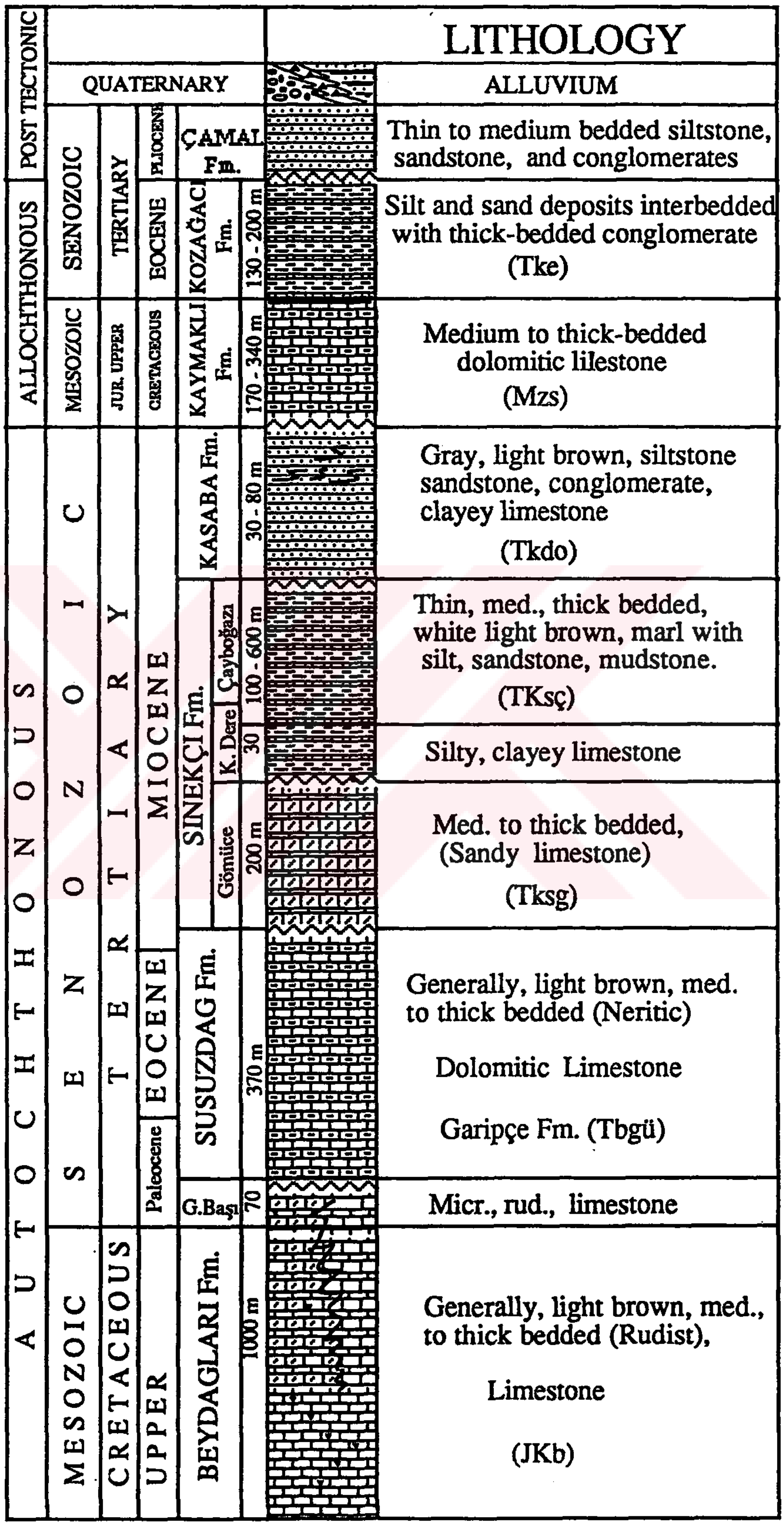


Figure 2.2. Generalized stratigraphic column for the southwestern part of the Central Autochthonous Unit, Beydağları platforms.

has a rather uniform sequence with thickness of about 1000 m. The Beydağları formation is composed mainly of white, grey, light brown, medium to thick-bedded to massive fossiliferous dolomitic limestone. It is conformably overlain by Gedikbaşı formation of Paleocene age. According to the Geological Researchers of MTA (in Ankara), the Beydağları formation is subdivided into two members depending on the basis of its lithostratigraphic characteristics. The lower member is composed of medium to thick-bedded massive limestone. Whereas, the upper member (Tekkeköy) is composed of medium to thick-bedded neritic limestone with lateral facies changes of thin to medium-bedded silty to clayey limestone. The Gedikbaşı formation has the same lithological features of this unit.

The field observations showed that the outcrops of the Beydağları limestone are highly fractured, folded, and karstified. The occurrence of surface and subsurface karstic features is dominant especially along the coastline. It is covered by surficial, reddish brown, thin layers of residual bauxite deposits and alluvium. Generally, the bauxite is encountered along with the karstic depressions in this area. The Gedikbaşı formation is about 50-70 m thick, and unconformably overlain by the Eocene dolomitic limestones of the Susuzdağ (Garipçe) formation (Tbgu).

2.2.2. Susuzdağ (Garipçe) formation

The Susuzdağ (Garipçe) formation (Tbgu) of Middle Eocene (Burdigalian) age, unconformably overlies the Beydağları formation (Jkb). It is unconformably overlain by the lower Miocene Gömüce limestones (Tksg), the lower member of the Miocene Sinekçe formation (Tks). The Garipçe formation (Tbgu) crops out in the northern and northeastern parts of the study area, with thickness of 250-300 m. It is mainly composed of light brown, medium to thick-bedded crystalline, neritic fossiliferous limestone. This unit forms the surrounding mountains of the Bozova plain site which is located at the northeastern part of Kaş.

2.2.3. Sinekçe formation

The Sinekçe formation (Tks) of Early-Middle Miocene (Burdigalian-Langhian) age is subdivided into mainly three members extending in the northern and northeastern parts of the study area. These members are Gömüce, Kıbrısdere, and Çayboğazı.

2.2.3.a. Gömüce member

The Gömüce member (Tksg) of Lower Miocene age is composed of light brown, medium to thick-bedded silty to sandy limestones. It is either unconformably overlies the Eocene Garipçe limestones (Tbgu), or locally, the Upper-Cretaceous Beydağları limestones (Jkb). It is conformably overlain by the Miocene Çayboğazı flysch member. The thickness of Gömüce member ranges between 50 to 150 m. It crops out in the north eastern of the study area.

2.2.3.b. Kıbrısdere member

According to the previous geological studies (Şenel M., 1989), it is about 20-50 m. thick and composed mainly of silty, clayey limestone. The Kıbrısdere member (Burdigalian) does not crop out at the study area.

2.2.3.c. Çayboğazı member

The Çayboğazı member (Tksç) is mainly composed of white, cream, light brown, medium to thick-bedded marl interbedded with greenish grey, light brown, thin to medium-bedded of siltstone and claystone. The thickness of this member ranges between 100-600 meters. The extended synclinal forms in the northern, and northeastern parts of the study area are indicated by this flysch unit.

The Miocene Çayboğazı member is unconformably overlain by the Kasaba formation, and unconformably overlies the Gömüce sandy limestones (Tkgs) representing a widespread distribution in the study area. The field observations showed that there is a tectonic contact zone between the Çayboğazı flysch and the Beydağları limestones units extending along the Arapyurdu, Yarıbaşı, and Sarıbelen (Sidek) at the northern parts between Kaş and Kalkan towns.

2.2.4. Kasaba (Dirgenler) formation

Kasaba (Dirgenler) formation (Tkdo) is composed mainly of gray, light brown, thin to medium-bedded, occasionally massive, crystalline silty to clayey limestone, interbedded with thin-beds of alternating clay, siltstone, sandstone and conglomerates of Late Miocene (Tortonian). Its thickness ranges between 30 to 80 meters. The Kasaba formation of Late Miocene (Tortonian), exists in the site area as the Ortabağ member which crops out along Kapıtaşdere (Intermittent stream), forming the two limbs of the synclinal shape of the Sidek Dağı. The Kasaba (Dirgenler) formation unconformably overlies the Çayboğazı flysch.

2.3. Allochthonous Units

The major existed allochthonous units of the study area are the Kaymaklı (Mzs) and the Kozağacı (Tke) formations which crop out in the northern and northeastern part of the Kalkan town. The Kaymaklı formation (Mzs) of Jurassic-Late Cretaceous is mainly composed of yellow, medium to thick-bedded dolomitic limestone, overthrusting the Paleocene-Eocene Kozağacı allochthonous formation which include two main lithological units. The upper unit of Late Eocene (Thanetian) is composed of thin to medium bedded silt and sand deposits interbedded with thick-bedded conglomerate. Whereas, the lower unit of Upper Paleocene-Eocene is mainly composed of flysch.

2.4. Post -Tectonic Units

The Post-Tectonic units include the Late Miocene-Pliocene deposits of the Çamal formation (Tç) and the Quaternary consolidated and/or unconsolidated alluvial deposits (Qal) which cover the northwestern part of the study area. The Çamal formation (Tç) unconformably overlies the Kaymaklı formation (Mzs), and is unconformably overlain by the Quaternary alluvium (Qal). It crops out in the northwestern part of the study area. This unit is composed mainly of interbedded thin to medium- bedded conglomerates, sandstones and siltstone, with thick-bedded of calcareous cemented conglomerates. The Quaternary deposits include alluvial fans, slope wash deposits, beach sands and alluvium (Fig. 2.3). The alluvial deposits (alluvium) which represent hydrogeological characteristics of semipervious unit, cover mainly the troughs and the widespread lowlands behind the Beydağları mountain in the study area. These deposits are mainly composed of brown to reddish brown silty clay, clay, and sandstone.

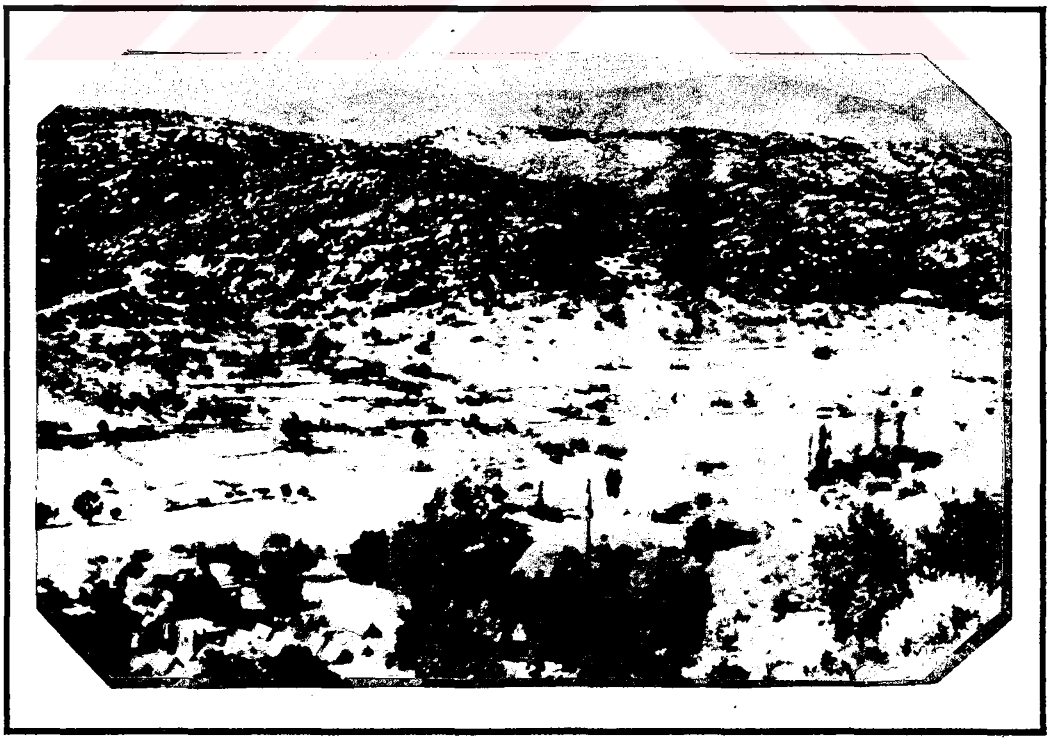


Figure 2.3. Quaternary deposits covering Bezirgan polje, north of Kalkan

The Quaternary alluvium is observed at the plains of Bezirgan and Gökçeören poljes in the north and northeastern parts of Kalkan, and at Çukurbağ and Düdenağzı sites, north of Kaş. It occurs both in consolidated and/or unconsolidated forms mainly composed of sandstone, silt, silty clay and clay.

2.5. Structural Geology

Most of the lithological units of the study area belong to the Beydağları Carbonate platform which is considered as one of the major tectonostratigraphic units of the Teke Lycian Taurus, the western limb of the western part of the Outer Taurus Mountains. Where the study area is located in the southwestern part of the Central Autochthonous Unit, Beydağları platform displays all the characters of the Alpine zone of orogeny, besides the Fethiye - Elmalı overthrust sheet (Şenel and Serdaroğlu, 1989).

Generally, the extention of the structural features is indicated by the ENE-WSW directed anticlines, synclines, normal and reverse faults, and the thrust faults which affect most of the lithological units (Autochthonous and Allochthonous) in the northern part of the study area, where most of the folds are rather asymmetrical and/or overturned.

The Outer Taurus Mountains also include two main allochthonous units, one is the "Teke Nappes" to the west and the "Antalya Nappes" to the east. These tectonostratigraphic units were emplaced during the Late Mesozoic and Early Tertiary orogenic events which caused the unconformity between the different lithological units existing in the study area.

3. KARST HYDROLOGY

3.1. Introduction

Hydrologic conditions of the study area were investigated basing on the geomorphological and climatic influences in such coastal karstic region. The available hydrologic data taken from the State Meteorological Organization (DMI) and the State Hydraulic Works (DSI), include the monthly precipitation, evaporation, and air temperature measurements covering 11 years (1980-1990). During the analyses of these data, the areal distribution of precipitation related to time and elevation, is graphically represented to illustrate the hydrologic regimen of the study area.

At the study area, there is no perennial stream, but there are some braided channels together with flood plains. Almost all creeks are dry especially during summer. Moreover, studying the nature of different topographical and geomorphological features, and the characteristics of different karstic springs in such coastal region may help in identifying the characteristics of the drainage area and the accuracy of hydrological budget.

Finally, the hydrological studies also included the isotopic survey of 14 water samples which were collected in April/May 1991 in accordance with the the sampling principles described by the International Atomic Energy Agency (IAEA), Vienna. The environmental isotope analyses of these water samples have been done in the IAEA Laboratories in Vienna, Austria.

3.2. Physiography and Climate

Study of physiographical and climatic conditions of the Kaş and Kalkan towns, is considered as one of the important tools for indicating the influence of the site topography in such coastal karstic region. The study area embraces three main topographical features including ridges and widespread troughs between them. The features which are elongated in the NE-SW and E-W directions, indicating the general topographic trends in the study area, are associated by numerous small bays and other topographic structural elements.

The inland side of the study area is highly dissected and became rugged due to intense faulting, folding and different rock weathering. The last phenomenon is clearly exhibited in the study area, where high resistant Beydağları carbonate unit forms the ridges (hills) extending along the Kaş-Kalkan coastline. While, the widespread troughs which are located behined these ridges, form the lowlands or plains of the study area (Fig.3.1). The Quaternary deposits which cover the Kaş-Kalkan bays were formed on wide, gently sloping topographic surfaces covering the Beydağları limestones.

At the study area, there are many small bays and beaches, such as Küçükçakıl and Büyükçakıl in the southeastern part of Kaş Bay, and Kaputaş and Blue Cave beaches to the southeast of Kalkan. These small beaches are developed on the coastline, where great influx of terrigenous materials or sediments occurs through the inland extended fault zones during heavy rain periods (Fig 3.2).

Most of the creeks in the hinterland side are ephemeral in nature, because of the small catchment area, much of infiltration, and intense karstification in vadose zone and in great depth along the coastline. This may sometimes cause the coastal and submarine discharges along the Kaş-Kalkan coastline.

In the study area, different topographical, geological and geomorphological structures affect and/or control the formation and development of these widespread karstic features. This is clearly exhibited in the development of different karstic springs, caves, sinkholes and poljes especially in the Düdenağzı, Gökçeören, Sarıbelen and Bezirgan regions (Fig.3.3).

a

b

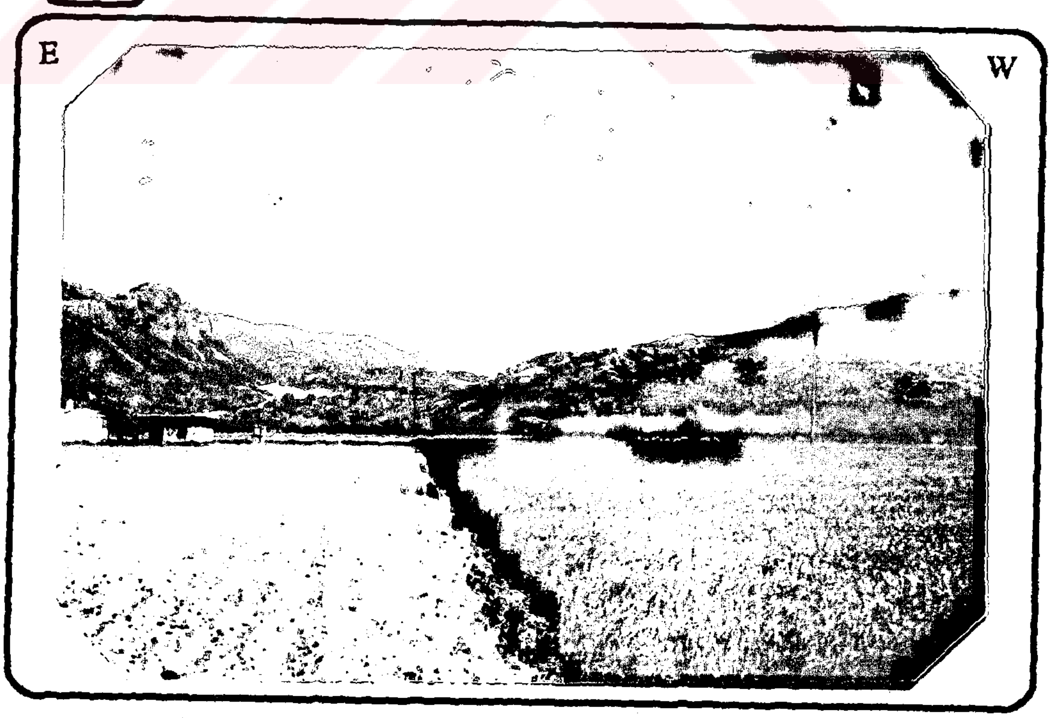


Figure 3.1. Topographical features existing in the study area
a) Beydağları mountains, b) widespread troughs

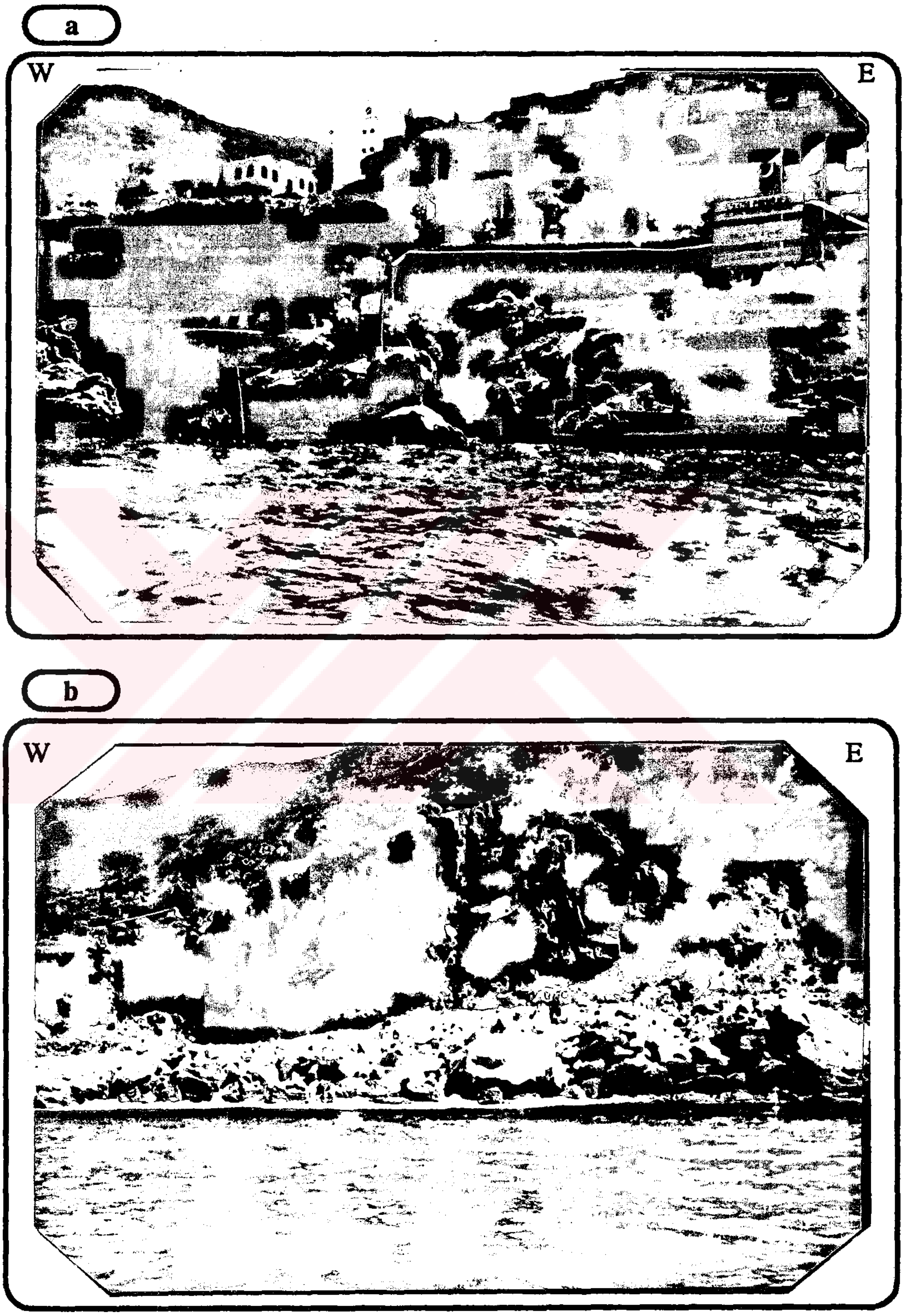


Figure 3.2. Small bays in the study area, a) Küçükçakıl, b) Kaputaş

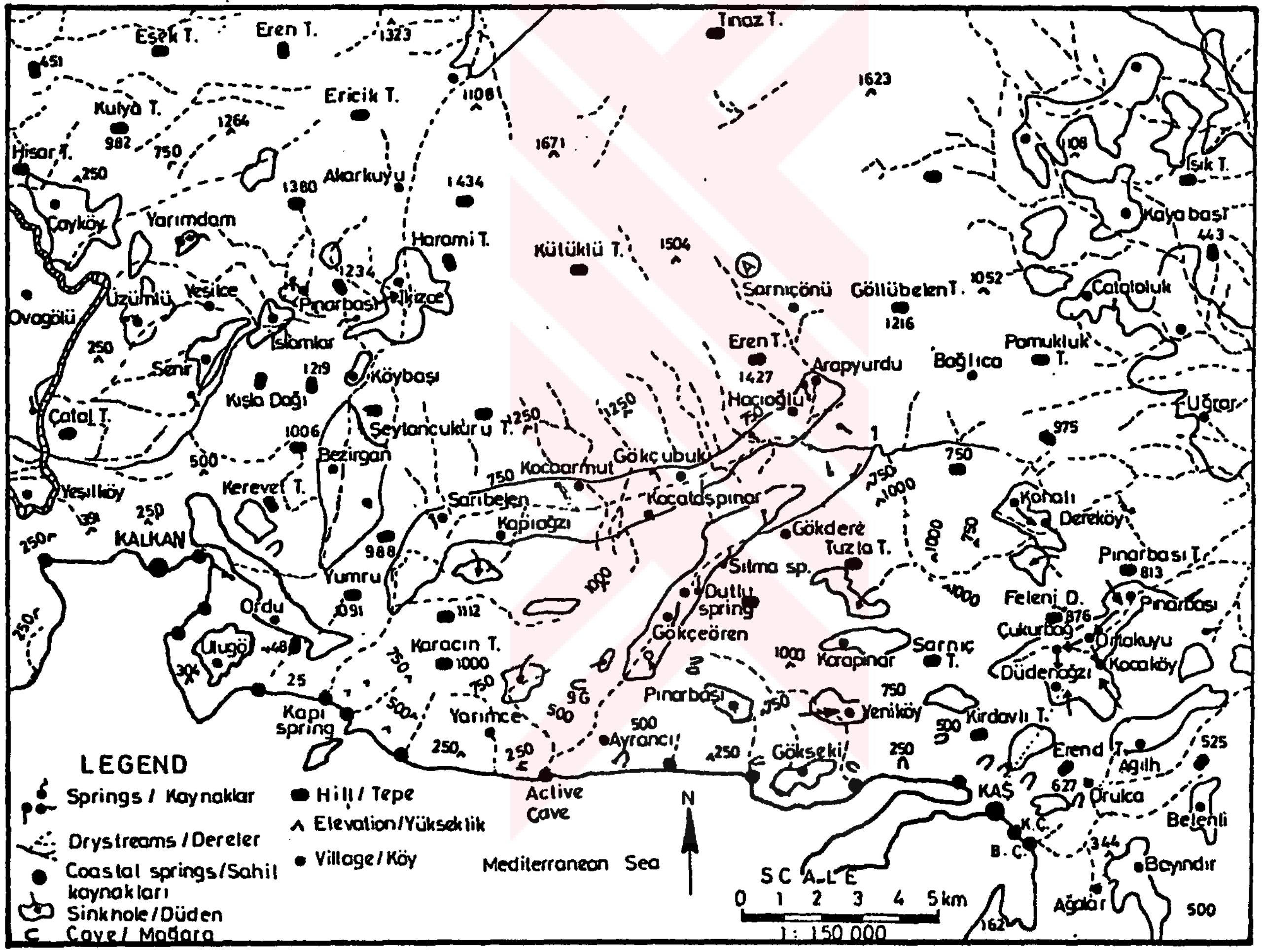


Figure 3.3. Geomorphological structures in the study area.

Bezirgan polje is considered as one of the typical karstic phenomenon which are developed along the Beydağları limestones. This polje is located at 5 km to the north of Kalkan town, covering an area of about 8 km^2. Although the southern part of Bezirgan polje may form an intermittent lake or swamp for a short time during the heavy rain periods, most of the collected surface water is drained through a sinkhole developed in the southern part of the plain. Bezirgan polje has a cultivated land covering an area of about 3 km^2, where most of the irrigation water demand is covered by the artificial pumping from the groundwater reservoirs. Field observations show that another two main sinkholes are located at the Düdenağzı and Gökçeören regions. The Düdenağzı sinkhole is formed or developed in the northeastern part of the Beydağları limestones at about 3 km. to the northeast of Kaş. While, the Gökçeören sinkhole is developed in the northeastern part of the Dirgenler formation, which is located at about 12 km. to the northwest of Kaş.

The development of the Düdenağzı sinkhole may be explained in the following manner; (1) the path followed by the water percolation throught the Beydağları limestone at Pınarbaşı hill, is controlled by the bedding planes and diverted toward the anticlinal axis which is almost coinciding with the topographic divide; (2) much of infiltrating water flows to the southwest and seeps out before reaching the groundwater table; (3) the dissolved and suspended materials contributed by the limestone have been leached but over a long period of time giving rise to the formation of a cave and eventually a sinkhole (Fig. 3.4).

The vegetation cover is generally present on the extended slopes of the surrounding Beydağları mountains, and at the planes or troughs in the northern part of the study area (Fig. 3.5). Mediterranen climate prevails in the study area, which is characterized by mild, wet winter and moderately hot and dry summer. The average annual temperatures at the study area during the given periods (1980-90) is about 19.3 °C. Almost all

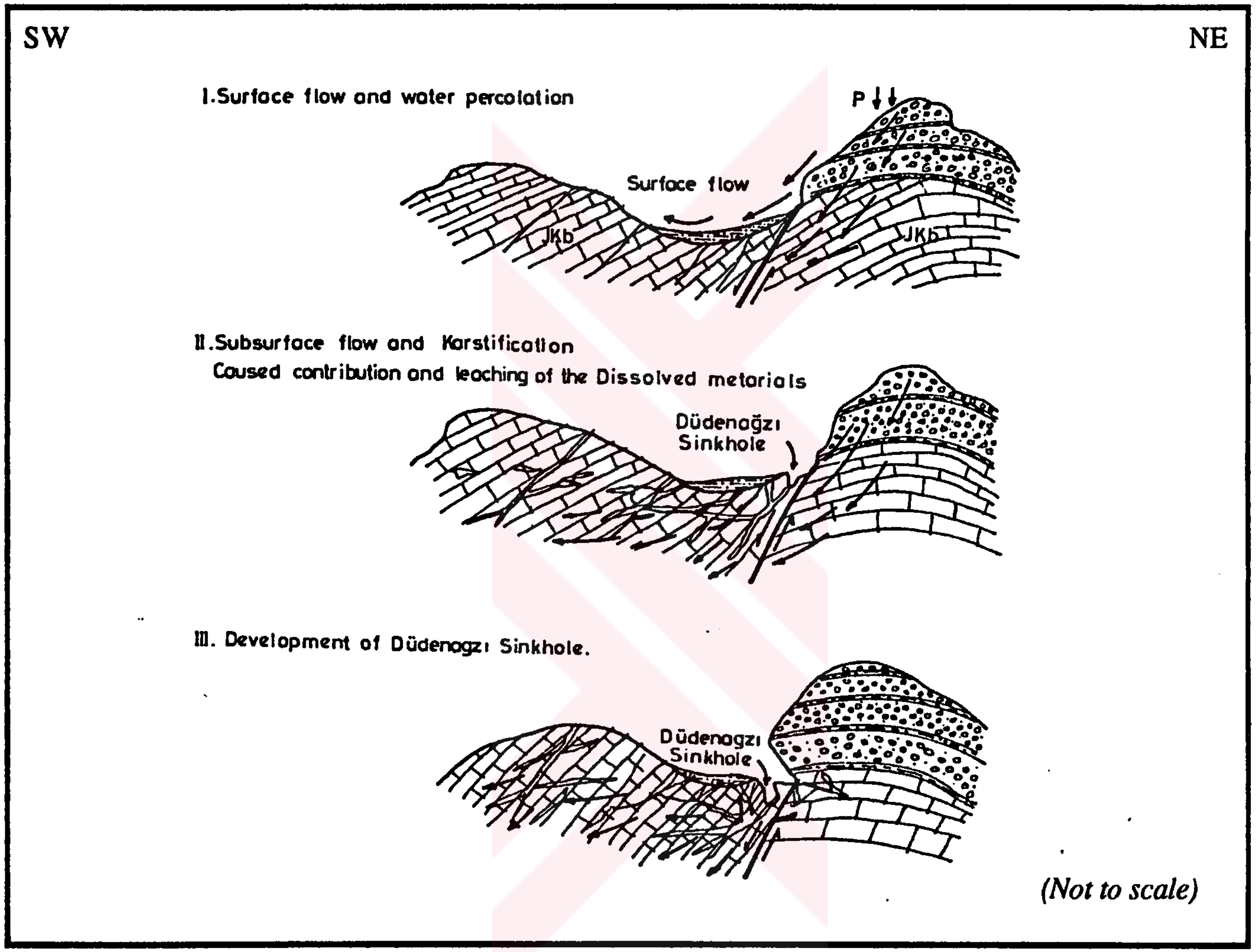


Figure 3.4. Development of Düdenağzı sinkhole.

Figure 3.5. Vegetation cover in the study area, a) in Kaş, b) in Kalkan

precipitation falls in the form of rain during the period October through May with a peak in January. Mean annual precipitation values of Kaş and Kalkan towns, during the periods between 1980-1990, are 949.7 mm. and 1118.4 mm., respectively (Table 3.1).

3.3. Analyses of Precipitation Data

In the analyses of the precipitation data location, distance from moisture source, and topography of the study area, should be considered as important factors affecting the precipitation. However, in most of precipitation distribution analyses, it is practically very difficult or even impossible to estimate the relative effectiveness of these factors (influences), especially in coastal regions. Correlation of precipitation data, drainage area and elevation of the nearby stations (surrounding the study area) may give more information about the areal distribution of precipitation and the hydrologic characters in such coastal karstic areas.

In this present study, components of precipiation data and altitudes of selected 5 stations (Kaş, Kalkan, Kale, Elmalı, Fethiye) were examined to identify the areal distribution of precipitation in the drainage area of Kaş-Kalkan and its vicinity. The available hydrologic data are obtained from the State Meteorological Organization (DMI) and the State Hydraulic Works (DSI) in Ankara (Table 3.1).

Information on the selected meteorologic stations located in and around the study area are given in Table 3.2. Length of the precipitation records of the selected meteorological observation stations is given in Figure 3.6. While, the results of the correlation analyses of these stations are given in Table 3.3. During the analyses of these data, the monthly average and annual distributions of precipitation were graphically represented for illustrating the hydrologic conditions of the study area during the wet and dry periods.

Table 3.1. Meteorological data of Kaş and Kalkan Stations

Kaş (Precipitation in mm.)

YEARS	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
1980	106.0	89.5	120.4	48.6	10.3	1.6	2.8	0.0	10.0	38.7	96.4	213.7	738.0
1981	122.6	75.4	105.2	23.8	10.0	0.0	0.0	8.0	29.6	92.7	157.3	198.4	823.0
1982	113.6	90.6	104.9	79.9	18.4	1.8	5.7	0.0	10.0	48.3	79.3	215.2	767.7
1983	125.9	187.3	146.6	42.5	11.2	1.8	4.8	2.2	18.6	51.8	97.8	197.8	888.3
1984	141.9	92.7	70.6	105.1	23.4	0.8	0.0	8.5	13.9	94.7	194.5	231.6	977.7
1985	172.5	123.4	82.9	39.3	12.5	1.4	4.0	3.1	62.9	123.4	187.5	199.2	1012.1
1986	205.6	134.8	79.9	31.4	17.9	0.0	17.2	0.0	13.8	53.9	124.8	150.6	829.9
1987	189.4	97.2	175.8	68.5	38.1	18.3	0.0	19.6	52.3	46.2	92.6	178.3	976.3
1988	117.3	251.5	207.8	89.7	18.4	0.0	0.0	17.6	47.9	82.6	163.1	195.2	1191.1
1989	129.8	172.6	203.0	114.8	41.7	13.9	0.0	13.8	53.9	49.8	129.7	207.3	1130.3
1990	184.9	128.4	172.8	57.9	23.1	6.0	0.0	13.2	23.7	91.3	148.0	197.9	1047.2
Average	146.3	131.2	133.6	58.2	19.0	11.3	3.1	12.8	30.6	70.3	133.7	198.6	949.7

Table 3.1. Continue.

Kalkan (Precipitation in mm.)

YEARS	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
1980	135.0	102.9	128.4	54.6	32.3	14.1	6.5	0.0	12.8	48.7	89.8	220.9	846.0
1981	248.3	105.2	127.6	45.6	18.4	0.0	0.0	13.2	34.7	97.8	164.9	217.6	1073.3
1982	168.7	112.3	95.2	86.3	72.0	12.4	4.5	0.0	18.0	59.6	93.2	229.8	952.0
1983	182.6	205.0	157.4	68.3	23.2	7.4	17.8	8.4	32.4	78.2	123.0	198.9	1102.6
1984	162.9	106.8	80.9	125.3	47.3	10.0	0.0	13.7	27.4	98.7	217.3	233.2	1123.5
1985	176.9	137.2	92.1	51.8	23.2	3.6	8.6	29.8	74.3	141.8	193.5	203.6	1136.4
1986	218.7	154,6	118.2	46.3	28.9	0.0	23.1	0.0	20.7	68.7	168.2	178.9	1026.3
1987	223.2	108.9	193.8	83.6	41.4	12.9	0.0	23.4	72.1	57.6	123.4	187.8	1128.1
1988	132.3	258.7	224.6	137.1	36.2	0.0	0.0	21.2	68.4	97.3	178.2	198.9	1352.9
1989	141.2	193.6	225.7	148.8	62.3	21.8	0.0	27.8	74.8	89.0	152.3	221.4	1358.7
1990	193.4	131.8	187.9	68.3	31.1	10.0	0.0	32.7	42.6	97.8	173.1	203.4	1172.1
Average	180.3	147.0	148.4	82.0	32.4	15.1	5.5	19.1	42.6	85.0	152.5	208.6	1118.4

Table 3.1. Continue.

Average temperature in the study area (in °C)												
YEARS	1	2	3	4	5	6	7	8	9	10	11	12
1980	14.8	11.3	13.2	17.4	16.9	18.8	20.9	24.2	26.0	22.3	17.2	13.6
1981	11.2	10.2	13.6	17.1	18.4	21.2	23.9	27.0	25.2	20.9	17.4	12.9
1982	12.9	11.0	13.3	16.8	21.3	23.8	27.5	28.2	24.6	22.0	16.5	13.4
1983	10.9	10.0	13.6	17.3	20.9	24.7	28.0	28.5	25.6	20.8	17.6	14.3
1984	13.2	11.4	14.3	16.5	21.6	23.8	27.3	27.6	24.2	21.6	16.8	17.7
1985	14.3	12.0	15.1	18.2	22.3	25.0	28.5	28.0	25.2	20.8	17.8	16.4
1986	13.4	12.3	15.6	19.3	22.7	24.6	26.8	27.9	26.3	21.3	16.5	13.2
1987	13.8	14.6	12.1	15.7	18.8	23.7	27.6	27.5	25.4	20.8	17.2	14.3
1988	13.6	10.2	11.8	16.7	20.3	25.2	28.0	27.6	24.8	20.7	16.9	13.8
1989	14.3	11.6	10.7	15.6	18.4	23.8	27.8	27.0	23.6	19.8	16.3	13.4
1990	13.9	14.6	11.4	18.8	21.6	24.7	28.9	28.5	25.0	20.4	17.8	14.2

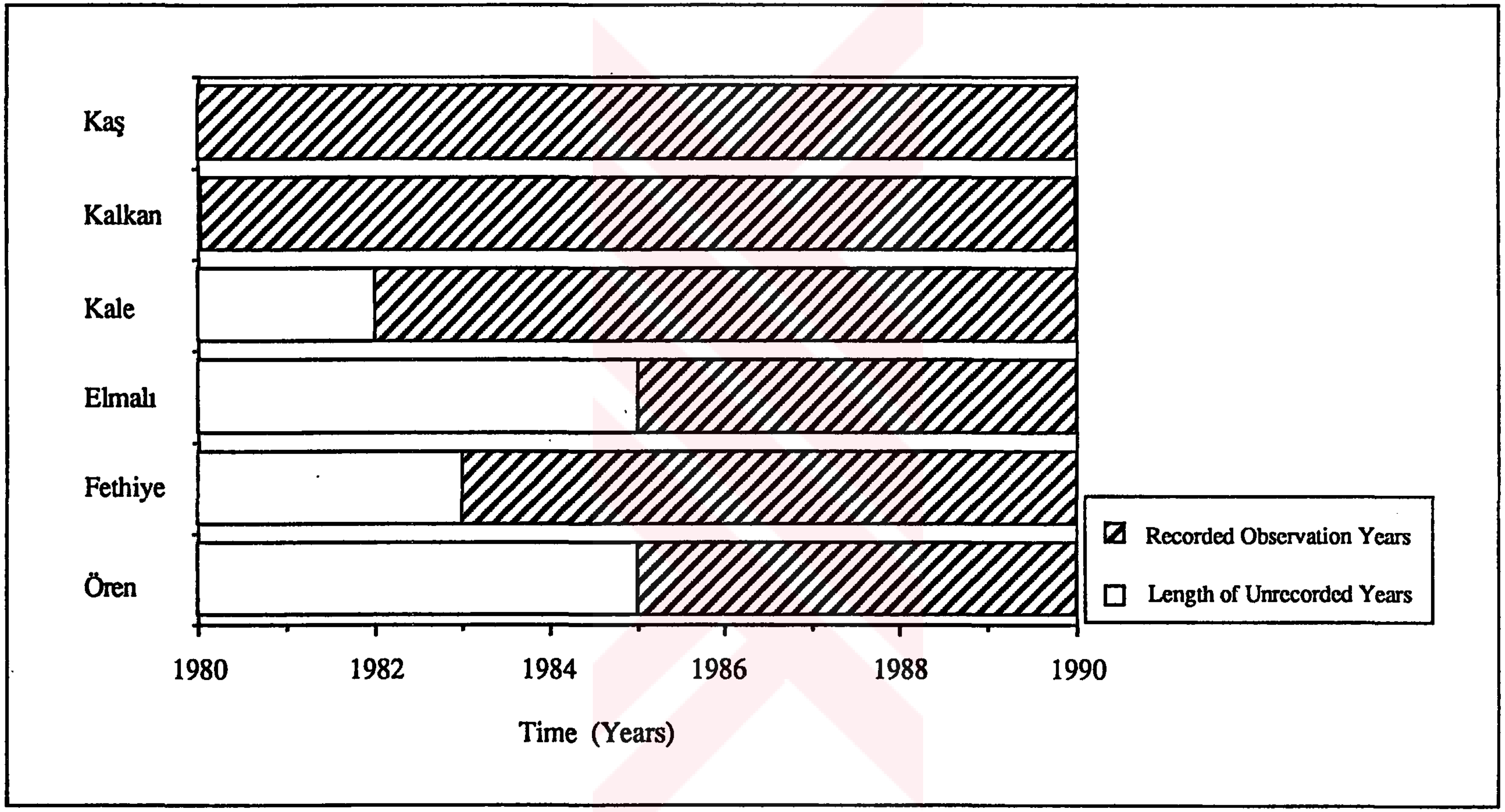


Figure 3.6. Length of precipitation records of the selected meteorological stations.

Table 3.2. Information on the Meteorological Stations nearby the study area

Station	Institutions	Altitudes (m.)	Observation periods	Mean annual precipitation (mm./year)
Kaş	DMI	35.0	1980 - 1990	949.7
Kalkan	DMI	15.0	1980 - 1990	1118.4
Kale	DMI	40.0	1982 - 1990	930.0
Fethiye	DMI	3.0	1983 - 1990	931.1
Ören	DSI	240.0	1985 - 1990	866.8
Elmalı	DMI	1113.0	1985 - 1990	633.1

Table 3.3. Results of the regression analyses of the selected Meteorological Stations

Stations	Kale	Kaş	Kalkan	Elmalı	Fethiye	Ören
Kale	1.000					
Kaş	0.935	1.000				
Kalkan	0.854	0.963	1.000			
Elmalı	0.276	0.195	0.137	1.000		
Fethiye	0.652	0.894	0.955	0.787	1.000	
Ören	0.763	0.861	0.892	0.671	0.745	1.000

For studying the orographic influences on the distribution of precipitation, the relationship between altitudes and maximum, minimum and average annual precipitation values of the selected observation stations is graphically presented. The analyses of precipitation data also include the comparison between minimum, average and maximum annual precipitation values observed in the selected stations, for studying the areal distribution of precipitation over the Kaş-Kalkan drainage area. From the correlation analyses the precipitation distribution over various elevation has been estimated for each one of the selected meteorological station.

Finally, the determination of the average areal distribution of precipitation at the study area, is carried out using the isohyetal method for the surrounding stations. This is also applied for the whole drainage area of Kaş and Kalkan towns.

3.3.1. Precipitation - time relationship

While portions of a precipitation record may suggest an increasing or decreasing trend, there is usually a tendency to return to the mean; abnormally wet periods tend to be balanced by dry periods. The regularity of these fluctuations has been widely noticed and investigated, especially in the coastal areas. However, with the exception of daily and seasonal variations, no persistent regular cycles of any appreciable magnitude have been conclusively demonstrated (Mitchell,1964).

During the analyses of the precipitation data for the period 1985-1990, the fluctuations of dry and wet seasons in the study area through the last six years show high regularity range (Fig.3.7). Where almost all precipitation falls in the form of rain during October through April with a peak in December. Thus, the wet periods in Kaş and Kalkan generally, take place from October to April and then the dry periods start from May to September.

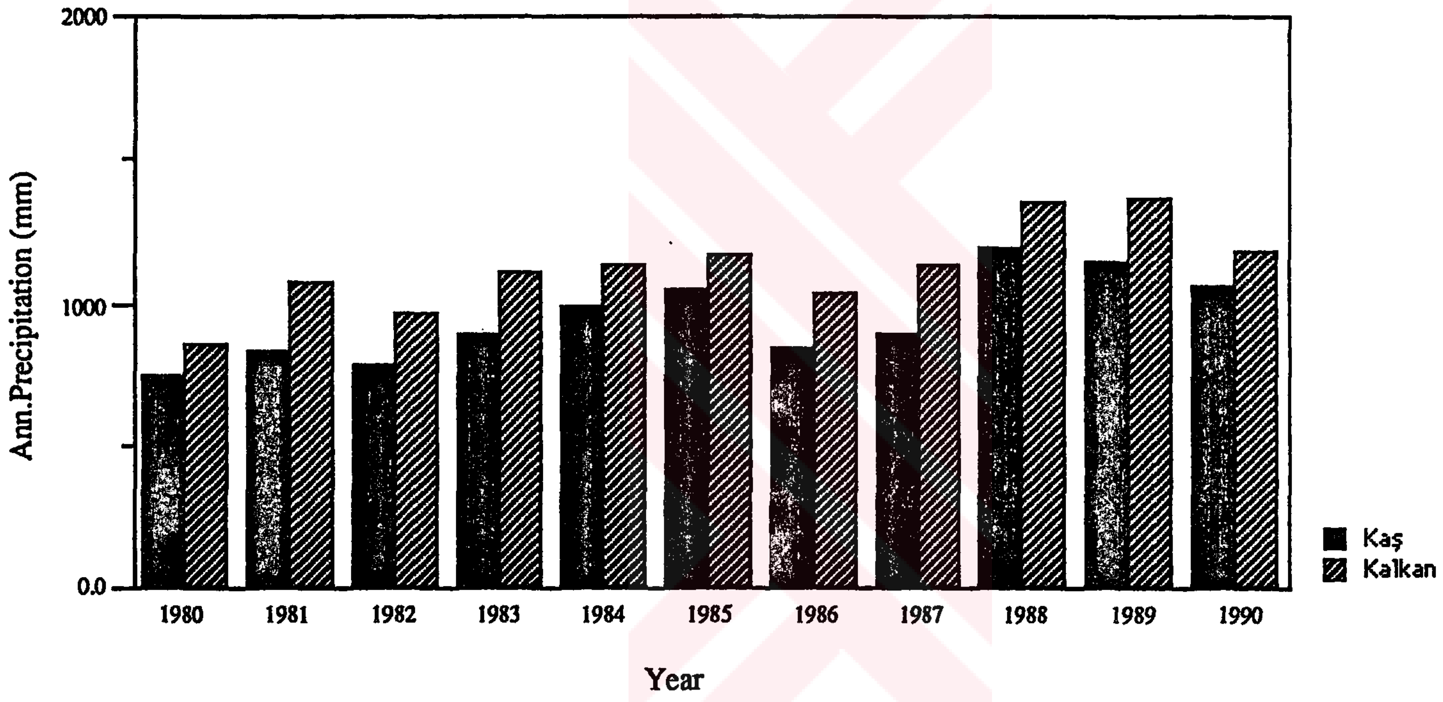


Figure 3.7. Distribution of annual precipitation in Kaş and Kalkan during the periods 1980 to 1990

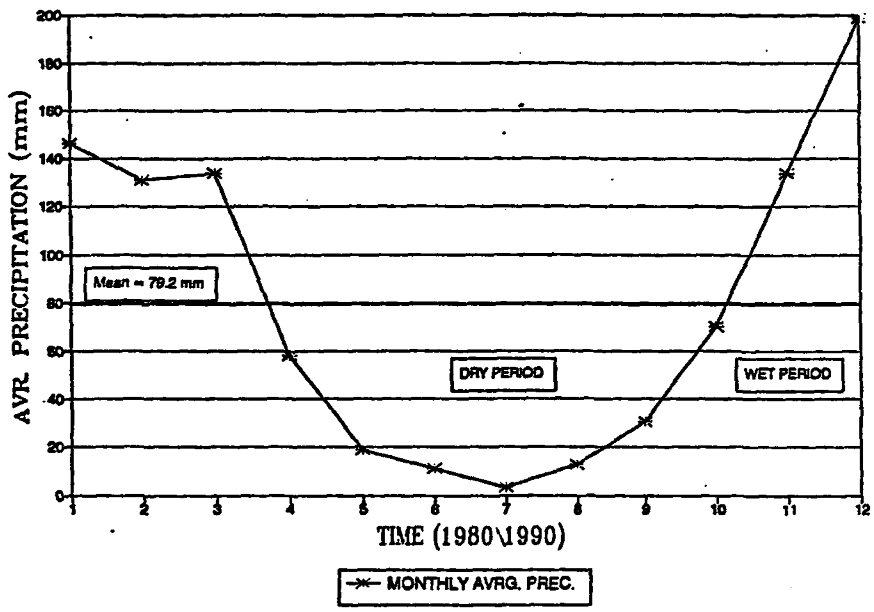
The distribution of the average monthly precipitation in the study area during the last eleven years (1980-1990), is given in Figure 3.8. Moreover, most of the selected observation meteorologic stations are located around the study area.

3.3.2. Precipitation - elevation relationship

Since precipitation is chiefly the result of air masses lifting, amounts and frequency are usually greater on the windward side of orographic barriers. Conversely, since the downslope motion of air results in a significant decrease of relative humidity, the coastal mountainuous regions have usually relatively light ranges of precipitation. In general, the main source of moisture for precipitation in the coastal regions is evaporation from the surface of large water bodies (sea).

Therefore, precipitation tends to be heavier near coastlines. Thus, the relationship between the topographic altitudes and the mean annual precipitation values of the selected observation stations nearby the study area, is graphically represented for identifying the orographic enfluences on the variation and distribution of precipitation in the study area.

Firstly, all available data of the selected stations have been checked and correlated for identifying the degree of similarity and the inconsistency between each other. Results of the regression analyses including the correlation coefficients between the selected stations, are given in Table 3.3. In this study, the minimum, average and maximum annual precipitation values of the selected observation stations which show high correlation coefficients (>0.85), were used for illustrating the general slope and variation of precipitation in the investigation area.



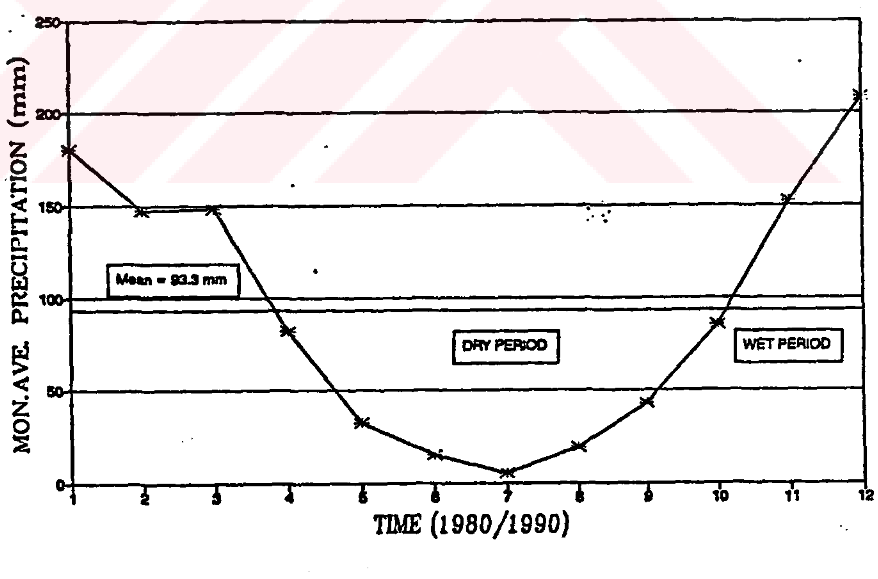


Figure 3.8. Distribution of monthly average precipitation in Kaş and Kalkan during 1980/1990.

As seen in Figure 3.9, there is no observation stations between the altitudes 300m. and 1100m. There are mainly three sub-regions reflecting the characteristics of precipitation regimen relating to the elevations above the mean sea level.

The graph shows that, the sub-regions X, Y and Z seem to be located in the regimes of shore, plateau and mountainuous types, respectively. Meanwhile, the sub-region Z (Elmalı) may represents different precipitation regimen characters from the others. This may be related to their different precipitation types, or to the geographical position of a closed basin, which exhibited in the sub-region Z.

Although, the minimum, average and maximum precipitation values of the sub-region Z are located on the same slope of this graph. It was not taken in consideration during the estimation of the precipitation amounts over the study area. Therefore, the regression analyses was carried out only between the sub-region X (Kaş, Kalkan, Fethiye and Kale) and Ören which symbolizes the sub-region Y (Fig. 3.10).

As seen in this graph, the precipitation seems to be decreased gradually from the coastal region (shore) to the hinterland sides. At the same time, the precipitation increases irregularly in some of the coastal regions, as in Kalkan and Fethiye. As result of the correlation between the altitudes and minimum, average and maximum precipitation values, the orographic distribution of precipitation in the study area might be calculated as;

a) Min. Estimated Precipitation = - 0.066 x Elevation + 544.7
b) Ave. Estimated Precipitation = - 0.550 x Elevation + 996.0
c) Max. Estimated Precipitation = - 0.900 x Elevation + 1292.9

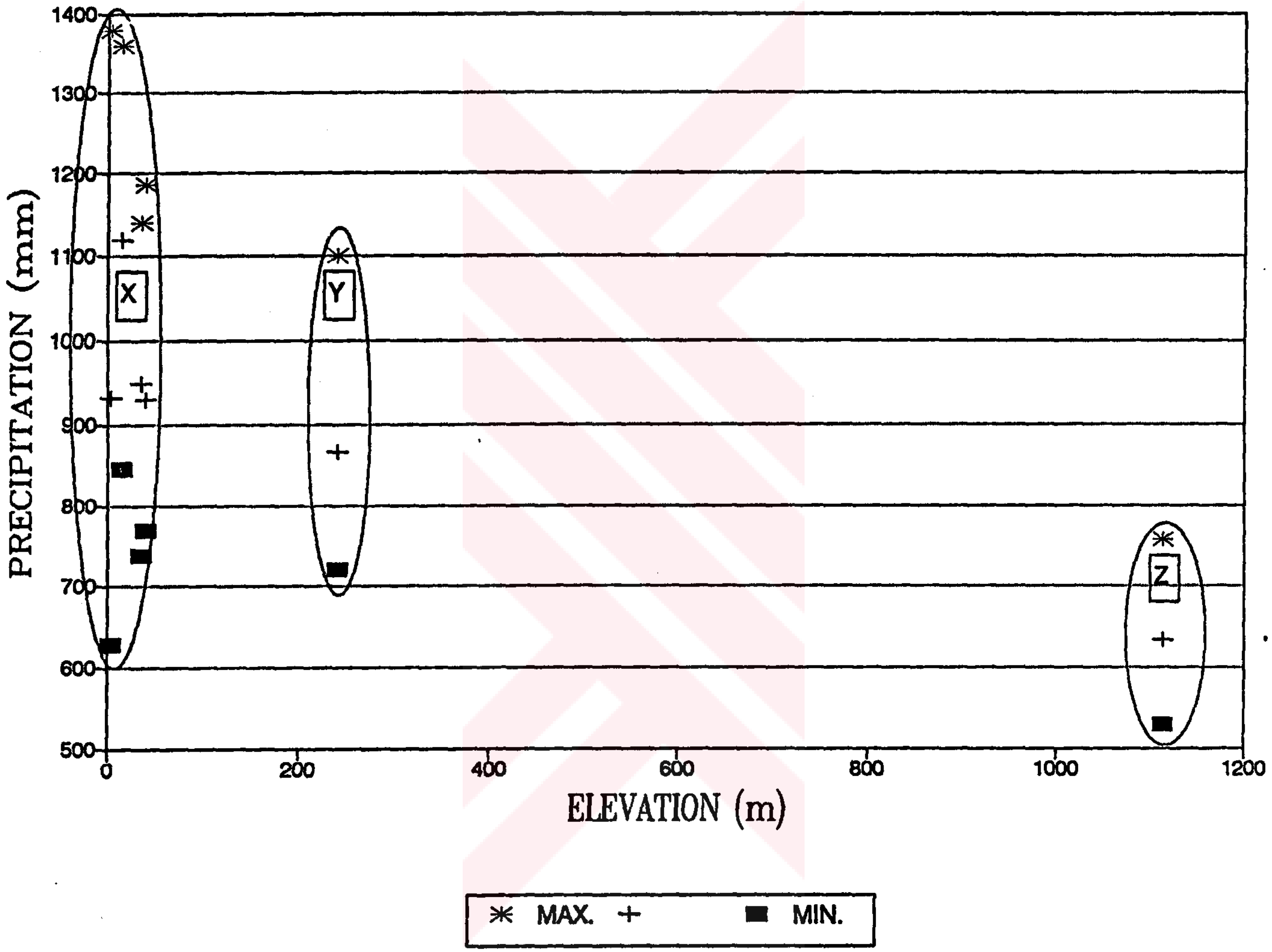


Figure 3.9. Precipitation - Elevation relationship graph of the study area.

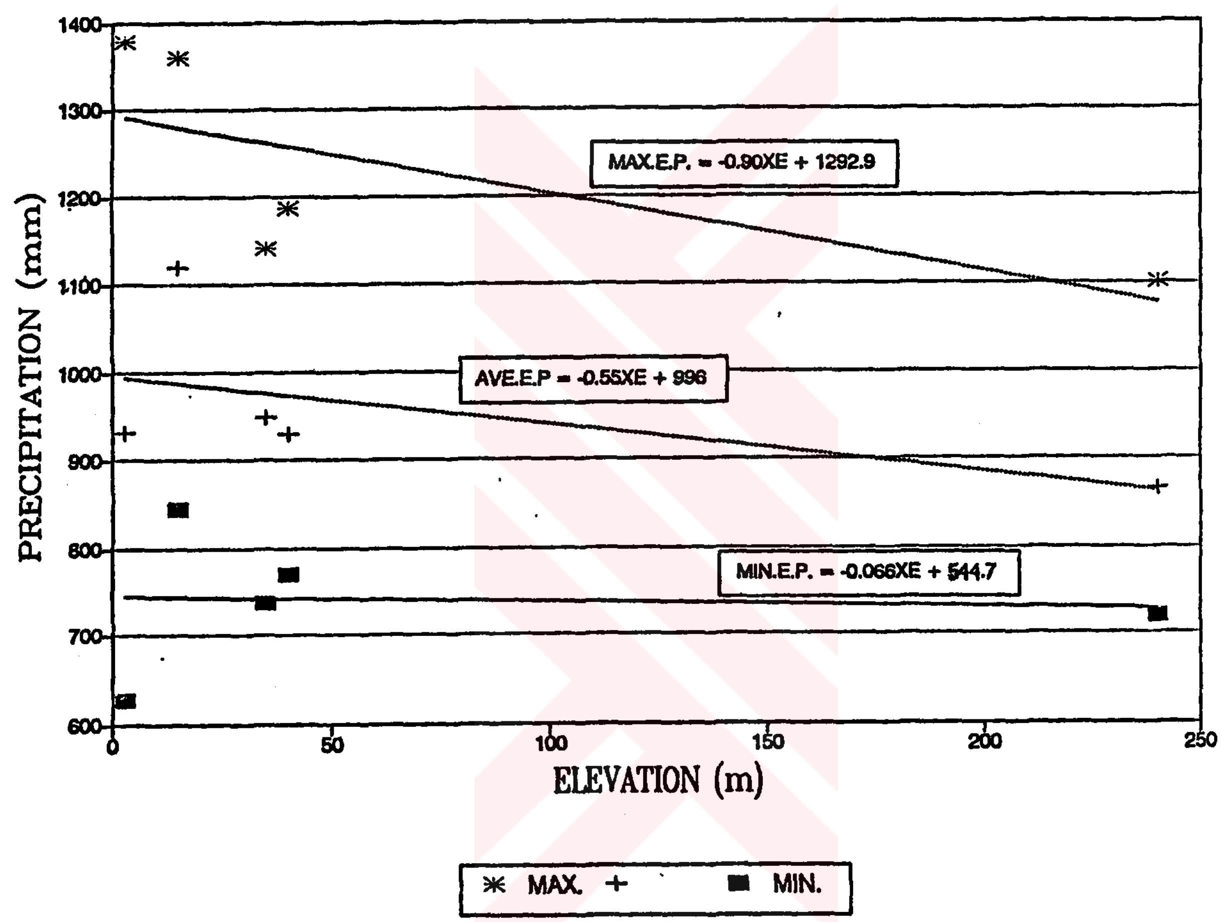


Figure 3.10. Regression analysis graph of the selected stations.

Note that the negative sign (-) is related to the reverse proportional relationship between elevation and precipitation distribution in the study area.

3.3.3. Areal distribution of precipitation

In order to determine the distribution of annual precipitation over the investigated basin, the estimated actual values have been calculated for the given periods (1985-1990), during the dry and wet seasons (Table 3.4). Note that the dry and wet periods may take place in May-September and October-April intervals respectively and show regular fluctuation or/and periodical variation in the distribution of precipitation through the last six years in the study area.

In many various hydrologic problems, which require analyses of time and elevation as well as areal distribution of precipitation, depth-area-duration analyses are also performed for determining the mean amounts of precipitation within various durations over area of different sizes. Therefore, areal distribution of precipitation over the investigation area, is studied by evaluation of the available data for the given common period (1985-1990).

In this study, the areal distribution of precipitation at the study area, is studied by using the isohyetal method. General view for the distribution of average annual precipitation over the study area and its vicinity, using the isohyetal method, is given in Figure 3.11. As seen from Table 3.5, the average annual precipitation over the research basin is about 568.0 mm.

Table 3.4. Estimated annual precipitation values of the selected Meteorological Stations.

Stations	Altitudes (m.)	Max. (mm./year)	Average (mm./year)	Min. (mm./year)	Estimated Max. (mm./year)	Estimated Ave. (mm./year)	Estimated Min. (mm./year)
Kaş	35	1140.3	949.7	738.0	1261.4	976.8	561.9
Kalkan	15	1358.7	1118.4	846.0	1279.4	976.7	563.5
Kale	40	1148.5	930.0	739.6	1256.9	974.0	561.9
Fethiye	3	1379.0	931.0	627.5	1290.2	994.4	564.3
Ören	240	1100.5	866.8	720.0	1076.9	864.0	548.7
Elmalı	1113	758.8	633.1	529.9	----	----	----

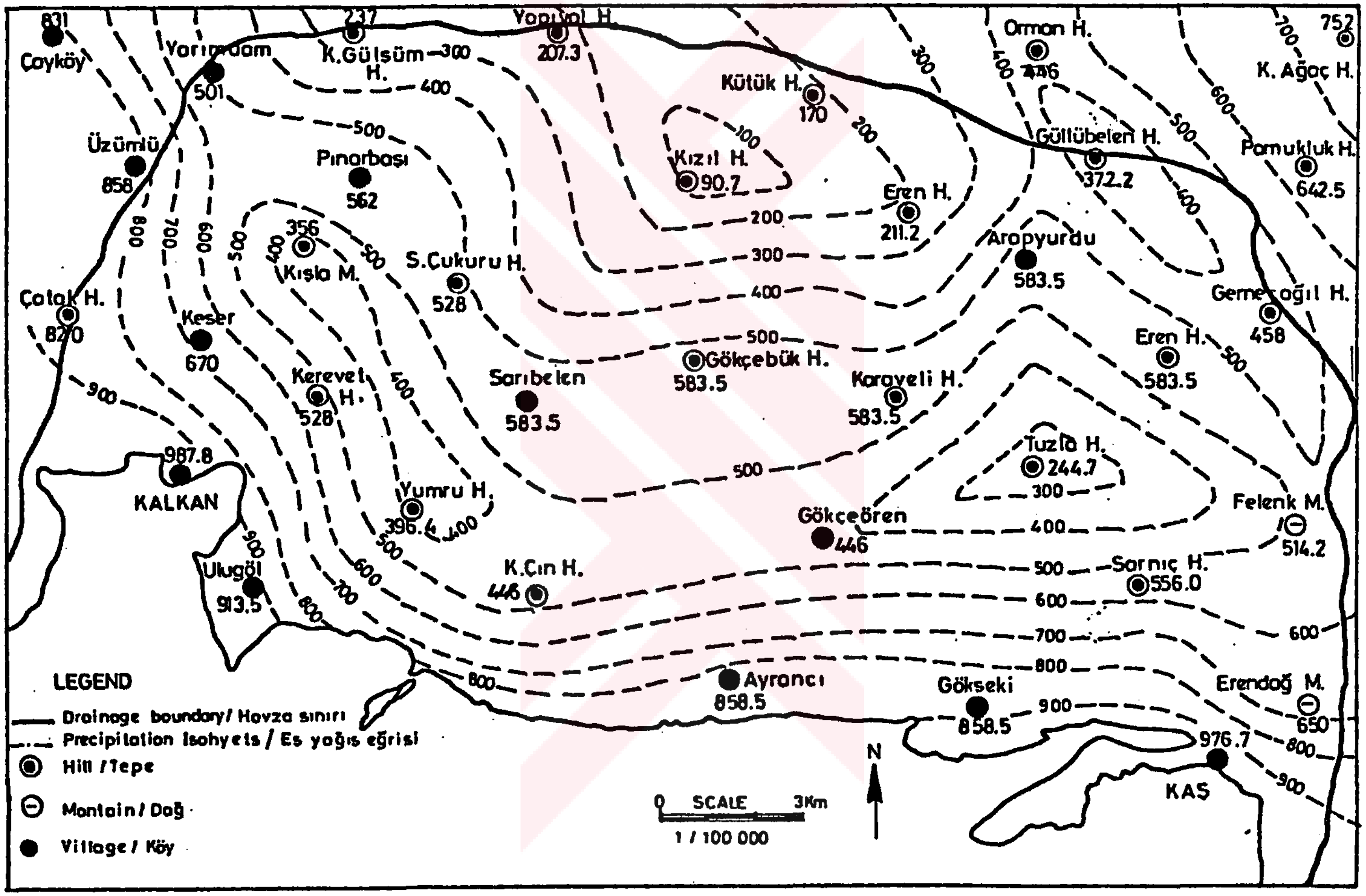


Figure 3.11. Isohyetal map of the study area.

Table 3.5. Results of the Isohyetal method applied in the study area

Isohyet No.	Area enclosed* $(km^2) \times 10^6$	Net Area (A) $(km^2) \times 10^6$	Average Precipition (P) (mm/year)x10^{-3}	Altitudes (m)	Precipitation Volume $(A \times P) \times 10^6$
1	5.5	5.5	< 100	> 1500	0.55
2	23.0	17.5	100 - 200	1300 - 1500	2.63
3	42.0	19.0	200 - 300	1150 - 1300	4.75
4	78.0	36.0	300 - 400	1000 - 1150	12.60
5	145.5	67.5	400 - 500	800 - 1000	30.40
6	251.0	105.5	500 - 600	600 - 800	58.03
7	326.0	75.0	600 - 700	400 - 600	48.75
8	359.5	33.5	700 - 800	200 - 400	25.13
9	396.5	37.0	800 - 900	100 - 200	31.45
10	425.0	28.5	900-1000	< 100	27.10
	TOTAL	**425.0**			**241.40**

* The enclosed area is calculated within the boundary of the surface drainage area

Total enclosed area = 425 km^2
Total Precipitation volume = 241.4 x 10^6 m^3/year

Average Precipitation = (241.4 x 10^6 / 425.0 x 10^6) = 0.568 m. / year

= 568.0 mm./year

* Average elevation at the research site, is determined from Elevation - Area relationship depending on 1/100.000 scale topographic map.

Average Elevation = 780 m.

3.4. Karstic Springs

In the present study, the structural and hydrological characteristics of the available karst springs are explained in detail for performing the hydrological conditions and regimen in the investigation area. The karstic springs were classified into two groups according to their location inside the basin of the study area. These groups are;

- Coastal karst springs, and
- Karstic springs in the Hinterland.

The discharge measurements of the coastal springs were carried out in mainly two methods; (1) estimating the average velocity (v) of the water flowing through cross-sectional area (a), and (2) determining the volume of discharged water in time (t). The field observations showed that the depth of the water discharging from these coastal springs was rather small to use the current meter in measuring the velocity of water. Therefore, floats were used to determine the average velocity of water for the entire section of each coastal spring.

On the otherhand, the discharge measurements of the karstic springs in the hinterland side were carried out using weirs which were constructed by State Hydraulic Works (DSI) nearby some of these springs in the study area. Moreover, the above mentioned two methods were also used for measuring the small discharges of the karstic springs at high elevations in the study area.

Finally, the physical and chemical characteristics of water samples taken from these coastal springs, were measured in the field studies during the dry (July-August, 1989-1991) and wet periods (January-February, 1990-1991), and analyzed in the Water Chemistry Laboratory of the Hydrogeological Engineering Department at Hacettepe University. These springs are also plotted on the attached hydrogeological map.

3.4.1. Coastal karst springs:

In the study area, more than 15 coastal karst springs are located at the Kaş-Kalkan coastline. These karstic springs symbolize typical developed coastal discharge points that had been formed on the intersection of mainland faultlines with the coastline in the study area. All the major ones of these coastal karst springs discharge from the Beydağları limestones. However, the coastal springs have significant continuously discharge during wet and dry periods, it was difficult to measure the actual value of this discharge. Therefore, an approximate discharge value for each one of them had been identified during the hydrogeological field studies.

3.4.1.a. Büyükçakıl springs:

The Büyükçakıl spring is located at about 2.5 km to the southeast of Kaş town, in the western bank of the Büyükçakıl beach. This spring is considered as one of the major coastal karst springs, which discharge from the Jurassic-Upper Cretaceous Beydağları limestones. The main structural feature that controls the coastal discharge from this point, is the faultline extending toward the sea after crossing the Beydağları limestones in the N70E direction.

The Büyükçakıl spring discharge from single outlet of about 50 cm. above mean sea level, with average value of 10 lt/sec and temperature below 12°C, especially during the winter season. While, during the dry periods, the discharge of the büyükçakıl spring may significantly decreases upto 2-3 lt/sec, with average temperature of 14 °C.

The outlet point of the Büyükçakıl spring is located at fault zone of about 100 m. long, filled with gravel deposits and conglomerate, indicating the extension of the mainland faultline (Fig. 3.12). Schematic cross-section was utilized for unerstanding or explaining the structural and hydrogeological conditions which cause the discharge of this coastal karst spring (Fig. 3.13).

Figure 3.12. Büyükçakıl discharges from the coastal Beydağları limestone.

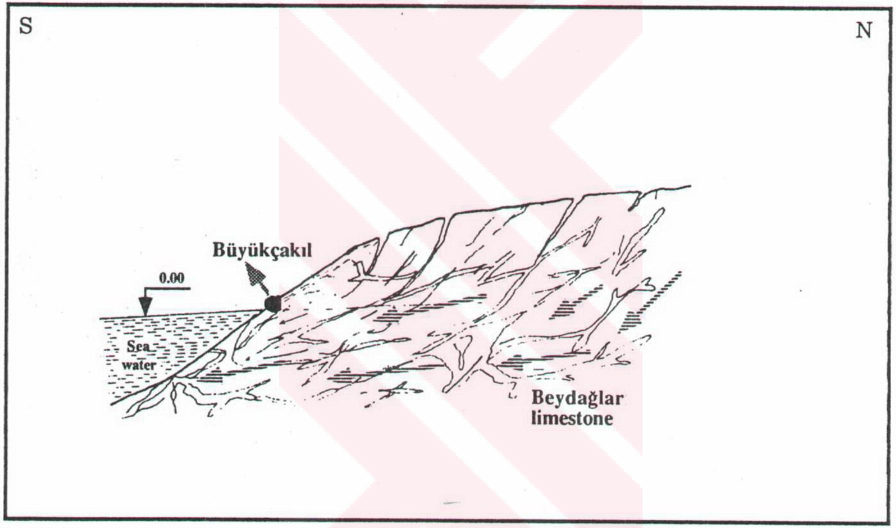


Figure 3.13. Schematic cross-section of the Büyükçakıl coastal springs.

3.4.1.b. Güvercinlik springs :

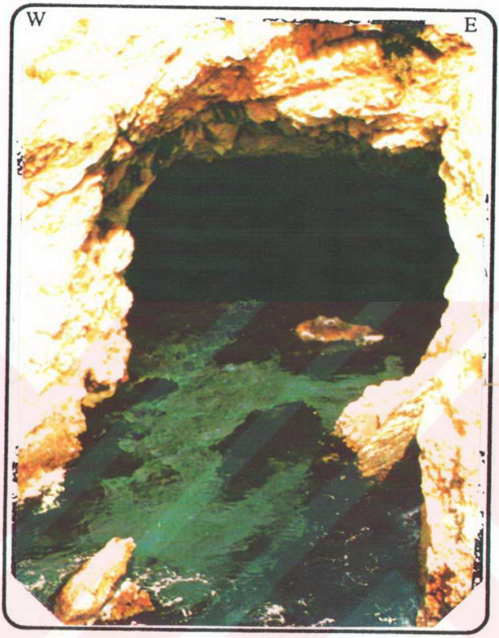
Güvercinlik (Blue) cave is located at about 12 km. to the west of Kaş, and 1.5 km to the south of Üçkuyu village. This cave, is considered as one of the most exhibit karstic features which were developed in the Beydağları limestones extending along the Kaş-Kalkan coastline (Fig. 3.14). In the eastern and western sides of the Güvercinlik cave, two main karstic springs discharge at elevation of about 25-30 cm above the mean sea level, with approximate total value of 15 lt/sec and average temperature of 15 °C.

The hyrogeological field investigations showed that, both of the springs discharge through enlarged weak structural zones within this cave. These weak zones had been developed at the intersection of two main faultlines extending in the N25E and N60W directions. Thus, the concentrated groundwater flow, in this part of the coastal aquifer, is structurally forced to be emerged toward the weakest zones, and causes the coastal discharge of these karstic springs.

3.4.1.c. Kömürlük spring :

Kömürlük spring is located on the eastern side of the Kalkan Bay, nearby the Ulugol site, about 3 km to the southeast of Kalkan town. This coastal karstic spring discharge through fracture zones of about 80 cm. which had been developed along the mainland faultline extending in the N80E direction (Fig. 3.15).

However, it is difficult to identify the depth of the inland faults, which extend toward the sea after crossing the Beydağları limastones, a significant coastal discharge of about 20 lt/sec with average temperature of 18.0 °C was measured during the hydrogeological field investigations.



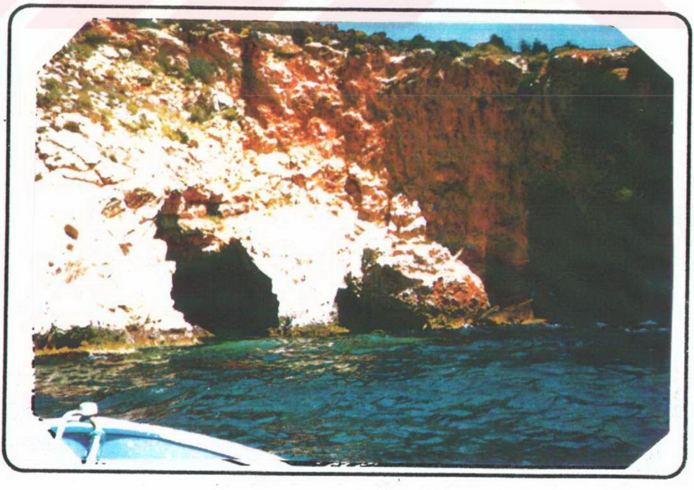


Figure 3.14. Güvercinlik (Blue cave) site.

Figure 3.15. Kömürlük coastal spring, near Kalkan.

Figure 3.16. Coastal discharges along Küçükçakıl, near Kaş.

3.4.1.d. Coastal discharge point in Kaş-Kalkan :

Series of coastal discharge points were identified during the field investigations nearby and/or in the Kaş and Kalkan towns. Most of the coastal discharges in this part of the study area, occur or take place throughout the weak karstic fracture zones which are located (aligned) along the N70-80E extended faultlines.

In Kaş, these discharge points are located at the eastern and western parts of the Bay. Three major discharge points are found on the Çukurbağ Yarımadası coastline, and one at the Küçükçakıl site in the southeastern part of the Kaş Bay (Fig. 3.16). The average temperature of the water discharging from these points is about 14°C. In Kalkan, there are mainly three major coastal discharge points. One is located nearby the Kalkan Mosque, while the others are found at lower elevations on the coastline of the Kalkan Bay. The average temperature of the coastal discharges in this part of the study area, is about 18°C.

Although the number of the coastal outlet points in Kaş is more than in Kalkan, the amount and the average temperature of the coastal discharges in Kalkan is higher than in Kaş. Significant groundwater recharge is transmitted at great depth throughout the allochthonous karstic units which are located at higher elevations north Kalkan. This groundwater recharge is considered as the main water resource which is hydraulically connecetd with the coastal karst springs in Kalkan.

3.4.2. Karstic springs in the hinterland

Identification of the hydrogeological conditions of the karstic springs available in the hinterland north Kaş-Kalkan, is one of the most important objectives in the present study. For achieving this object, series of relevant geological, hydrological, and hydrogeological studies were carried out.

During the field investigations, the geological and structural features that affect and/or control the main water resources in such karstic area, were studied for identifying its hydraulic connections with these springs.

3.4.2.a. Dereköy (Dayaklı) spring :

Dayaklı spring is located at the southern part of Dereköy village, about 15 km. north of Kaş. This spring is found on the foot of the Pınarbaşı (Tepe) hill at elevation of 425 m. above the mean sea level. The hydrogeological field investigations show that the Dayaklı spring discharge through the contact zone between thick-bedded of conglomerates of the Late Miocene kasaba formation interbedded with thin-medium bedded of Miocene detritic materials (clay).

Although, the main water outlet of this spring discharge from the upper part of the Kasaba formation as result of shallow water circulation. It is considered as an intermittent spring discharging with an average value of 5 lt/sec during the winter and dry in the summer. The average temperature of the water discharging from this spring ranges between 10 to 14°C. Schematic cross-section showing the structural and hydrogeological conditions which control the discharge of the Dayaklı spring is given in figure 3.17.

3.4.2.b. Gökçeören (Sıtma) spring :

Sıtma spring is located at the northern part of the Gökçeören village, about 12 km. to the northwest of Kaş. This spring is considered as one of the spring series which are aligned on the fault zone crossing the syncline axis that extends along the Gökçeören and Gökdere (planes) villages. This series include Dutlu, Sıtma, Halime, and Dağlık springs. The sıtma spring is located on the foot of the Tuzla (tepe) hill to the southwest of Gökdere village, at elevation of 820 m. above the mean sea level.

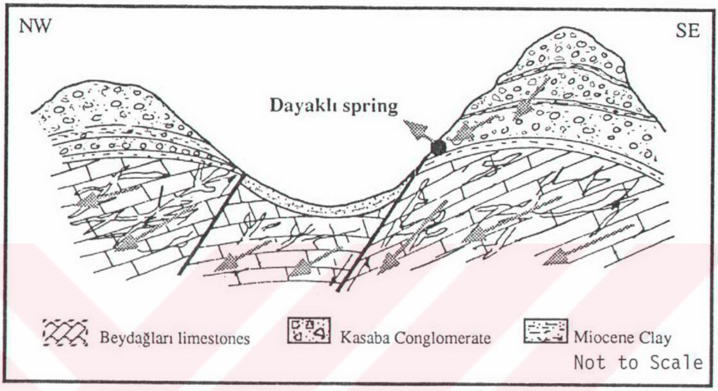


Figure 3.17. Schematic cross-section of the Dayaklı spring

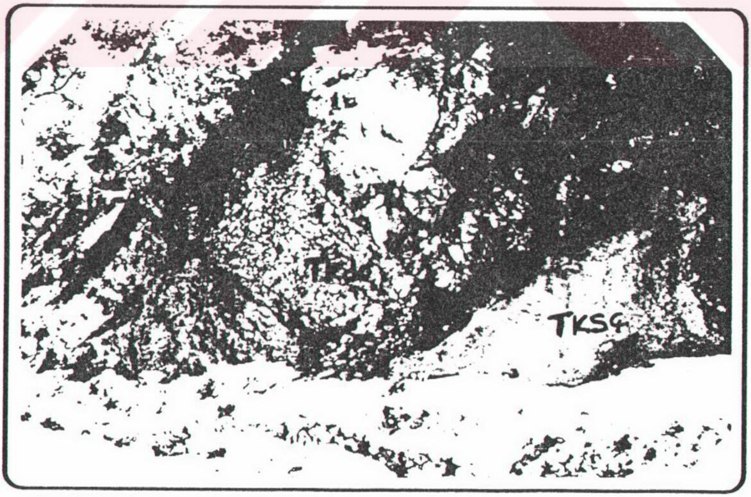


Figure 3.18. Contact zone between Kasaba Conglomerates (Tkdo) and Çayboğazı Flysch (Tksç) nearby the Sıtma spring in Gökçeören

Sıtma spring discharge permanently from the Late Miocene Kasaba formation with approximate value of 10 lt/sec and temperature ranged between 13 to 15 °C. The field observations show that, the outlet of this spring is located at the contact zone between the Kasaba conglomerates and the Miocene flysch of the Çayboğazı unit (Fig. 3.18).

3.4.2.c. Islamlar spring :

Islamlar spring is located on the northwestern foot of the Kışla Mountain (Göltepe hill) at the eastern part of the Islamlar village, about 6 km. north Kalkan town. This karst spring is one of the series which is aligned on the thrust faultline extending along the Pınarbaşı, Islamlar, Yeşilce, and Yarımdam villages. The Islamlar spring is found at elevation of 625 m. above the mean sea level, and permanently discharges from the allochthonous Kaymaklı limestones with average value of 120 lt/sec.

The average temperature of water discharging from this spring is about 12 °C. The maximum discharge of this spring, is about 150 lt/sec during the wet periods. Whereas during the dry periods, the discharge may decrease to about 80 lt/sec, with average temperature of 14 °C. The main outlet of the Islamlar spring is located on the contact zone between the allochthonous Jurassic-Upper Cretaceous Kaymaklı limestones and the Upper Miocene allochthonous impervious unit of the Kozağacı formation which is mainly composed of silty clay and clay deposits.

In Islamlar village, the water demand is covered significantly from this spring. Where about four water mills are used for covering the drinking and irrigation water demand. The Islamlar spring is probably the largest karst spring in the study area. Schematic cross-section is given in figure 3.19 for identifying the hydrogeological conditions of the Islamlar spring.

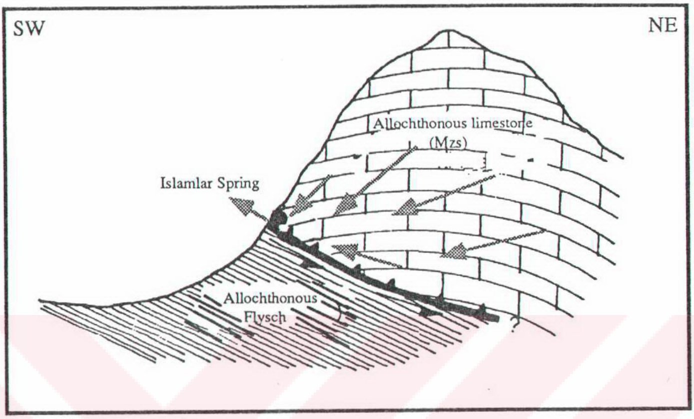


Figure 3.19. Schematic cross-section of the Islamlar spring.

3.4.2.d. Yeşilce (Lapaz) springs :

Yeşilce (Lapaz) village is located at about 2 km. northwest the Islamlar village. In the southwestern part of the Yeşilce village, there are two main karstic springs (Lapaz-1 and 2). Both of these karstic springs discharge from the Jurassic-Upper Cretaceous Kaymaklı dolomitic limestones (allochthonous unit) at elevation of 650 m. above the mean sea level, with average values of 4 and 20 lt/sec during the winter. The average temperatures of these springs are about 15 and 13°C.

During the hydrogeological field investigations which had been carried-out in the summer, it was found that the discharge of the Lapaz-2 spring decreased to about 10 lt/sec. Whereas, the Lapaz-1 spring was completely dry. However, both of the Yeşilce Lapaz-1 and 2 springs discharge through the contact zone between the allochthonous units of the Kaymaklı dolomitic limestone and the Kozağacı flysch. The discharge of the Lapaz-2 spring seems to be about 5 times the one of the first spring, especially during the wet periods. This may be related to the structural features and the position of the impervious layers which may control and/or affect the discharge of these karstic springs.

3.4.2.e. Gökçesu spring :

The Gökçesu karst spring is located in a narrow gorge at which the Karacay stream, a tributary of Esencay river flows, about 25 km. north Kalkan. Although, this karst spring is located outside of the surface and groundwater drainage area, it is considered as an important water resource for covering the great water demand in Kaş and Kalkan for the near future plans. Since there is a recent project between the Municipalities of Kaş and Kalkan for transporting water of about 150 lt/sec from the Gökçesu springs to Kaş and Kalkan towns.

The Gökçesu spring is one of the principal karstic discharges encountered in the Teke Taurids region. However, it has a small surface catchment area of 220 km^2, its mean discharge may reach to around 12 m^3/sec. Therefore, it can be pointed out that significant amount of water from the neighboring basins recharge permanently this karst spring. The spring is recharged by the autochthonous and allochthonous limestones which occupy this area. These units are the Elmalı-Akdag peak at the north and Xanthos at the west.

A normal fault (an elemant of Esencay graben) extending roughly in the NE-SW direction, creates a barrier that may force the springs to emerge to the surface in this particular area. The impervious unit which is located on the foot of the surrounding hills, is mainly composed of detritic materials of post-tectonic and Eocene-Oligocene wild-flysch type rock units. Schematic cross-section of the Gökçesu springs is given in figure 3.20.

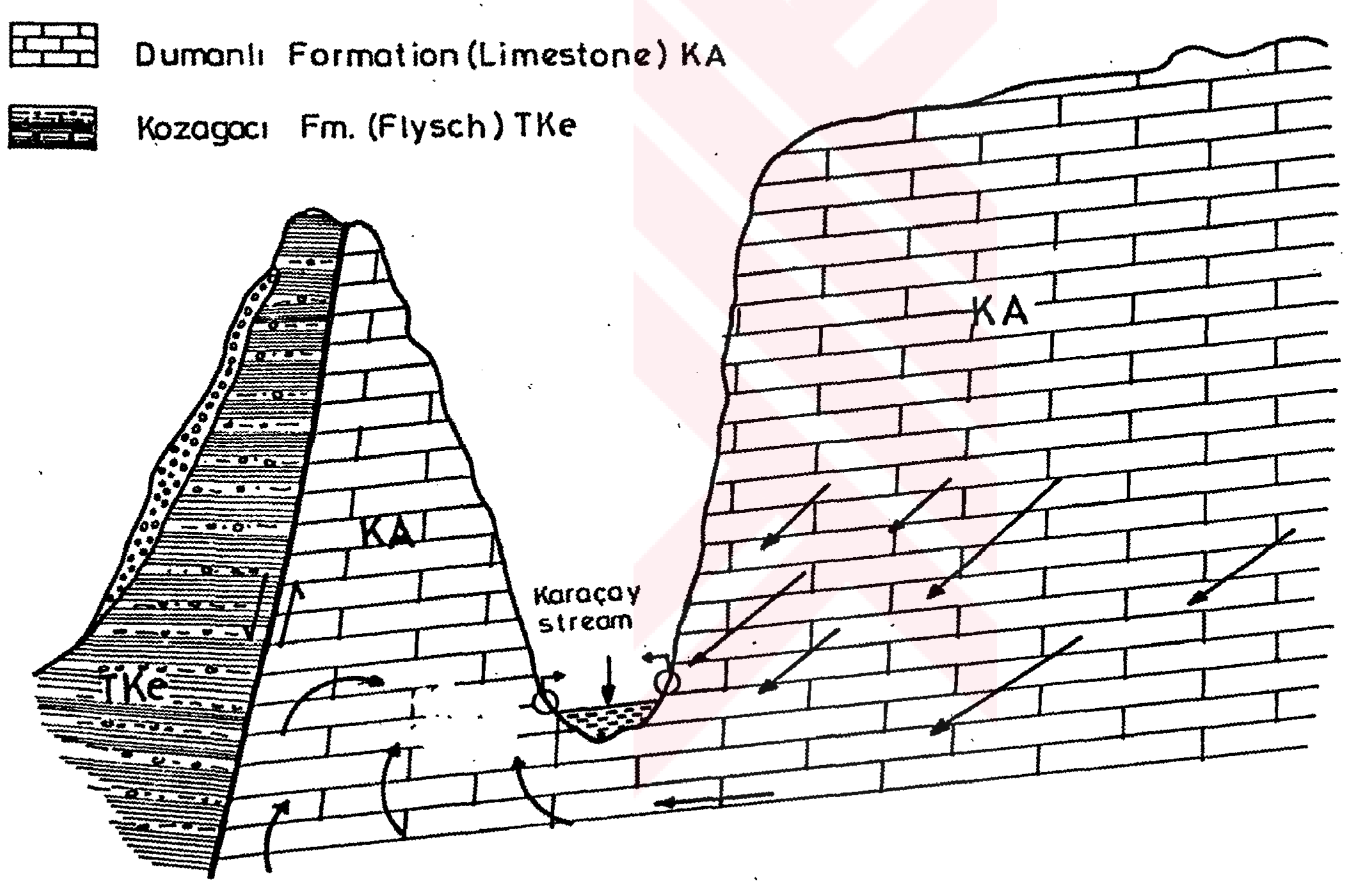


Figure 3.20 Schematic cross-section of the Gökçesu spring.

3.4.3. Comparison of karst springs in Kaş and Kalkan

Comparison of the karst springs in Kaş and Kalkan regions is considered as an important tool for identifying the hydrological characteristics and responses of different karstic units according to the location of these natural springs in the study area, differences in their discharge amounts during the dry and wet periods, and the hydraulic connection between them. Characteristics of the karstic springs in the coastline and the hinterland sides of the study area are given in table 3.6.

Table 3.6. Characteristics of different karstic springs in the study area

	at the coastline	at the hinterland side
KAŞ	Büyükçakıl spring	Dereköy (Dayaklı) spring
Temp. (°C)	12 - 14	10 - 14
Disch.(lt/s)	2 - 10	5
Elev. a.s.l (m)	0.3 - 0.5	425
KAŞ-KALKAN	Güvercinlik spring	Arapyurdu spring
Temp. (°C)	14 - 16	13 - 15
Disch.(lt/s)	10 - 15	35 - 60
Elev. a.s.l (m)	0.25 - 0.30	750
KALKAN	Kömürlük spring	Islamlar spring
Temp. (°C)	17 - 19	12 - 14
Disch.(lt/s)	> 20	80 - 150
Elev. a.s.l (m)	0.1 - 0.0	625

Field observations have shown that;

- although the extention and number of the coastal outlet points in Kaş is more than in Kalkan, the amount of the coastal discharge in Kalkan is higher than in Kaş. The increament in discharge amount could be observed along the coastline from Kaş toward Kalkan,

- the temperature of the coastal outlets in Kaş is lower than in Kalkan. Gradual increament in temperature is measured along the Kaş-Kalkan coastline,

- the elevation of the coastal outlets above the mean sea level in Kaş is higher than in Kalkan. Since most of the submarine outlets are located around the Kalkan coastline. This may reflect an idea about the structural characteristics and the depth of base level of erosion in this part of the study area.

For identifying the main water resources of the karst springs in the hinterland side and the expected groundwater flow paths that may recharge the coastal springs in the study area, 14 water samples were collected during the field studies for the environmental isotope analyses. Evaluation of the environmental isotope data is explained in the following section.

3.5. Evaluation of Environmental Isotope Data

3.5.1. Sampling and analysis

Evaluation of the environmental isotope data is considered as one of the most important tools in identifying the variations of the isotopic composition of the natural water and the hydrological behaviour of the groundwater basin in the study area. Therefore, 14 water samples were collected during the field studies in accordance with the isotopic sampling principles described by the International Atomic Energy Agency (IAEA), Vienna, Austria.

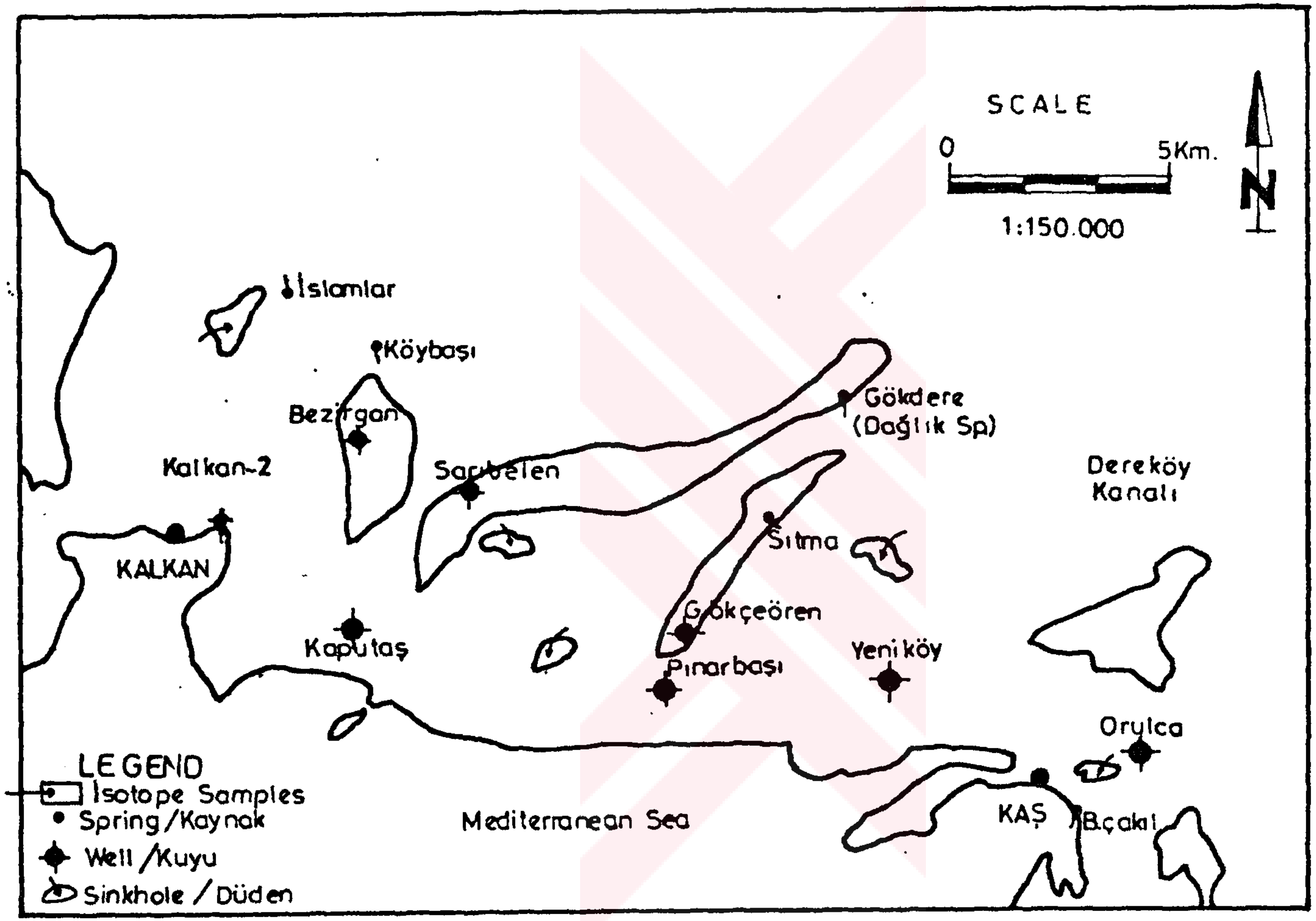


Figure 3.21. Location map of the selected isotope sampling points

The environmental isotope analyses of these water samples were done in the IAEA Laboratories, Vienna. These analyses include the stable environmental isotopes (Deuterium ^2H and Oxygen 18) and the radioactive isotope of the Tritium (^3H). Location of the selected water samples is given in figure 3.21. The results of the environmental isotope analyses and the field measurements of different physical and chemical properties of the selected water samples are given in Table 3.7.

Table 3.7. Environmental isotope data of the selected water samples

Samples	^{18}O ‰ SMOW**	D	^3H (TU)***	Error*	Temp. (°C)	Elevation (m)	Conduct. (umohs/cm)
1. İslamlar springs	- 7.91	- 44.2	15.60	0.64	12.0	625	230
2. Köybaşı spring	- 6.98	- 38.4	9.98	0.52	13.5	860	250
3. Bezirgen (Well)	- 6.47	- 31.8	6.99	0.45	15.0	700	800
4. Sarıbelen (Well)	- 6.46	- 31.9	6.97	0.44	17.5	675	450
5. Kaputaş (Well)	- 6.13	- 31.0	6.61	0.41	17.5	325	600
6. Kalkan-2 (Well)	- 5.12	- 24.3	2.80	0.35	18.3	5.0	1200
7. Dereköy (Konalı) sp	- 6.39	- 34.9	9.27	0.50	12.5	340	325
8. Pınarbaşı (Well)	- 6.45	- 33.0	7.88	0.44	16.3	575	460
9. Orulca (Well)	- 6.00	- 31.4	8.14	0.46	14.5	225	390
10. Büyükçakıl spring	- 5.32	- 26.8	5.48	0.41	14.0	0.5	12500
11. Gökdere Dağlık sp.	- 6.69	- 35.0	9.97	0.50	12.0	850	200
12. Sıtma spring	- 6.66	- 34.8	9.76	0.50	13.0	820	340
13. Gökçeören (Well)	- 6.59	- 34.4	9.61	0.51	15.0	750	230
14. Yeniköy (Well)	- 6.42	- 32.5	7.84	0.47	15.0	600	350

* Tritium measurement error ** Vienna, Standard Mean Ocean Water *** Tritium Unit

3.5.2. Oxygen 18 - Deuterium relationship

The plots of the water samples on the Oxygen 18 - Deuterium graph represent the similarity of the recharge basins and also types of precipitation which may recharge the study area can be grouped.

As can be inferred from this graph (Fig. 3.22), plots of the selected water points fall on an estimated meteoric line expressed as;

$$\delta D = 8.0 * \delta^{18}O + 14.45$$

The estimated meteoric line in the study area is compared with the other meteoric line equations obtained through similar studies that were carried out for different region in Turkey (Table 3.8).

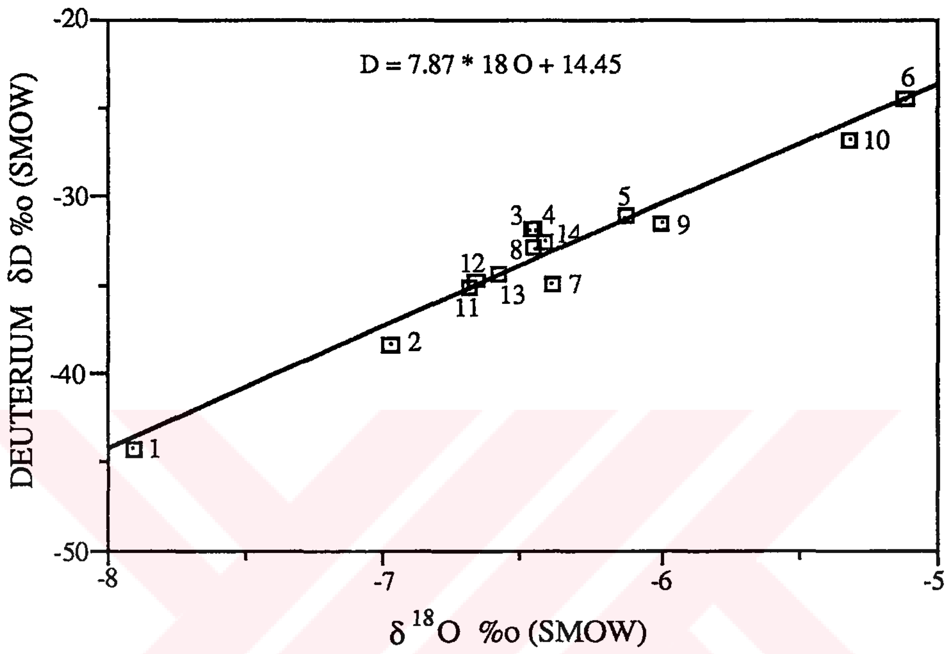


Figure 3.22. Oxygen 18 - Deuterium graph.

Table 3.8. Meteoric line equations determined for various basins in Turkey (after Günay et al., 1990)

Basin	Meteoric Line Equation	References
Antalya	$\delta D = 8 * \delta\, ^{18}O + 14.3$	Yurtsever, 1980
Central Anatolia	$\delta D = 8 * \delta\, ^{18}O + 10.0$	Önhon et.al, 1979
Eastern Mediterranean	$\delta D = 8 * \delta\, ^{18}O + 22.0$	Payne and Dinçer, 1965
Edremit	$\delta D = 8 * \delta\, ^{18}O + 9.44$	Önhon et.al, 1979
Konya	$\delta D = 8 * \delta\, ^{18}O + 16.0$	Önhon et.al, 1979
Global Meteoric	$\delta D = 8 * \delta\, ^{18}O + 10.0$	Payne and Dinçer, 1965
Zamantı Basin	$\delta D = 8.76 * \delta\, ^{18}O + 23.6$	Günay et.al, 1990
Kaş-Kalkan Basin	$\delta D = 7.87 * \delta\, ^{18}O + 14.45$	This study

Comparison shows that the Deuterium excess value (14.45) of the study area is quite similar to that of the Antalya meteoric (Yurtsever, 1980). Thus, the basin of study area is recharged by Mediterranean originated atmospheric water vapour which reflects high evaporation rates, while most of the water samples which collected from karstic springs at high elevations were plotted on straight line representing low evaporation effects. This may be related to the rapid or very fast infiltration process of the precipitation to the groundwater throughout the weak zones into the relatively high karstified limestone units at high elevations.

On the otherhand, the water samples which were collected either from shallow wells (Bezirgan-3, Sarıbelen-4 and Orulca-9), or from the karstic springs (Konalı-7 and Büyükçakıl-10), represent considerable enrichment in the heavy isotope contents due to evaporation and isotopic exchange with the atmospheric moisture. Based on the Oxygen 18 and Deuterium contents of the selected water samples, it is possible to distinguish the water points which may be influenced by similar or common recharge processes.

The graph reveals that some of the water points which have similar plots or close to each other, may represent the same karst flow system. For example; Gökdere (Dağlık-11) and Sıtma (12) springs discharge from the same unit (Kasaba conglomerate) at high elevation, and the Gökçeören (13), Pınarbaşı (8) and Yeniköy (14) deep wells penetrate the Beydağları limestones at the southern part of these springs.

Bezirgan (3), Sarıbelen (4) and Kaputaş (5) are deep wells penetrating the Beydağları limestones at the northeastern part of Kalkan, and represent the same karst flow system which may be extended to Kalkan (6). While, Dereköy Konalı spring (7) and Orulca well (9) are located at the northern part of K aş representing another flow system within the Beydağları limestones which may extend toward the Büyükçakıl coastal spring.

3.5.3. Oxygen 18 - Tritium relationship

The relationship between Oxygen 18 and Tritium contents may give an idea about the recharge elevations and the turnover time of the karst water flow system in the study area. The confidence limits of the turnover time comparisons on this graph depend upon how representative are the tritium values.

For the coastal karstic aquifers, in which a proper mixture of precipitation from several years takes place, the fluctuation of environmental isotope content through a certain year is not significant. Therefore, the isotope contents of the selected water samples (springs) may vary to a great extent throughout a period of one year, and the seasonal isotopic variations in precipitation is directly reflected in the coastal aquifer.

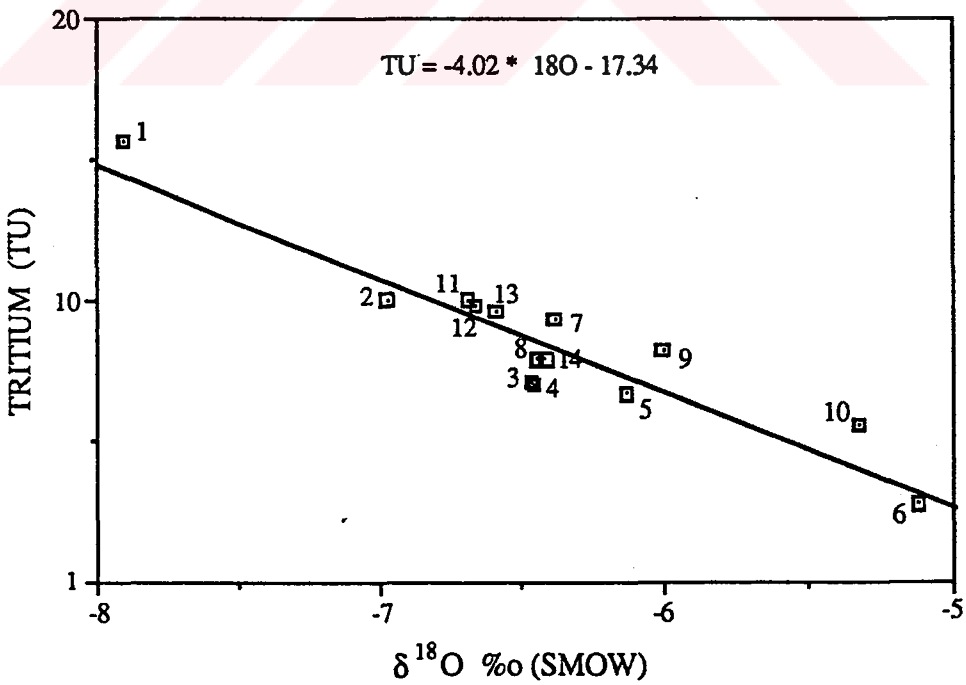


Figure 3.23. Oxygen 18 - Tritium graph.

Along the horizontal axis of the Oxygen18 - Tritium graph (Fig.3.23), recharge elevation increases as the plots of the selected water samples approach the origin point (main recharge point), whereas along the vertical axis the values that getting close to the origin point may represent increasing in turnover time. As can be inferred from this graph, the Köybaşı spring (2) represents the highest recharge elevation for the water samples which were collected from the northern part of Kalkan town; Bezirgan (3), Sarıbelen (4), Kaputaş (5) and Kalkan (6). Since these plots (3,4 and 5) are located approach the origin point (2) along the horizontal axis, and getting close to this point along the vertical axis of this graph. This may represent an increasing in the recharge elevation and respectively, increasing in the groundwater flow time, toward Kalkan (6) which have the lowest tritium content comparing with the other water samples in this part of the study area.

On the otherhand, the water sample Gökdere Dağlık spring (11) belongs to the lowest recharge elevation for the water samples which were collected from the area between Kaş and Kalkan towns; Sıtma spring (12), Gökçeören (13), Pınarbaşı (8), Yeniköy (14) wells. The Sıtma spring (12) is approximately matched the origin point (11), whereas a small increasing in the distance between the origin point and the plots (13, 8 and 14) may reflect a gradual increasing in recharge elevation and the turnover time during the movement of the groundwater toward these wells. This groundwater flow system may be continued toward the Güvercinlik coastal spring which discharges though the Güvercinlik cave along a fault zone extending toward the coastline after crossing the mainland Beydağları limestones.

The water samples which were collected from the northern part of Kaş town include the Dereköy Konalı spring (7), Orulca shallow well (9), and Büyükçakıl coastal spring (10). Although, these samples are located at lower elevations than the water samples of the first group (3,4, and 5), they have high tritium contents plotted on a straight line above the main meteoric line of the study area.

The enrichment of tritium contents in these samples is related directly to the effects of higher evaporation rates than the water sample which were collected from higher elevations. It is concluded that, these water samples may belong to a shallow groundwater flow system of shorter time of travel, recharging the coastal springs which are located at this part of the study area.

3.5.4. Oxygen 18 - Temperature relationship

The Oxygen 18 - temperature graph relationship may represent an excellent example for identifying different karst water circulation patterns dominating in the basin. Thus, water samples from streams, shallow and deep groundwater circulation can be differentiated by this mean. The plot of the Oxygen 18 versus temperature for the selected water samples is given in figure 3.24.

As can be inferred from this graph, the water samples reveal two different linear relationships in terms of the above mentioned parameters. The water samples which are included in each linear relationship are shown as following;

<u>Line number I</u> : Islamlar (1), Köybaşı (2), Dereköy Konalı (7), Gökdere Dağlık (11) springs, Orulca (9) well, and Büyükçakıl coastal spring (10)

<u>Line number II</u> : Bezirgan (3), Sarıbelen (4), Kaputaş (5), Pınarbaşı (8), Gökçeören (13), Yeniköy (14), and Kalkan (6).

Since there is no any heat input into the karst groundwater system due to geothermal processes within the study area, it is a well known fact that the groundwater temperature of line number II seems to be around the value of the annual average temperature of the study area. On the otherhand, the Oxygen-18 of the meteoric groundwater varies inversely with the elevation of the recharge area.

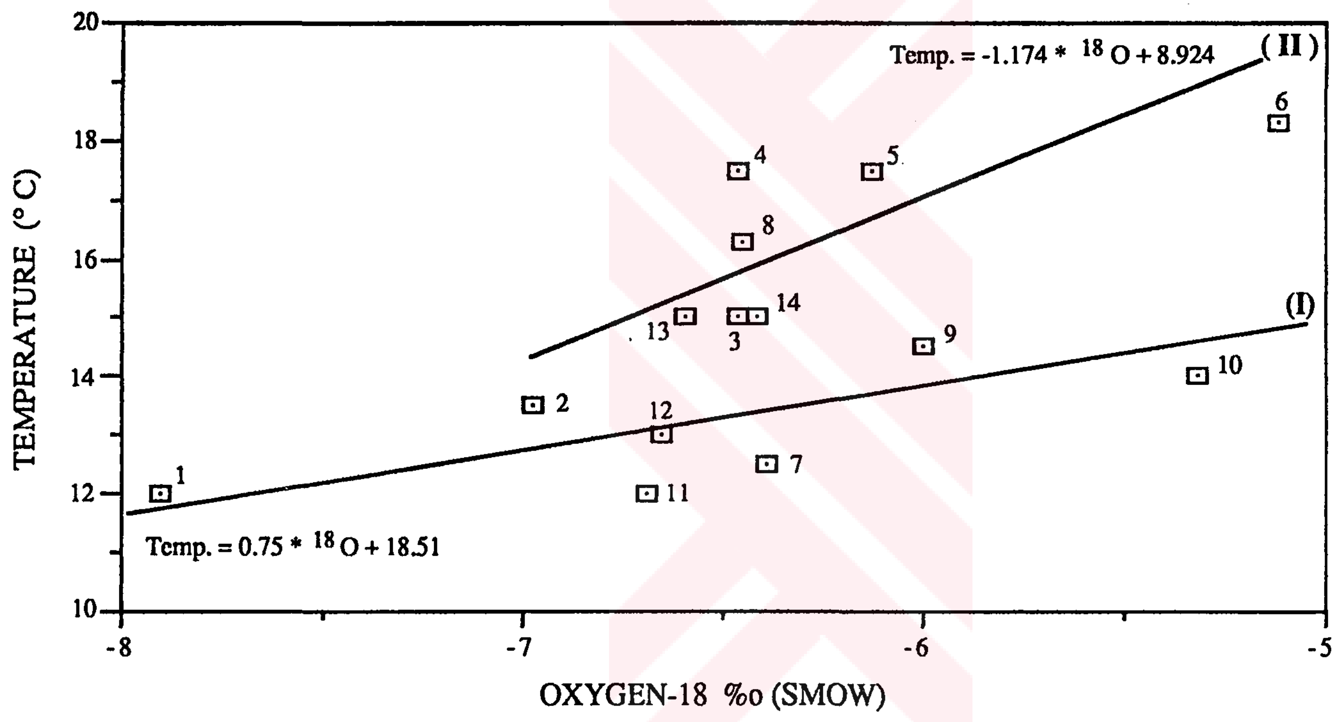


Figure 3.24. Oxygen 18 - Temperature graph

Line number I include samples which were collected from springs located at high elevations, shallow well, and coastal submarine spring of high Oxygen-18 content and low temperature values. Location of these samples below the recharge elevation and low temperature values may represent a type of shallow karst water circulation system of shorter time of travel at the northern part of Kaş. Whereas, the water samples of the second line (4, 5, 8, and 6) represent deeper karst water circulation with longer time of travel at the northern part of Kalkan town.

While, the water sample 3,13, and 14 are located in the transition zone between the shallow and deep flow systems. This may prove the previously mentioned idea about the availability of mainly two groundwater flow systems, which was explained during the comparison of different karst springs in Kaş and kalkan towns.

4. HYDROGEOLOGY

4.1. Introduction

Hydrogeological characteristics of different lithological units and their position for the base of erosion are essential factors in the determination of groundwater distribution in such coastal karstic area. Hydrogeological investigation involves identification of characteristics of various hydrogeologic units, discharge of karstic springs, and distribution of different karstic features existing in the study area. Groundwater level measurements from existing boreholes, distributed in the hinterland and along Kaş-Kalkan coastline were carried out carefully depending on reference code elevation above the mean sea level. These studies may give information about groundwater distribution in such coastal karstic region.

Hydrogeological investigations of the study area also involve other revelant studies including identification of the hydrological and hydrogeological regimen of the Kaş-Kalkan basin, and analyses of remote sensing imagery for indicating the distribution of different karstic features and occurrence of the coastal karst springs. Analyses of remote sensing data is carried out depending on the results of the hydrological and hydrogeological studies for identifying the main geological and structural features that affect and/or control the main water resources and its hydraulic connections with the coastal karst springs in the study area.

4.2. Hydrogeological Units

There are four major hydrogeological units existing in the study area. These hydrogeological units have been differentiated according to their individual structural and hydrogeological characteristics into Karstic Lower Unit (KLU), Imprevious Lower Unit (ILU), Karstic Upper Unit (KUU) and the Quaternary deposits.

This differentiation is plotted on the hydrogeological map which was performed depending mainly on the regional and local geological and hydrogeological field studies. The regional distribution of these hydrogeologic units is given in Table 4.1.

4.2.1. Karstic lower unit (KLU)

The karstic lower unit (KLU) comprises the autochthonous carbonate platform of the Beydağları and Susuzdağ formations which domenantly crop out inside the surface drainage basin of the study area. Typical outcrops of Beydağları formation (limestones) can be noticed along the Kaş-Kalkan coastline and in the northern part of the study area. The Susuzdağ (Garipçe) formation cropsout in the Bozova at the northeastern part of Kaş (Fig. 4.1).

The Beydağları formation symbolizes a typical open coastal karstic aquifer from the hydrogeological point of view. Most of the representative morphological forms and/or karstic features including sinkholes, spring, dry valleys, and coastal (submarine) springs are developed in this karstic lower unit, especially in the northern and northeastern parts of the study area. Most of these features are located along the mainland faultlines which extend into the sea after crossing the Susuzdağ and Beydağları formations in the N70-80E direction. However, the depth of the faultlines crossing this karstic unit at the bottom of the sea cannot be recognized, they provide significant coastal and submarine discharges of turbid water (Fig.4.2).

The base level of erosion and the extension of the available karstic features may reflect their hydrogeologic role in identifying the main direction of the groundwater movement through the Beydağları formation. Although, this karstic lower unit has a quite large extended groundwater reservoir, the high and deep level of karstification, intense local structural features, and high rate of infiltration make it difficult to supply enough water for beneficial uses in the study area.

Table 4.1. Areal distribution of hydrogeological units

Geologic Units	Hydrogeologic Units	Areal distribution * (km^2)
- Jur. Upper Cretaceous Limestones (Beydağları Formation)	- Karst Lower Unit (Jkb) (Permeable)	235.0
- Eocene Susuzdağ Formation (Garipçe and Gömüce Limestones)	- karst Lower Unit (Tbgü) (Permeable)	20.0
- Eocene Sinekçi Formation (Çayboğazı flysch Tksç)	- Impervious Lower Unit (Impermeable)	84.0
- Dirgenler Formation (Tkdo) (Kasaba Conglomerates)	- Karst Upper Unit (Permeable)	23.5
- Quaternary Deposits	- Semepervious Unit	8.0
- Kaymaklı Formation (Mzs) (Allochthonous Limestones)	- Karst Upper Unit (Permeable)	32.0
- Kozağacı Formation (Tke) (Allochthonous Flysch)	- Impervious Unit	20.0
- Çamal Formation (TÇ) (Post Tectonic-Detritic material)	- Semipervious to Impervious Unit	2.5

* **Areal distribution** is calculated within the given drainage area.

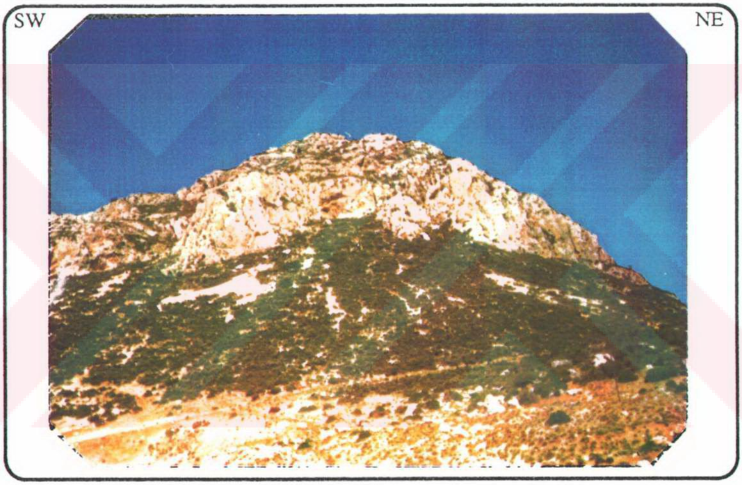


Figure 4.1. Outcrop of Garipçe Eocene limestones.

Figure 4.2. Coastal discharges near Kalkan town.

Eventually, the exhibited hydrogeological role of this water bearing formation is to take the water from the sinkholes found at high elevations in the northern and northeastern sides of Kaş-Kalkan basin and conducts it to near springs or transmits it deeper toward coastline providing coastal submarine springs.

4.2.2. Impervious lower unit (ILU)

The impervious lower unit (ILU) is mainly composed of detritic materials of both autochthonous and allochthonous series. This unit stratigraphically overlies the KL unit. The Çayboğazı (flysch) member, the upper part of Sinekçi formation is the best exhibited outcrops of this unit (Fig.4.3). The thickness of the impervious lower flysch unit (IL) is approximately ranged between 150-600 m. In the northern and northeastern parts of the study area, where most of the pervious materials are abundant, the IL unit acts as a barrier preventing groundwater flow throughout the pervious units. The field studies have showed that there is no karstification noticed in this unit, but most of the developed karstic features are located along the contact zone between the detritic material of this unit and the Karstic Upper Unit (KU).

4.2.3. Karstic upper unit (KUU)

Karstic upper unit (KUU) comprises the autochthonous and allochthonous sedimentary rocks which are located in the north and northwestern parts of the study area. The autochthonous Upper Miocene Kasaba conglomerate which crops out at the Felenk mountain and at Pınarbaşı village, unconformably overlies the impervious flysch unit (IL). It is mainly composed of thin to medium bedded massive silty and sandy limestones with thich-bedded sandstone and conglomerates. The thickness of the Kasaba formation ranges between 30-80 m.

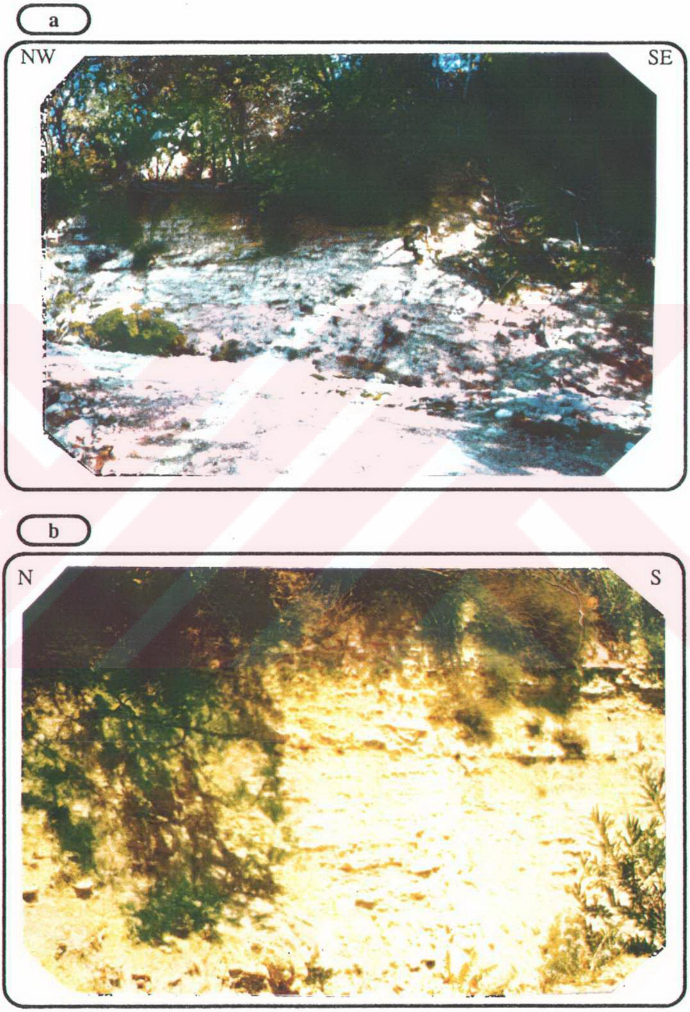


Figure 4.3. Impervious Lower Unit (Çayboğazı flysch),
a) in Gökçeören, b) in Arabyurdu

The allochthonous carbonate of the karst upper unit (KU) has gerat outcrops extend unconformably over the Beydağları limestones and the detritic material of the impervious lower unit (IL) in the northwestern part of the study area. The most exhibit allochthonous unit is the Kaymaklı formation which crops out in the north and northwestern part of Kalkan. Kaymaklı formation is mainly composed of medium to thick-bedded dolomitic limestones. Generally, the most common structural features which affect and/or control this unit are reverse fault and over thrusts. Almost no folding is present.

The karstic upper unit (KU) has an important hydrogeological role, as the main karst aquifer system in the study area. Most of the major karstic springs which discharge from the Kaymaklı dolomitic limestone unit, such as Islamlar, Yarımdam, Üzümlü and Lapaz springs, are located on the contact zone with the impervious allochthonous Kozağacı flysch unit, in the northwestern part of the study area (north of Kalkan). Finally, karstic springs discharging from this unit at high elevations, are caused by the shallow subsurface water circulation. This phenomena is also predominantly occured throughout the Kasaba conglomerate unit which is located in the northeastern part of the study area.

4.2.4. Quaternary deposits (Alluvium)

The Quaternary deposits which may represent hydrogeological characteristics of pervious aquifers, cover the Çukurbağ plain in the northeastern part of Kaş and the Bezirgan polje in the northeastern part of the Kalkan town. During the heavy rain periods, the southern part of Bezirgan polje forms an intermittent lake or swamp, whereas during the dry periods, the depth of the groundwater level may reach to 25-30 m in this part of the study area. The widespread extension of the Quaternary deposits covering the karstified beydağları limestone unit (KLU), may give information about the representative relationship between surface-water and groundwater distribution in such coastal karstic area.

4.3. Water Budget

Coastal karstic regions require a special approach in calculating the hydrologic budget for understanding the relationship between the surface-water and underground water systems. Note that, a representative hydrogeological volume does not exist in practice for the coastal karstic aquifers. The hydrologic budget is just considered as a material of balance that may determine all inputs and outputs of groundwater and changes in the storage within a system defined by prescribed boundaries. The water budget of the investigation area, is mainly calculated in order to identify the groundwater potential and the discharge of the submarine springs in the study area.

At the study area, there is no perennial streams which may be considered as surface water storages, but there are numerous creeks distributed within the troughs in the northern part crossing the surrounding ridges. These creeks are almost dry during the summer, whereas during the heavy rain periods, some of them in the northeastern and northwestern parts of the study area may have a restricted amount of surface water runoff.

Moreover, the topographic, hydrologic and hydrogeologic characteristics of the widespread water bearing formation were taken into consideration during the determination of the average areal distribution of precipitation and the calculation of the water budget of the study area. Areal annual distribution of precipitation and amounts of water gains and losses were identified depending on the result of correlation analysis of the mean annual precipitation over various altitudes at the study area (section 3.3.2, Fig. 3.10). This was considered as an appreciable tool for estimating the expected percentages or amounts of water distribution which may be infiltrared or evaporated (recharged or discharged) in such coastal karstic area. Finally, determination of recharge and discharge amounts throughout the whole catchment area is very important in performing and controlling the results of the arised water balance of the study area.

4.3.1. Drainage area and water balance

The investigation site has a surface drainage area of 425 km^2 limited by the surrounding ridges. These ridges include the Çam, Felenk and Dumanlı mountains at eastern, northern and western part of the study area (Fig. 4.4). No perennial streams exist within the area, but some braided channels and creeks may be present. Almost all these creeks are dry during the summer. Thus, the expected amount of recharge from the surface runoff is rather small during this period.

The autochthonous Jurassic-Upper Cretaceous Beydağları limestone covers about 55 % of the total surface drainage area, providing a large catchment area of about 235.0 km^2 surrounding the eastern, northeastern and northern parts of the study area. Most of the geomorphologic karstic structures or features are developed in this water bearing unit.

Generally, the whole catchment area including the autochthonous, allochthonous and post tectonic porous sedimentary rocks, provide a large groundwater basin at the investigation area. Area covered by the autochthonous porous units including Garipçe, Gömüce and Dirgenler formations is 6.5, 13.5 and 23.5 km^2 respectively. While, the autochthonous impervious unit Çayboğazı flysch covers a surface area of 84.0 km^2.

The Allochthonous Units which cover surface drainage area of 52.0 km^2 include the Kaymaklı limestones (32.0 km^2) and the impervious Kozağacı flysch (20.0 km^2). Whereas the post tectonic unit of the semipervious Çamel detritic series, represent a very restricted surface drainage area of 2.5 square kilometers. During the determination of the recharge and discharge amounts of water throughout the whole catchment area, different percentages of infiltrated and evaporated waters were calculated according to the hydrogeological characteristics of various units.

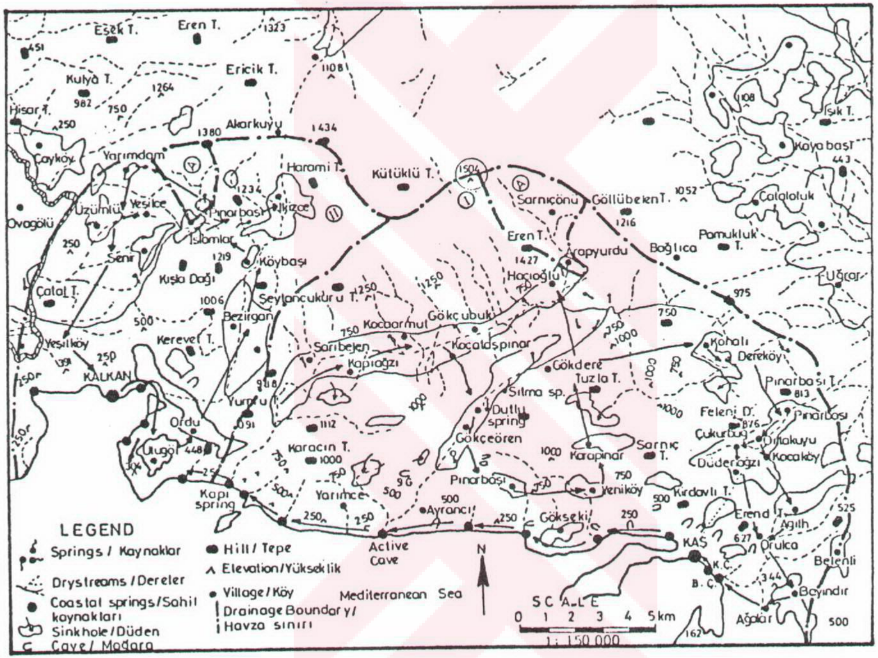


Figure 4.4. Surface drainage basin of the study area.

Therefore, two main sub-basins symbolizing the hydrologic and hydrogeologic regimen of the whole drainage area were selected. The amounts of infiltrated and evaporated water may be controlled by different orographic, lithologic and hydrologic characteristics of various hydrogeologic units. Thus, the actual percentages of infiltrated and evaporated waters, were calculated from the water balance of two main groups of karstic springs reflecting the potential of the groundwater and hydrological regimen characteristics of the selected two sub-basins in the study area (see Fig. 4.4).

The first isolated sub-basin (I-A) indicates the hydrologic and hydrogeologic regimen characteristics of the autochthonous Beydağları limestones covering surface drainage area of about 278.5 km^2. In this area, the evaporated and infiltrared water were calculated depending on the determination of water gain and/or loss from the Arapyurdu karstic springs, that discharge from autochthonous limestones with an average value of 50.0 lt/sec, at elevation of 750 m above the mean sea level.

The field observations have shown that the maximum discharge of the Arapyurdu spring increases up to 60 lt/sec during the wet periods, Whereas during the dry periods, the discharge may decrease to about 35 lt/sec. The sub-drainage area (I-A) covers about 5.7 km^2 of the whole surface drainage area. Mean annual precipitation of 583.5 mm/year falls over this area. This value is estimated, depending on the relationship between precipitation and elevation that was mentioned in section 3.3.2.

The second isolated sub-basin (II-A') may represent the hydrologic and hydrogeologic regimen of the allochthonous pervious unit (Kaymaklı limestones) which cover about 34.5 km^2 of the surface drainage area. The Islamlar spring which discharge from this unit with average value of 120 lt/sec and at elevation of 625 m. above the mean sea level, is the most distinct example for calculating the infiltrated and evaporated amounts of water in this part of the study area.

The surface drainage area of the Islamlar springs is about 11.5 km^2 and is limited from the south by the allochthonous Kozağacı flysch unit (impervious). The estimated mean annual precipitation over this area is calculated from section 3.3.2 as 652.3 mm/year. According to the hydrogeological field studies, the maximum discharge of these springs during the wet periods is about 150 lt/sec, whereas during the dry periods, the discharge may decrease to about 80 lt/sec.

4.3.2. Recharge and discharge of the basin

The recharge and discharge percentages (amounts) of the isolated sub-basin (I-A) which represents the hydrologic regimen characteristics of autochthonous porous units in this part of the study area, is determined as follows;

a) Estimation of the expected average precipitation at elevation of 750 m above mean sea level (section 3.3.2).

$$\text{Ave. Est.P} = -0.55 \times 750 + 996 = \mathbf{583.5}\ \text{mm/year}$$

b) Since, this amount of precipitation falls over surface drainage area (A') of 5.7 km^2. Then, the recharge of precipitation in this area is;

$$R_p = 0.5835 \times 5.7 \times 10^6 = \mathbf{3.33 \times 10^6}\ m^3/\text{year}.$$

c) The total discharge of the Arapyurdu springs within this area is about 50.0 lt/sec. So, the total discharge of these springs is converted to surface runoff as;

$$Dr = 50.0 \times 10^{-3} \times 31.55 \times 10^6 = \mathbf{1.58 \times 10^6}\ m^3/\text{year}.$$

This is considered as the effective amount of precipitation which may be discharged from these springs.

d) From the simple relationship between precipitation and evaporation in this area.

$$\text{Est. ETp} = R_p - Dr$$

Where, Est. Etp: is the estimated water loss from evaporation in this area, R_p: is total recharge of precipitation and surface runoff, and Dr: is the total discharge of these springs considering as surface water runoff. The estimated amount of the water loss from evaporation is;

$$\text{Est. ETp.} = 3.33 \times 10^6 - 1.58 \times 10^6 = \mathbf{1.75 \times 10^6} \ \text{m}^3 \text{/year.}$$

This value may take place within drainage area of 5.7 km^2. Then the total actual water loss is expected to be 307.0 mm/year. This means, about 52.5 % of the annual precipitation waters may be lost or evaporated before recharging the groundwater reservoir of the pervious autochthonous units (Beydağları limestones). Whereas, the rest of about 47.5 % is considered as amount of water that may recharge the groundwater basin from precipitation and surface runoff in the study area. This percentage could be slightly increased or decreased according to the orographical and hydrogeological characteristics of this unit, and the vegetation cover existed on the surface area of this unit.

Similarly, the recharge and discharge amounts of the isolated sub-basin (II-'A) are calculated for Islamlar springs which may represent the hydrogeological regimen characteristics of the allochthonous porous units, as;

- Ave. Est. Precip. = $-0.55 \times 625 + 996 =$ **652.3** mm/year

- Recharge of precipitation (R_p) = $0.6523 \times 11.5 \times 10^6 = \mathbf{7.5 \times 10^6}$ m^3/year

- Discharge from springs (Dr)=$120 \times 10^{-3} \times 31.55 \times 10^6 = \mathbf{3.78 \times 10^6}$ m^3/year

2) Recharge to allochthonous units :

The allochthonous porous units cover an area of about 34.5 km^2. This may represent around 8.0% of the total drainage area. For infiltration ratio of 50 %, the total recharge through these units will be;

Recharge (2) = $568.0 \times 10^{-3} \times 0.50 \times 34.5 \times 10^6$ = $\mathbf{9.80 \times 10^6}$ m^3/year

3) Recharge to alluvium:

The Quaternary deposits (alluvium) cover surface drainage area of about 8.0 km^2. These deposits include the clay, silt, sand and gravels which cover the Çukurbağ and Bezirgan planes at the northern part of study area.

For calculating the recharge amount of surface water runoff (R_s), the actual water loss from the evapotranspiration is calculated from Turc formula (1954) as;

$$Eta = \frac{P}{\sqrt{0.9 + \frac{P^2}{L^2}}}$$

$$L = 300 + 25 \times T + 0.05\,(T)^3 .$$

At the study area, the mean annual temperature (T) is 19.5 °C. From the estimated annual precipitation (P) of 568.0 mm, the actual amount of water loss Eta is calculated as 530.8 mm/year. This amount is substracted from the annual precipitation, and the recharge amount of surface runoff (D) is calculated as;

$$D = P - Eta$$

$$D = 568.0 - 530.0 = 37.2 \text{ mm/year.}$$

This amount of water may represent about 6.6 % of the total annual precipitation over this part of the study area. Then, the amount of water recharge (R3) to the alluvium which covers an area of 8.0 km^2 is;

Recharge (3) = $568.0 \times 10^{-3} \times 0.066 \times 8.0 \times 10^6$ = $\mathbf{0.30 \times 10^6}$ m^3 /year.

The total recharge (R_T) of precipitation and surface runoff is calculated as;

Total Recharge = R1 + R2 + R3

Total Recharge = $(75.14 + 9.80 + 0.3) \times 10^6$ = $\mathbf{85.24 \times 10^6}$ m^3 /year

= $(85.24 \times 10^6) / (31.55 \times 10^6)$ = **2.70** m^3 /sec

Then the total amount of water that may recharge the groundwater basin due to the infiltration of precipitation and surface runoff through out the porous units is about 85.24×10^6 m^3/year. This means, about 46.8 % of the total annual precipitation recharge the groundwater basin with about 265.5 mm/year by infiltration through different porous units covering total area of about 321 km^2.

Moreover, the recharge by infiltration of precipitation and surface runoff (85.24×10^6 m^3/year) is calculated as 35.3 % (200.6 mm/year) of the total annual precipitation which falls over the whole drainage area (425 km^2). This amount of water may be increased or decreased according to different lithological and orographical characteristics of the widespread various water bearing formations in such coastal karstic area.

4.3.2.b. Discharge :

Discharge from the groundwater basin at the study area include three main elements. These elements are; discharge from artificial pumping, outlets of the karstic springs in the hinterland side, and discharge to the sea through the coastal and submarine springs.

1) Discharge from artificial pumping (Q_p) :

At the study area, there are two main groups of wells supplying water for drinking and agricultural demands. The first group includes about 30 existing wells distributed around and within the widespread valleys and karstic poljes (Çukurbağ and Bezirgan) in the northern part of Kaş and Kalkan.

The average discharge (Q_{p1}) from these wells is about 15 lt/sec/well for the whole year. While, the second one is located at the Establishment of Irrigation Water (DSI, 1985) in Kalkan (Fig.4.5), and along the Kaş-Kalkan coastline. The average discharge of these two wells (Q_{p2}) is about 30 lt/sec/well.

Then, water loss by artificial pumping will be;

$$Q_{p1} = 15.0 \times 10^{-3} \times 31.55\times10^{6} \times 30 = \mathbf{14.2 \times 10^{6}} \ m^3/year$$
$$Q_{p2} = 30.0 \times 10^{-3} \times 31.55\times10^{6} \times 2 = \mathbf{1.9 \times 10^{6}} \ m^3/year$$

The total discharge by artificial pumping (Qpt), is:

$$Q_{p\,t} = (14.2 + 1.9) \times 10^{6} = \mathbf{16.1 \times 10^{6}} \ m^3/year$$

2) Discharge from karstic springs (Qs) :

Discharge from the karstic springs of the hinterland side of the study area is determined for three main groups. These groups are;

- Ave. discharge from Islamlar springs = 120 lt/s = **3.8 x 10^6** m^3/year
- Ave. discharge from Arapyurdu springs= 50 lt/s = **1.6 x 10^6** m^3/year
- Total discharge from other springs = 500 lt/s = **16.0 x 10^6** m^3/year

Then the total discharge from karstic springs (Qs) at the hinterland side is about **21.4 x 10^6** m^3/year.

Figure 4.5. Establishment of irrigation water in Kalkan.

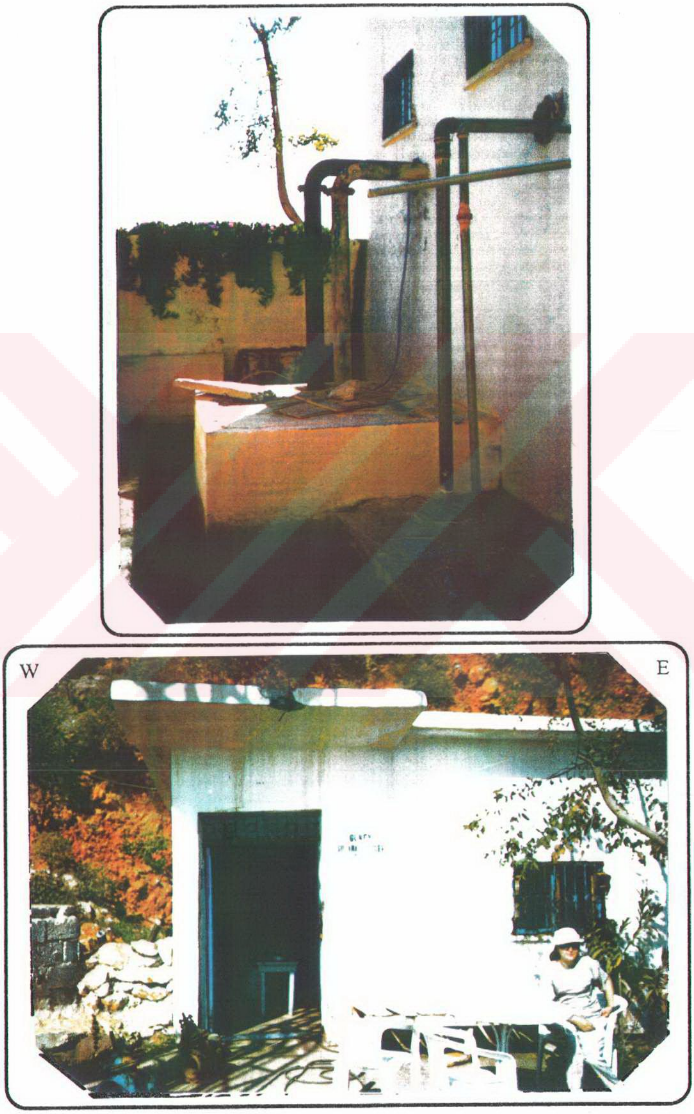


Figure 4.5. Establishment of irrigation water in Kalkan.

3) Discharge from Coastal springs (Qcs):

At the study area, there is a series of coastal karst springs along the Kaş-Kalkan coastline. These springs include Kaş, Büyükçakıl, Küçükçakıl, Gemibatan, Gemidere, Güvercinlik, Likye, Kömürlük, and Kalkan discharge points (see section 3.4.1).

However, the field observations during the wet and dry seasons have shown that the average disharge of about 15 coastal springs is less than 30 lt/sec/spring. Since these springs are located in the lower zone of groundwater flow system. So, comparing with the karstic springs that found at higher elevation in the hinterland side, the amount of groundwater discharge throughout the coastal and submarine springs will slightly change during the dry and wet periods. Then, the estimated total discharge of these springs may not be more than 450 lt/sec.

$$Qc_S = 450 \times 10^{-3} \times 31.55 \times 10^6 = \mathbf{14.2 \times 10^6}\ m^3/year$$

Finally, the total discharge from the artificial pumping (Q_{pt}), karstic springs (Q_S), and coastal springs (Qc_S), is equal to;

$$Q\ Total = Q_{pt} + Q_S + Qc_S$$

$$Q_{Total} = (16.1 + 21.4 + 14.2) \times 10^6 = \mathbf{51.7 \times 10^6}\ m^3/year$$

$$\text{Total discharge} = \mathbf{1.64}\ m^3/sec.$$

4.3.2.c. Results of the water budget:

Determination of total discharge and recharge amounts throughout the catchment area is important in performing the water balance and calculating the discharge of the submarine springs extending along Kaş-Kalkan coastline. According to the estimation of the areal distribution of precipitation over the whole drainage area, the total recharge from infilitration throughout different porous units is calculated as **85.24 x 10⁶** m³/year.

On the otherhand, the total discharge from the groundwater basin by artificial pumping, karstic springs outlets and coastal springs is **51.7 x 10^6** m^3/year. Thus, the discharge of the submarine springs (Q_{sp}) will be calculated as the difference between the total recharge and discharge amounts of water. Then the expected discharge of the submarine springs is about **33.54 x 10^6** m^3/year (1.06 m^3/sec) along the whole Kaş-Kalkan coastline.

4.4. Potential of Remote Sensing Techniques

Hydrogeological investigation of Kaş-Kalkan region by means of remote sensing techniques is considered as a tool for identifying the geological and structural features controlling different hydro-geological units, tracing the widespread distribution of different karstic features and the above mentioned coastal discharges, and indicating their structural and hydraulic connections with the main water resources in the study area.

However, the applications of remote sensing technology in general cannot provide all the requiste hydrogeologic information needed for studying karstic area. It can be a tool that appreciably assist in the different numerous planning, development, and management problems which are related to such karstic region. Therefore, analyses of remote sensing data might be applied after covering detailed hydrological and hydrogeological studies for achieving the main objectives of the study.

4.4.1. Data used

The selected remote sensing imagery for studying the potential of the groundwater in Kaş-Kalkan regions, include the Landsat Multi-spectral Scanner (MSS) and the Landsat Multitemporal images (TM), bands 5 and 6. These types of imagery can be effectively used for the hydrogeological studies of water recourses in such karstic regions.

Landsat TM image covering the study area has Path 179, Row 35 scenes. Black and white prints (films) of Landsat- MSS bands 4 and 7 (at 1/1000.000, 1/250.000 scale) and Landsat-TM images bands 5 at 1/1000.000, 1/350.000 scales were analyzed before the field investigations and used in enlarged scales during the in-situ studies. The enlargment of scales, analysis and interpretation of imageries were carried out in the remote sensing laboratory of the General Directorate of the Mineral Research and Exploration (MTA), Ankara in 1990/91.

Landsat images may give a good overview of the general geologic and hydrologic conditions of the Kaş-Kalkan area. Enlarged Landsat-MSS and TM infrared images yield valuable information about the extension of the widespread distributed karstic features and the changes in the vegetation cover in such coastal karstic area.

4.4.2. Interpretation

4.4.2.a. Lineaments:

Interpratation of the landsat images was started with the preparation of a lineament map of the present study area. From the Landsat-MSS photographs (Bands 4 and 7 at 1/250.000 scale) and the TM-infrared image band-5 at 1/350.000 scale, the main directions of lineaments were identified as NE-SW and NW-SE (Fig. 4.6).

Most of the long lineaments (major structural features) are extended toward the Kaş-Kalkan coastline after crossing the Beydağları mountains (Beydağları carbonate platforms) in the N70-80E and N25-30W directions. While combining these lineaments, it was found that most of the developed karstic features including caves, sinkholes and springs are located on the intersections of the continuously extended lineaments coinciding along or/and around the northern part of the study area, especially in the area between Kaş-Kalkan towns.

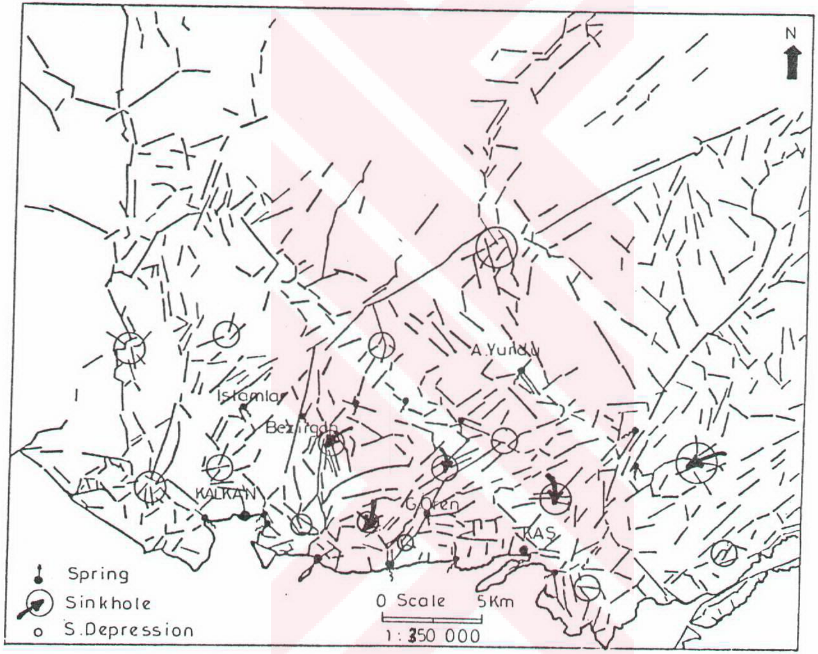


Figure 4.6 Analyses of Landsat-TM (Infrared band-5)

The widespread intersections of these lineaments may reflect the effect of the structural features (fault or developed fractures) controlled in the underlying beds of the Beydağları limestones. Generally, these linear features indicate the form and position of individual faults, veins and lithological contacts which may control the distribution of different karstic features in the study area.

4.4.2.b. Solution depressional features :

Small rounded and ellipsoidal features showing dark colours with a white collars around, were detected from the remotely sensed data of Landsat-MSS and TM imagery. These features are interprated as "solution depression" that may be related to the widespread karstic dolines and sinkholes in the study area. Mainly, they are distributed on the foots of the Beydağları mountains surrounding the northern part of the study area, especially in the boundaries of Gökçeören and Bezirgan poljes (see Fig. 4.6).

The remotely sensed data has shown that the dark colours in the middle of these features are mostly related to the vegetation cover and to the high moisture content, while, the white collars around being due to the highly reflective exposed carbonate rocks. These circular features are generally identified by the same kind of morphologic features and they seem to be developed and concentrated in certain regions according to the structural and geological setting of the study area.

4.4.2.c. Surface springs :

Comparison of the field observation, geological and lineament maps has shown that most of the surface karstic springs were distributed around the northern and northwestern parts of the study area where most of the intersection images were plotted (Fig. 4.7).

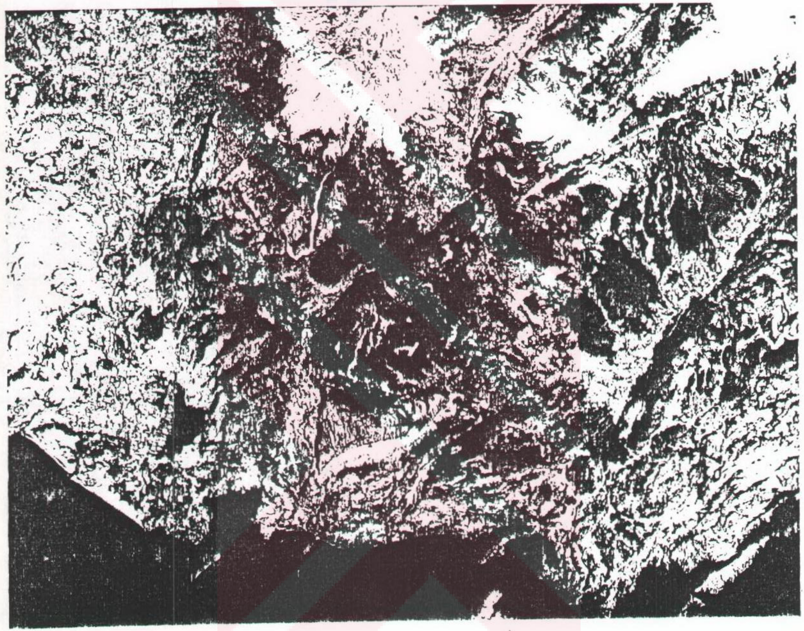
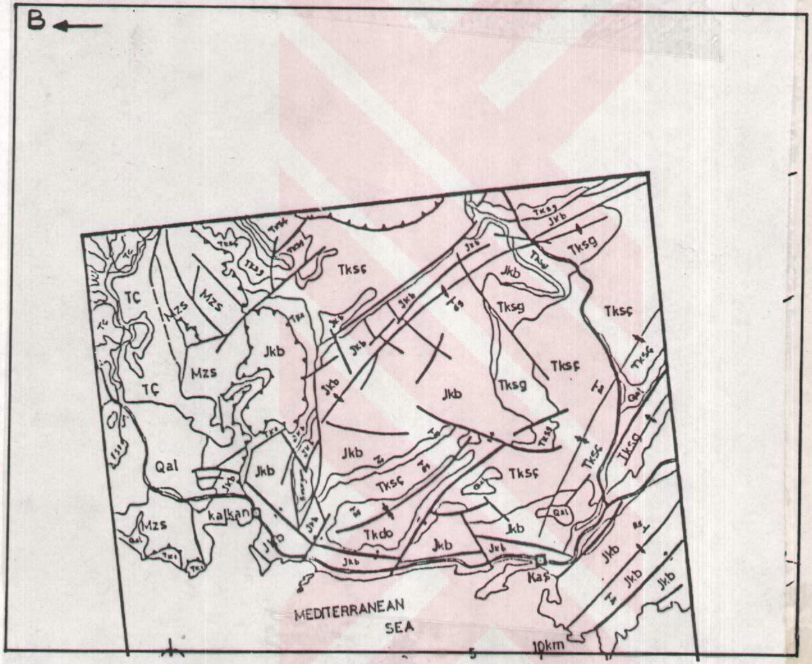


Figure. 4. 7. Comparison of Landsat-TM a), and geological map b).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The relationship between the regional faults and other structural features shows parallelism generally with natural karstic springs, whereas they are particularly with the small fracture systems. However, the surrounding karstic terranes provide a large catchment area which may recharge the internal regions with significant amounts of water, depending on the characteristics of the available geological units and the structural features controlling these units. The discharge of the surface karstic springs is limited or restricted especially in the northern and northwestern part of Kaş. This may be related to the subdivision of the total available recharge water into three parts; one may sink through the alluvial deposits covering the foot of the surrounding mountain, others seep through the highly developed fractures (deep and enlarged karstic channels), and the rest shows up at the surface as karstic springs.

4.4.2.d. Coastal and submarine springs :

Analyses of the black and white Landsat images cannot identify the surface trace of the coastal and submarine discharges through the linear features which may extend in the Kaş-Kalkan coastline. But, it gives a good overview of the geological and structural features characterizing this part of the study area.

From the hydrogeological field studies, it was observed that most of the coastal springs in Kaş are located in the southeastern side of the Kaş bay, where four main parallel fractures extending toward the coastline after crossing the mainland Beydağları limestones in the N50-70E direction. While, the coastal and submarine springs in Kalkan and along the Kaş-Kalkan coastline are located on the intersections of the linear features which extend into the sea after crossing the Beydağları formation in the N25E and N60W directions. Comparison of the field observations, the Landsat-TM images, and the geological map shows that the extension of these linear features toward the coastline or into the sea, were associated with the extentions of long lineaments which are considered as faultlines in the underlying beds of the coastal aquifer.

Comparisons of the hydrological, hydrogeological studies and interpretation of the remote sesing data showed that the coastal karstic springs in Kaş are recharged from shallow groundwater circulation system through faultlines extending in the N70E direction. Whereas, a deeper groundwater flow system may recharge the coastal springs on the kalkan coastline. However, the depth of these faultlines at the bottom of the sea can not be recognized by using the Landsat imagery. They may provide significant coastal and submarine discharges of turbid water with an average value of about 1.5 m^3/sec, especially during the heavy rain period.

The availability of the different karstic features along the mainland faultlines may also reflect the main direction of the groundwater movement through the coastal aquifer (Beydağları limestones). While, the general direction of the groundwater movement in the study area is plotted on the detailed hydrogeological map which is given in the Appendix-2.

5. HYDROCHEMISTRY

5.1. Introduction

Identification of groundwater quality interms of chemical constituents is considered as one of the most important requirements for most of hydrogeological investigations. The specific chemical and physical characteristics of the groundwater are controlled by the lithology and hydraulic characteristics of the aquifers, especially in the coastal karstic regions.

The physical and chemical characteristics of the groundwater at Kaş-Kalkan regions were measured during the field studies and in the hydrochemistry laboratory of the Hydrogeological Engineering Department. The hydrochemical investigations of the groundwater at the study area were carried out on mainly two groups of water samples which were collected from the widespread wells, fountains, and coastal karstic springs during the wet and dry periods. As soon as each sample was recovered, its pH, temperature, Dissolved Oxygen (DO), and Electrical Conductivity (EC) values were recorded in the field.

The hydrochemical evaluations have been derived from the results of the saturation and evolution analyses for identifying or determining more information on the hydrogeological structure of the basin in such coastal karstic area. Generally, most of the hydrochemical evaluations have been represented graphically, using the output parameters of the WATEQB hydrochemical model program (Arikan, 1985) which used for calculating the chemical equilibrium of the natural waters in study area.

Graphical representation methods including Trilinear, Schoeller semilogarithmic and Wilcox diagrams were also used for providing or arising the main chemical composition of the groundwater and its suitability for various uses in the study area.

5.2. Hydrochemical Analyses Methods

The groundwater quality determination involves mainly two hydrochemical analyses methods including the insitu and laboratory studies. The pH, temperature, Dissolved Oxygen (DO) and Electrical Conductivity (EC) determinations are recorded in the field, as soon as each sample was recovered. The location of selected water sample is given in Figure 5.1. Detailed physical and chemical characteristics of the water samples are given in Table 5.1.

All of the hydrochemical evaluations which have been mainly based on the detailed graphical representations for identifying the chemical composition and equilibrium of the groundwater in the study area, were carried out by using some parameters arised from the WATEQB model program (Arikan, 1985). The output (results) of this program is given in Appendix 1.

The saturation and evolution analyses have been applied graphically in order to define the main saturation levels, with respect to the calcite and dolomite for each particular sample, and to arise the similarity of the flow paths followed or releated to different time of travel through the groundwater flow system in the study area.

Graphical representation of the hydrochemical analyses is very useful technique for comparing groundwater samples with each other and emphasizing differences and similarities between them. It may also aid in detecting water-types of different compositions and identifying hydrochemical processes which may take place during the groundwater circulation in the investigation area. In the present study, the representative graphs include Trilinear, Schoeller and Wilcox diagrams.

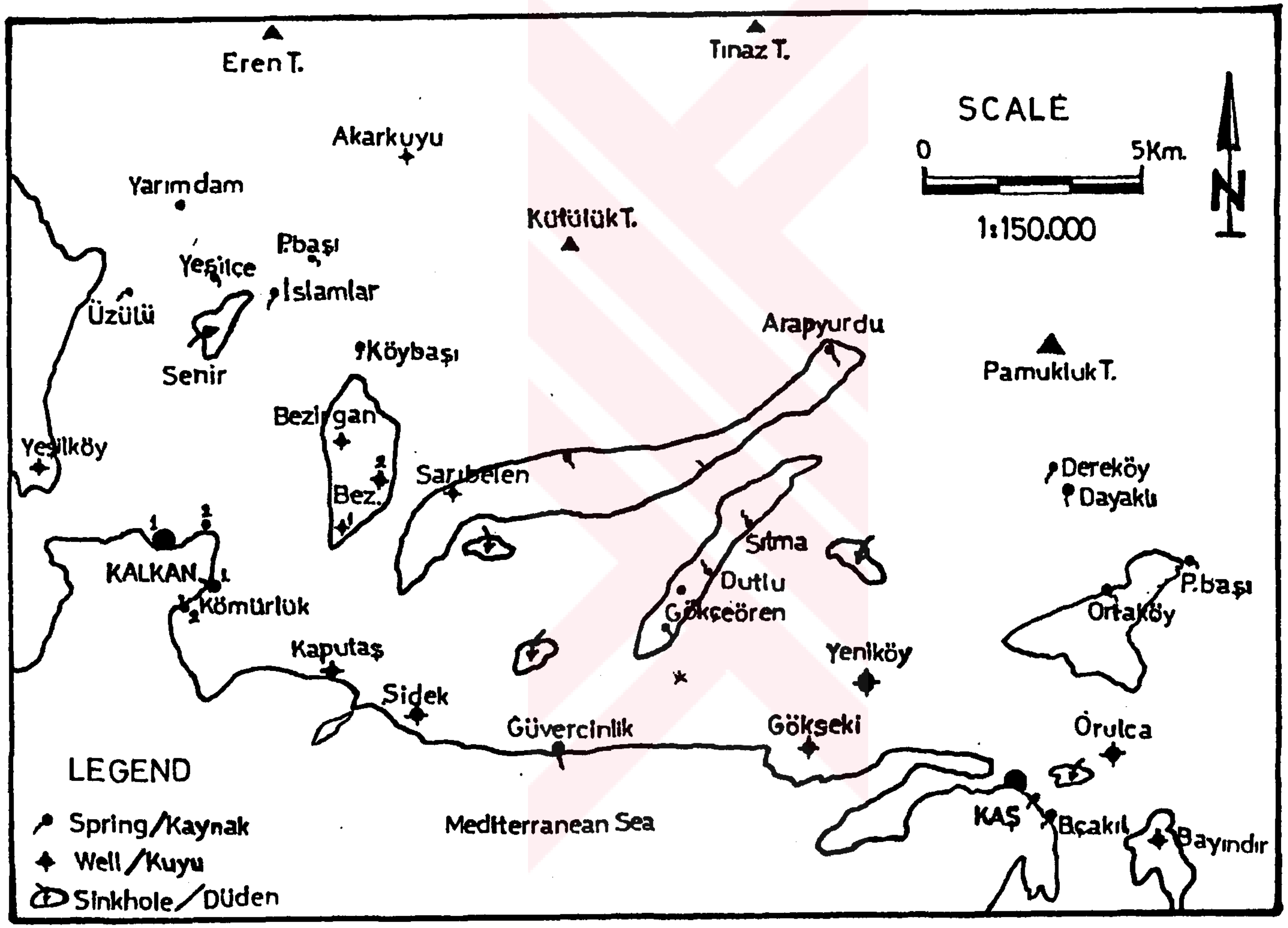

Figure 5.1. Location map of the selected water samples.

Table 5.1. Physical and chemical analyses of the groundwater samples.

	Samples	Temp. (°C)	EC μmohs/cm	PH	DO (mg/lt)	CO2 (mg/lt)	Ca (meq./lt.)	Mg (meq./lt.)	Na+K (meq./lt.)	Cl (meq./lt.)	SO4 (meq./lt.)	CO3+HCO3 (meq./lt.)	Hardness (° F)
1	Kalkan.1	17.0	1150	7.28	3.80	4.5	5.41	1.48	3.74	6.4	1.15	3.40	34.45
2	Kalkan.2	18.3	1200	7.40	2.60	2.0	5.84	1.49	3.80	6.0	1.32	4.2	36.65
3	Yeşilköy (Lapaz.2)	13.0	700	7.76	8.80	1.8	5.33	2.89	1.71	1.3	0.53	7.7	41.10
4	Kaputaş (W.)	17.5	600	7.32	2.70	8.4	3.42	1.06	0.877	0.7	0.85	4.1	22.40
5	Sidek (W.)	15.8	340	7.54	9.40	2.0	3.04	0.38	0.67	0.4	0.59	3.2	17.10
6	Orulca (W.)	14.5	390	7.10	10.20	8.0	3.72	0.14	0.65	0.8	0.15	3.5	19.30
7	Pınarbaşı	16.3	460	7.65	9.30	2.6	4.60	0.42	0.79	0.4	0.19	5.2	25.10
8	Köybaşı (Sp.)	13.5	250	7.12	8.50	10.4	1.67	0.31	0.60	0.3	0.1	2.2	2.00
9	Sarıbelen (W)	17.6	450	7.78	6.20	1.8	5.19	0.52	0.62	0.4	0.29	6.0	28.55
10	Gökçeören (Sp.)	15.0	230	7.15	8.90	8.5	1.87	0.065	0.29	0.1	0.12	2.0	9.67
11	Üzümlü (Sp.)	13.8	250	7.12	10.6	9.8	1.80	0.20	0.33	0.2	0.015	2.1	10.0
12	İslamlar (Sp.)	12.0	230	7.12	11.4	4.6	2.12	0.19	0.253	0.25	0.25	2.2	11.58
13	Bezirgan (W.)	15.8	850	7.28	2.60	6.2	2.37	2.08	0.91	0.6	0.35	4.35	22.25
14	Bez.1 (W.)	17.5	1400	7.54	3.80	2.0	12.25	2.06	0.76	0.7	0.16	4.2	21.55
15	Bez.2 (W.)	15.0	800	7.25	3.20	7.8	2.32	2.44	1.20	0.9	0.25	4.6	23.80
16	Kömürlük.1 (Cs)	17.5	20000	6.75	---	---	23.39	54.0	585.8	600	46.74	2.6	389.65
17	Kömürlük.2 (Cs)	17.0	18700	6.75	---	---	19.21	37.87	394.5	400	46.18	3.0	285.4
18	Güvercinlik (Cs)	15.0	11000	6.80	---	1.4	7.98	39.26	623.4	600	47.12	2.8	236.2
19	B.Çakıl (Cs)	12.0	12500	6.85	---	1.0	12.22	15.2	535.2	580	0.10	3.8	137.1
20	Ortaköy (Sp.)	14.5	300	7.38	8.60	3.6	2.81	0.14	0.77	0.5	0.06	3.0	14.75
21	Yeniköy (W.)	15.0	350	7.32	10.0	5.8	3.66	0.15	1.69	0.9	0.038	4.6	19.05
22	Sıtma (Sp.)	13.0	340	7.10	8.70	4.0	3.12	0.51	1.36	0.35	0.017	4.0	18.15
23	Bayındır (W.)	14.5	200	7.48	5.80	6.2	1.65	0.13	0.39	0.2	0.083	1.8	8.90
24	Gökseki (W.)	17.0	390	7.32	6.40	8.0	3.57	0.23	0.28	1.4	0.22	3.0	19.0
25	Gökdere (Arapyurdu)	14.5	325	7.54	9.80	6.5	2.42	0.16	2.1	0.2	0.10	3.8	12.9
26	Dereköy (Sp.) (Dayaklı Spring)	14.0	450	7.48	11.60	8.0	5.43	0.33	1.2	1.0	0.14	5.8	28.8

* **NOTE :** (W.): Wells, (Sp.): Springs, (Cs.): Coastal Springs.

5.2.1. Saturation analyses

The saturation analyses were applied for identifying mainly the saturation levels of the calcite and dolomite for each particular sample in the study area. The evaluations of these analyses were carried-out graphically depending on the results and parameters of the hydrochemical model program WATEQB (Arikan, 1985) including SiCa, SiMg, LogPCO_2 and $CaCO_3$. The relationship between the Saturation Index of the calcite and dolomite (SiCa-SiMg) and the partial pressure of the Carbondioxide (Log PCO_2) is given in figure 5.2.

Comparison of the water samples which were selected from the hinterland sides of the study area, with respecting to the saturation of the $CaCO_3$ content, shows that they have CO_2 atmospheric partial pressure (LogPCO_2) values of over about 2.2. The graph shows that all the water samples are located in the mixed and slightly high calcite saturation zone, where the Saturation Index of the calcite (SiCa) is less than zero. Whereas, the water samples which were collected from the Islamlar spring (discharging from dolomitic limestone unit), have relatively significant increment in the dolomite saturation level.

Some of the water samples (Gökçeören-1 and Sarıbelen) which have slightly high calcite saturation level, show significant decrease in the dolomite saturation level. These samples were collected from the wells penetrating the Beydağları limestone. Whereas, most of the samples which have low calcite saturation levels (Bezirgan, Sıtma and Çukurbağ), show also significant high decreases in the dolomite saturation levels. These water samples were collected from; (1) wells penetrating the alluvium which covers the Bezirgan polje, (2) Çukurbağ (Düdenağzı), and (3) Sıtma spring which discharges from the contact zone between the Kasaba conglomerates and the Çayboğazı flysch. The decreases in calcite and dolomite saturations of these samples may be related to ionic exchange effects which may

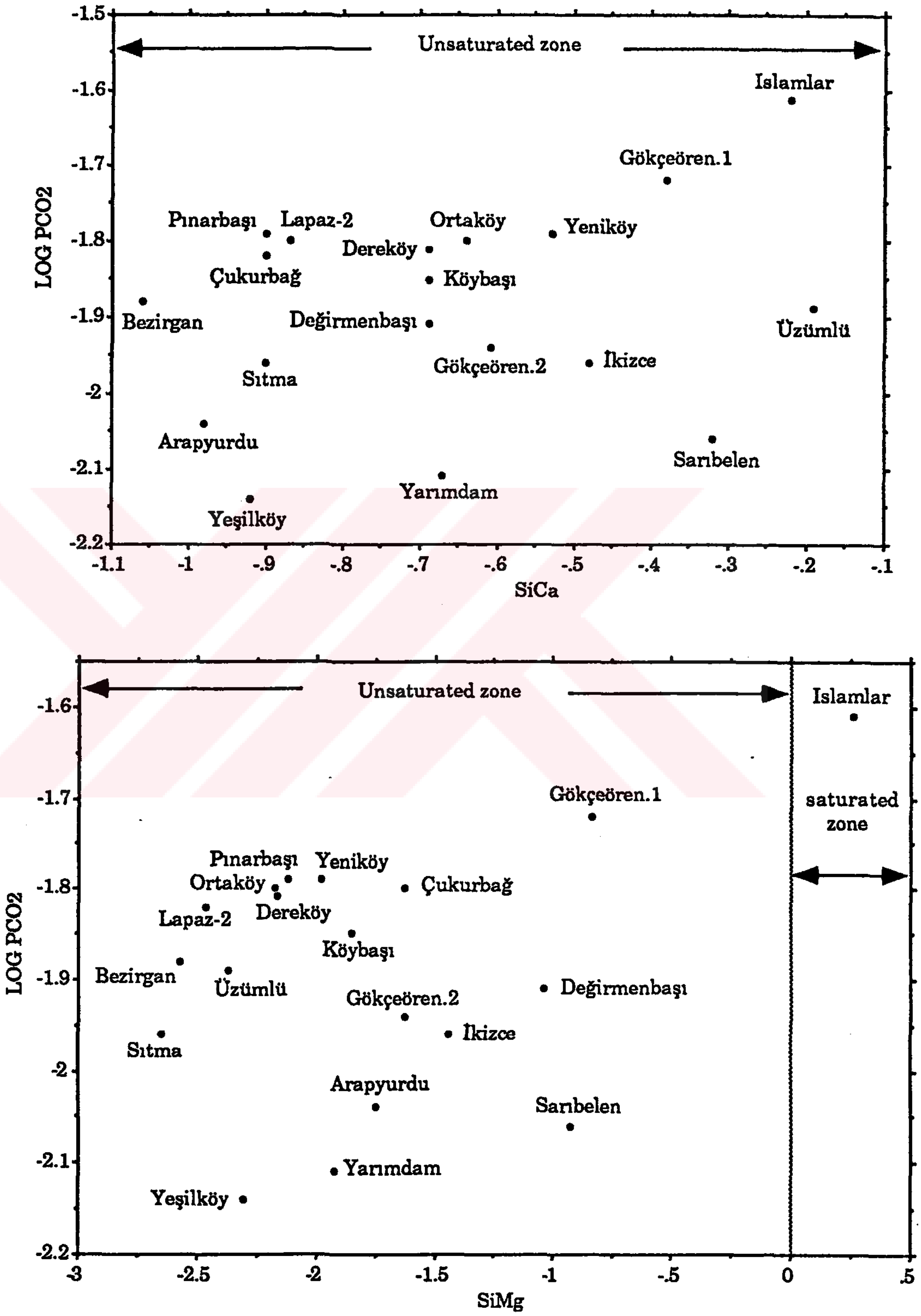

Figure 5.2. Saturation graphs of the water samples with respect to;
a) calcite, b) dolomite

take place under long time of travel and deep groundwater flow system.

All the water samples which were collected from the coastal springs discharging throughout the Beydağları limestones along Kaş-Kalkan coastline (Kömürlük 16, 17, Güvercinlik 18 and Büyükçakıl 19), were not plotted on these graphs. These samples have great and sharp decreases in the calcite and dolomite saturation levels, and significant increase in the Na^+ + Cl^- saturation level. The sudden increament of Na^+ and Cl^- concentrations is mainly related to the influences of the sea water intrusion in this part of the study area.

Finally, most of the water samples which have approximately the same hydrochemical characteristics in this graph, may be occured or taken place under the same natural conditions. Note that, they are also graphically close to each other in the study area.

5.2.2. Evolution analysis

Evolution analysis has been applied in order to define the similarity of the flow paths followed and the relative time and depth of travel of groundwater in the study area. Generally, in the karstic regions where the groundwater flow systems follow deep and weak karstic channels, the Redox Potential (Eh) and most likely the pH shows reverse relationship with the relative time and depth of travel (Freeze and Cherry, 1979). This means that, the longer the relative time of travel, the lower Eh and pH values.

Figure 5.3 illustrates the relative classifications on the evolution level of the groundwater types at the study area. All the pH values were measured accurately as soon as each sample was recovered during the field studies. In correspondence, the Eh values are determined (calculated) from the WATEQB model program (Arıkan, 1985). Figure 5.3 illustrates the relative classifications on the evolution level of the groundwater types in the study area.

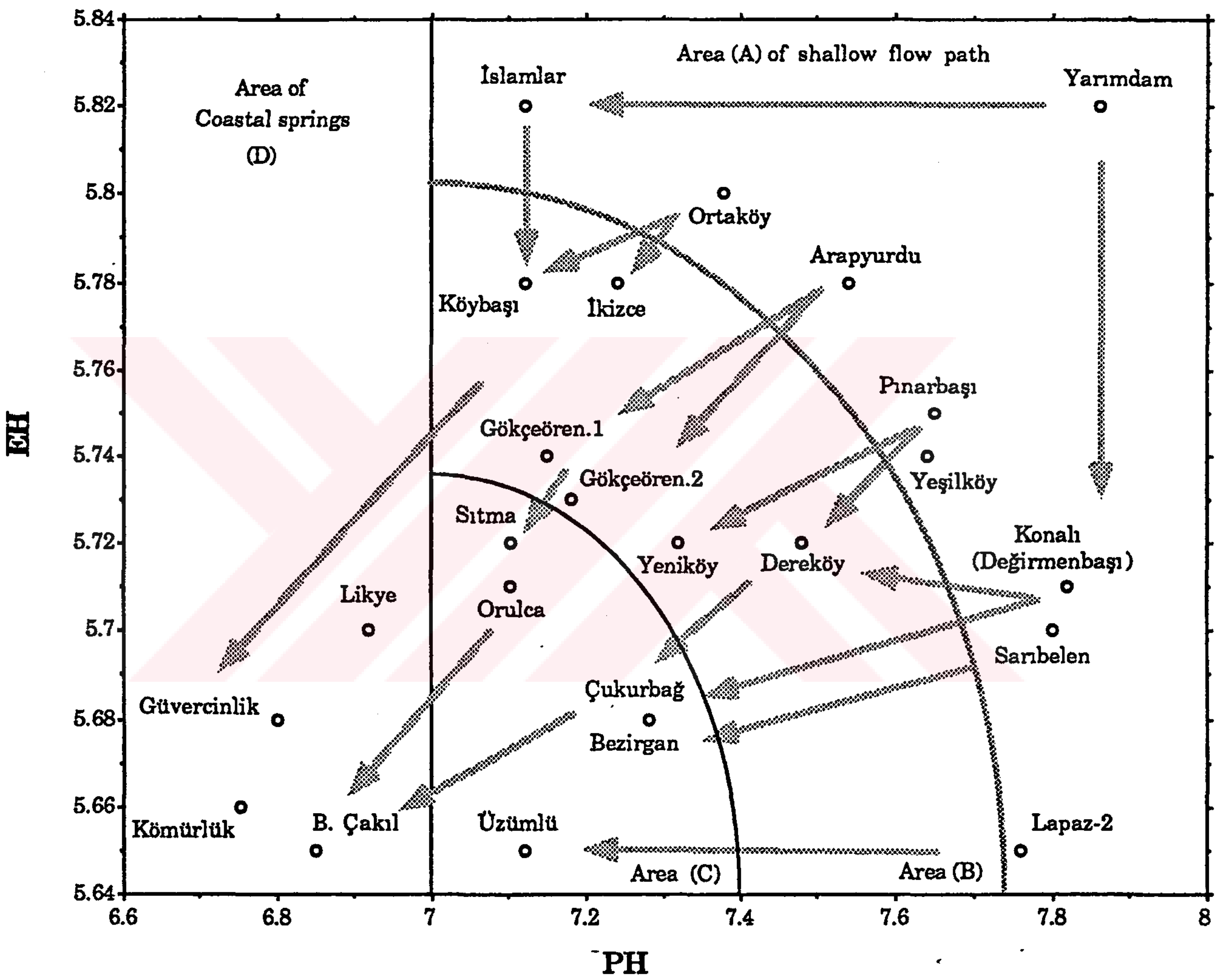

Figure 5.3. PH - EH graph

This graph shows that, the water samples which are located at the beginning of the evolution path area **A** (upper right side of the graph), indicate recent water types of short time of travel following shallow path circulation (flow system). Whereas, all water samples which are located at the end of the evolution path area **C** (lower left side), may be considered as waters belonging to deep karstic flow systems under relatively significant long time of travel throghout the coastal aquifer of the study area (Beydağları limestone). While, the water samples in area **B** (Ikizce, Gökçeören, Dereköy and Yeniköy), are located in the transition zone between the shallow and deep flow systems.

The water samples which were collected from different coastal karstic springs are located in area **D**. This area may reflect the hydrogeological characteristics of very deep groundwater flow system significantly long time of travel. This may arise or poited out the hydraulic connection between all the coastal springs and the widespread karstic springs which are located on the same straight parallelizm in this graph.

5.2.3. Relationship between cation and anion concentrations

The relationship between cation and anion concentrations, indicates the chemical composition of the groundwater in the study area. This may give more information on the classification of the groundwater types according to its nature or/and source of occurrence and influences of different lithological media at the study area. Moreover, this relationship may represent the purity of carbonate water type of the groundwater samples and the mixing water regions.

In order to achieve these objectives, the relationship between Ca^{++} + Mg^{++}, Na^{+} + K^{+} and Cl^{-} + SO_4^{--} concentrations were applied graphically for the selected water samples around the investigation area (Fig. 5.4). The relationship diagrams were done depending on

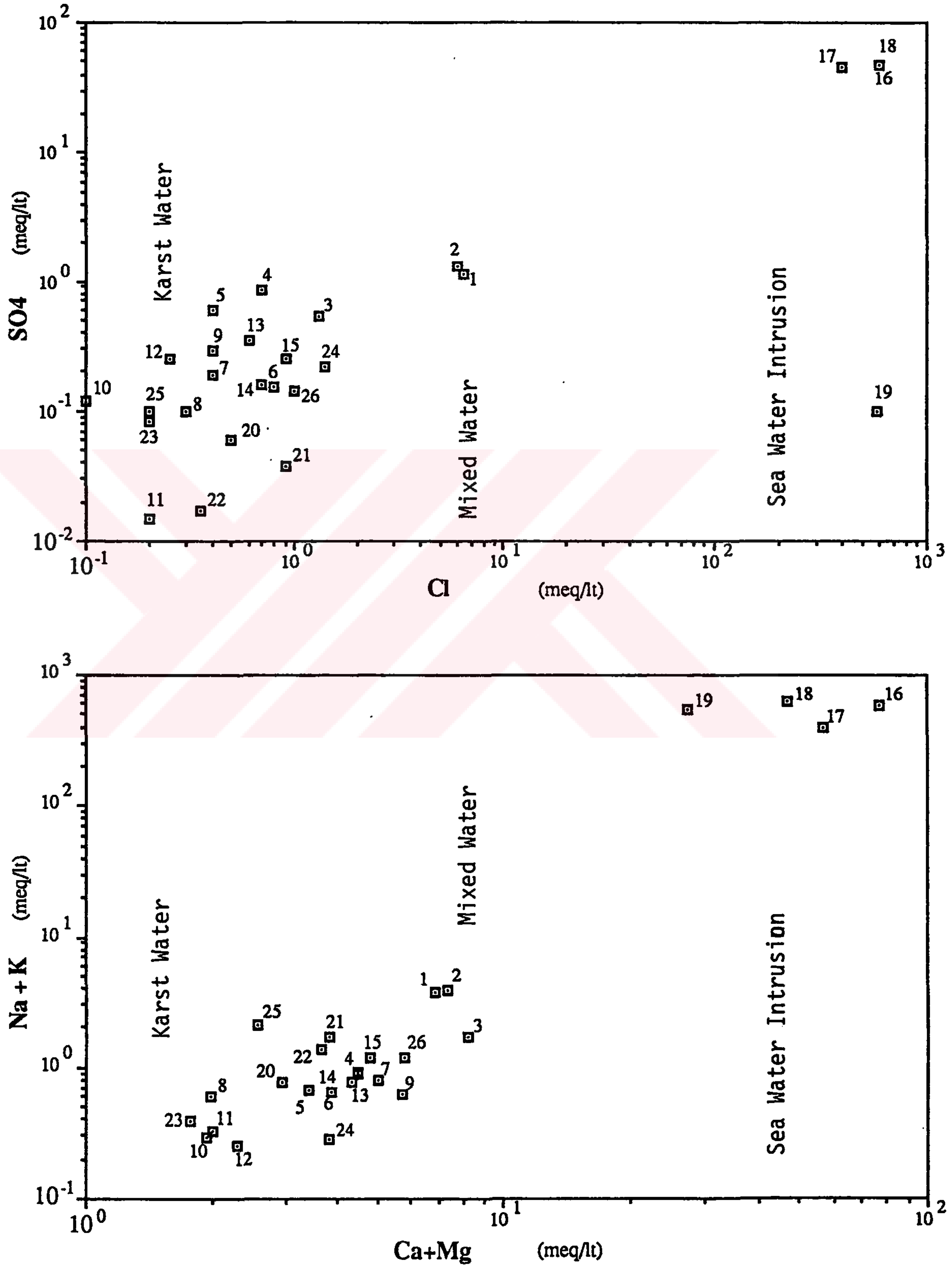

Figure 5.4. Water types according to the major cations and anions relationship of the groundwater samples

the logarithmic values of the major cation and anion concentrations which were expressed in milliequivalents per liter. The numbers of the water samples which are plotted on the graph, have the same order of the water samples given in Table 5.1.

This graph shows that, most of the water samples which were collected from the karstic springs in the hinterland side, are located in the area of the carbonate water type, with low $Na^+ + K^+$, Cl^- and $SO4^{--}$ contents. While, water samples (1,2) which were collected from Kalkan, show small increases in these contents, comparing with the other water samples.

On the otherhand, the water samples which were collected from the coastal springs in the southeastern part of Kalkan (Kömürlük-16,17, Güvercinlik-18) have high $Ca^{++} + Mg^{++}$, $Na^+ + K^+$, Cl^- and SO_4^{--} concentrations. Although, Büyükçakıl-19 was also collected from coastal spring, it represents significant decreases in the $Ca^{++} + Mg^{++}$ and $SO4^{--}$ contents. Note that, the main coastal aquifer for these springs is the Beydağları limestones. Therefore, two main factors may affect this significant change. First one is the allochthonous dolomitic limestone (Kaymaklı formation) surrounding the northern and northeastern part of Kalkan town. The second reason is the ionic exchange which may take place through long time of travel and deep flow system.

5.2.4. Graphical representation

5.2.4.a. Trilinear diagram

The Trilinear diagram is one of the most important and useful graphs for comparing different water types. In this diagram the concentration of different cations and anions had been plotted as the percentage of total ions in miliequivalents per liter on two triangles. The intersection point which is projected into the central diamond shaped area, is thus uniquely related to the total ionic distribution of the water samples.

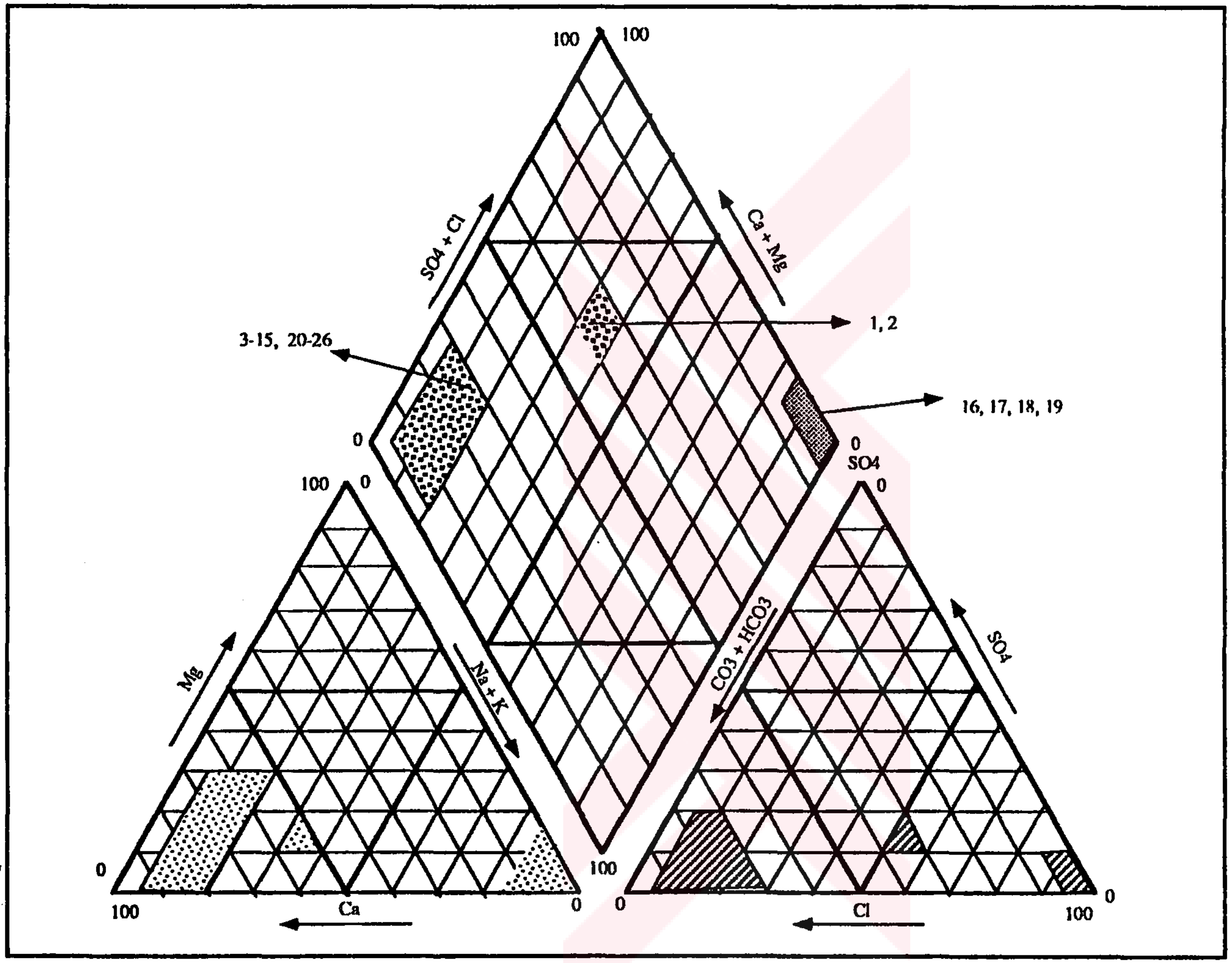

Figure 5.5. Groundwater samples plotted on the Trilinear diagram.

The groundwater samples which were collected from the study area during the field investigations in different seasons, were plotted on the trilinear diagrams in Figure 5.5. This figure illustrates the concentrations of the major cations and anions for different or similar water types in the study area.

5.2.4.b. Schoeller semilogarithmic diagram

The semilogarithmic diagram which had been introduced into the groundwater literature by Schoeller (1955) is mainly used to demonstrate the differences between the major cation and anion compositions of the selected water samples. The concentrations of different ions are expressed in miliequivalents per liter. The major ionic concentrations of the selected water samples, are plotted on the Schoeller semilogarithmic diagram in figure 5.6.

5.2.4.c. Classification of irrigation water by Wilcox diagram

The study of groundwater quality is mainly related to its suitability for various purposes, depending on the criteria standards of acceptable quality limits for that uses. The conditions or factors controlling the groundwater quality for agricultural purposes, include (1) the total dissolved solids, (2) the concentration of some specific ions that may have unfavorable effect on crops, (3) the concentration of cations that may cause soil land damages.

Classification of groundwater types by using Wilcox diagram, is mainly based on the Sodium percentage (%Na), Sodium Adsorption Ratio (SAR) and the Electrical Conductivity (EC) of the groundwater in the study area. Although it is generally used for the classification of water for irrigation purposes, it however, provides an apportunity to compare different samples in terms of salinity and sodium (alkali) hazards.

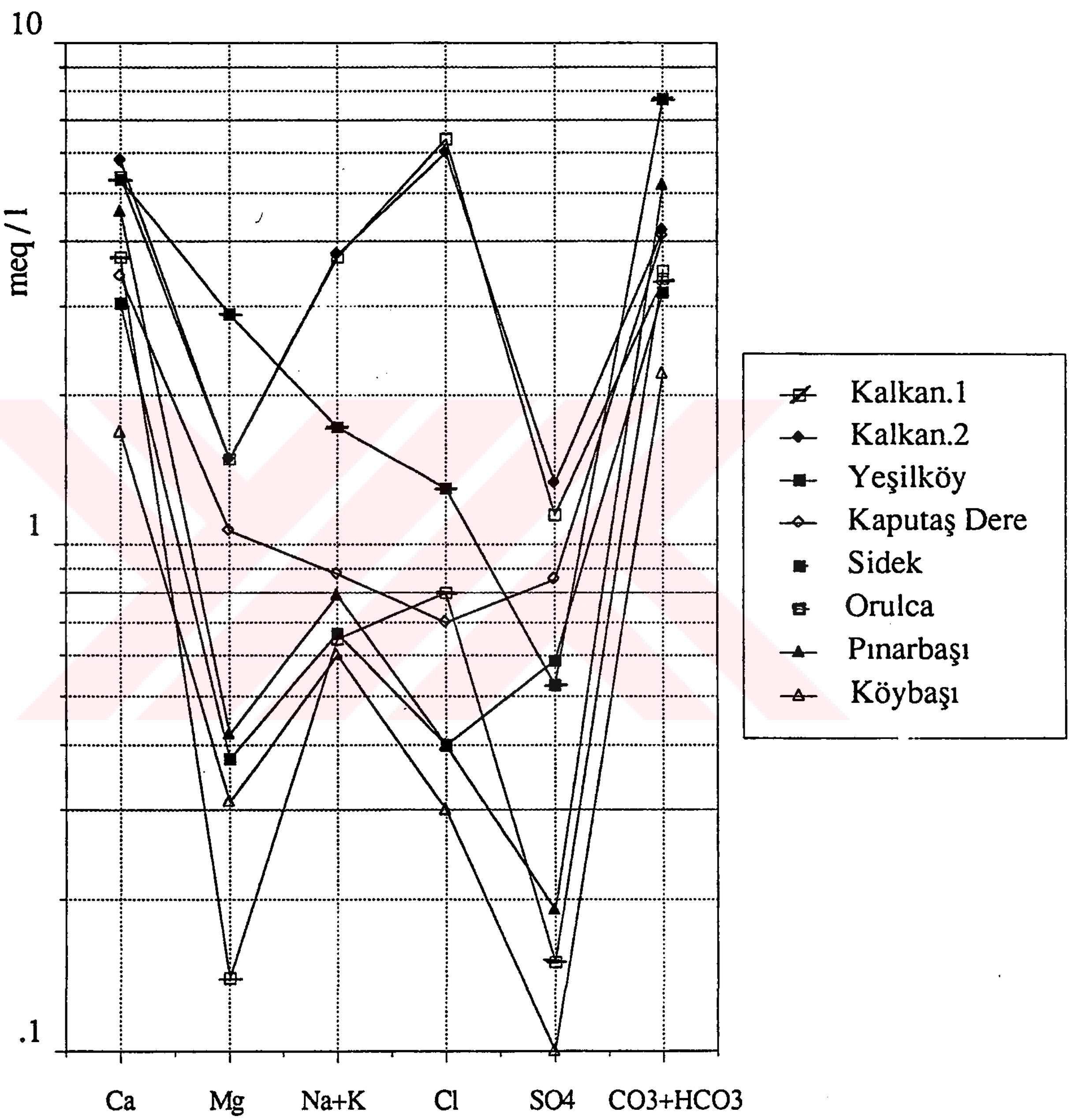

Figure 5.6. Schoeller semilogarithmic diagram diagram demonstrating different cation and anion compositions.

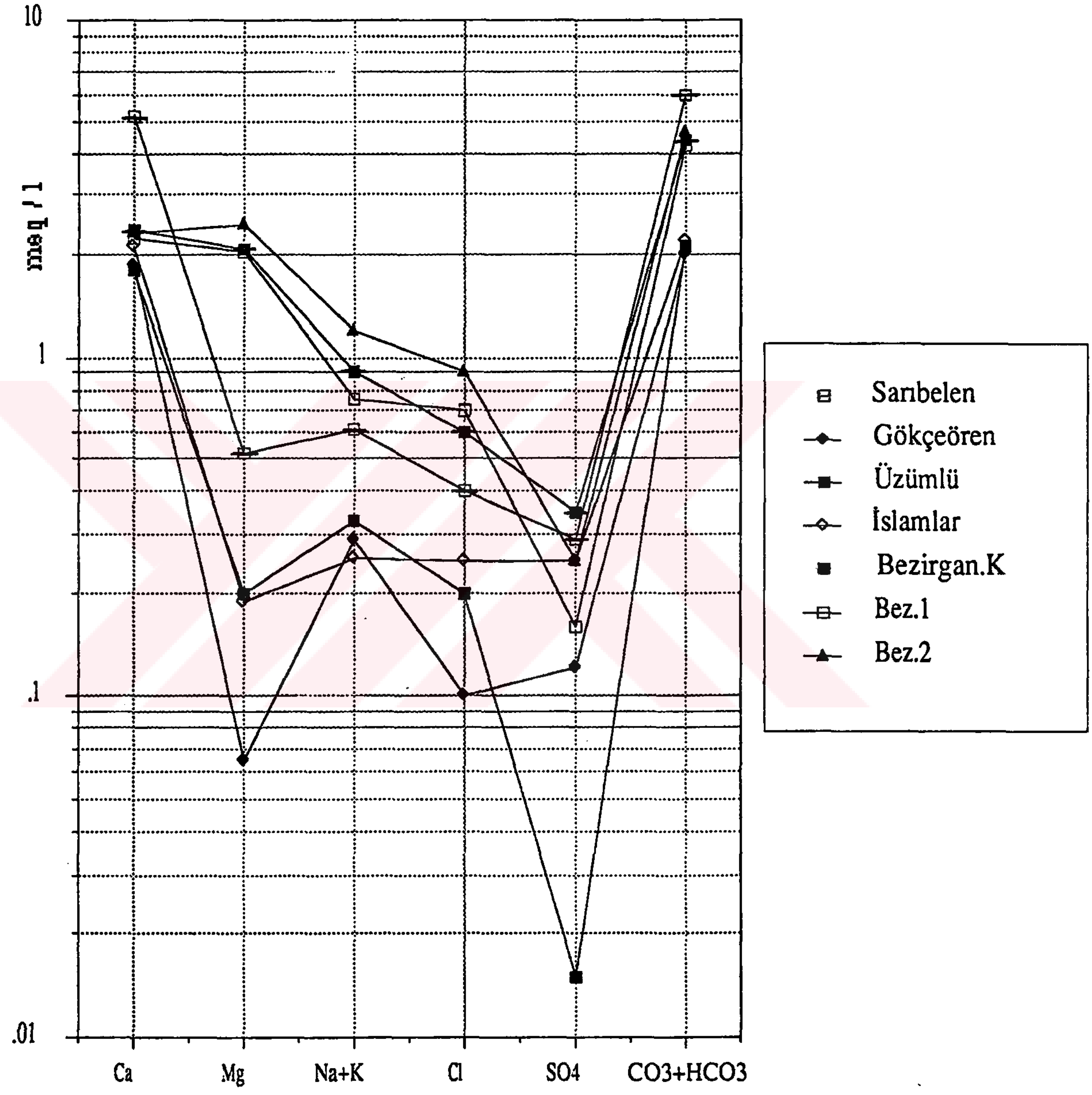

Figure 5.6. Continue..

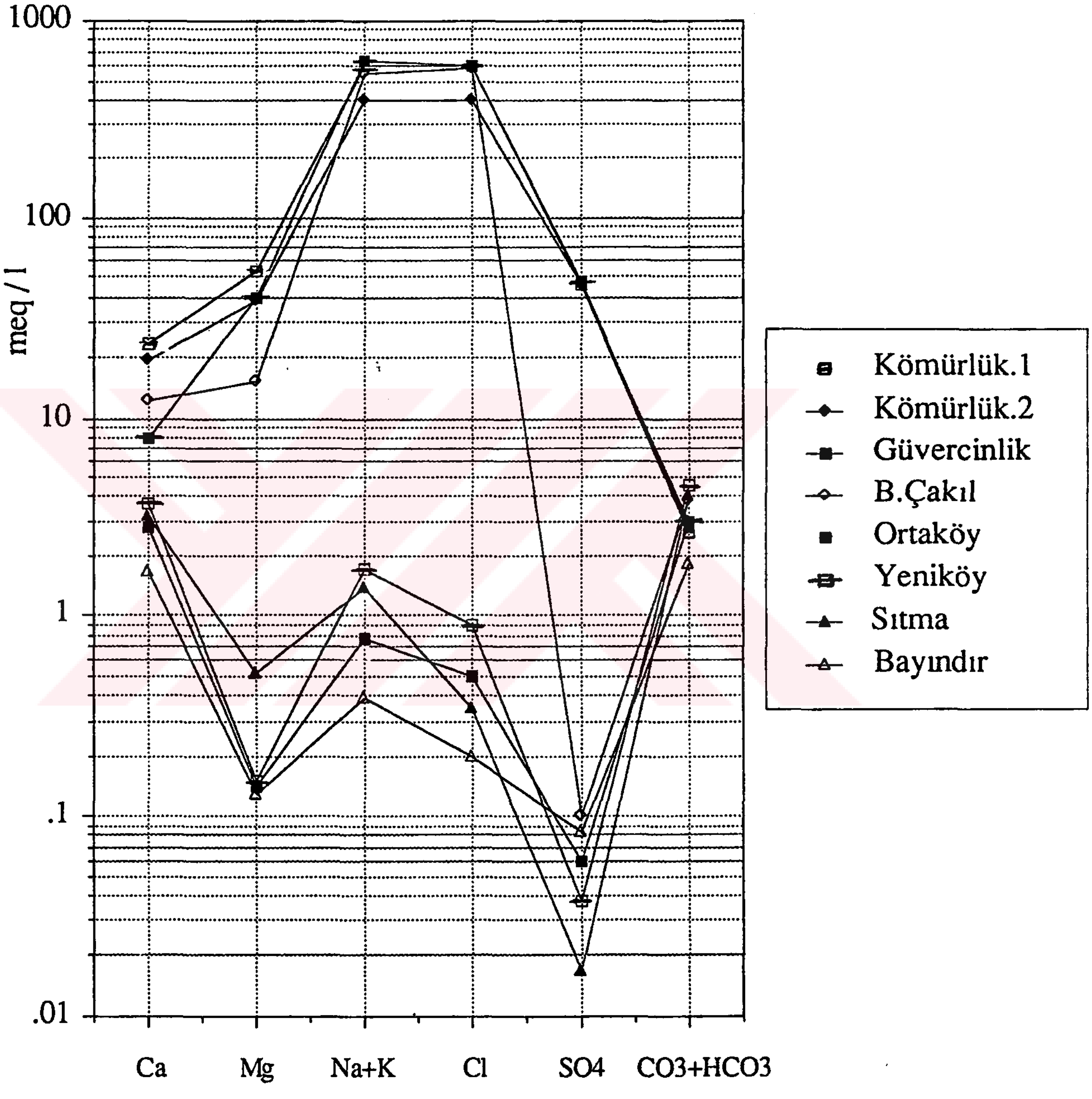

Figure 5.6. Continue.

The sodium percentage (%Na), electrical conductivity (EC) and sodium adsorption ratio (SAR) of the selected groundwater samples are listed in Table 5.2. While, the classification of water for irrigation uses according to standard %Na, EC and SAR values, is given in Table 5.3 (Wilcox, 1953, in Todd,1980). The classification of groundwater samples by Wilcox diagram, is given in Figure 5.7.

5.2.4.d. Interpretation of graphical representation

The position of the selected water samples in the Trilinear, Schoeller and Wilcox diagrams are given in figures 5.5, 5.6 and 5.7 respevtively.

- According to the subdivisions of the Trilinear diagram, all of the groundwater samples which were collected from the hinterland side of the study area, have high Ca+Mg and CO_3 + HCO_3 contents (concentrations) and dominate as alkaline earths and weak acid water type of carbonate hardness more than 50 % . Pointing out that dominant chemical composition of the aquifer is mainly carbonate rich. Whereas, the water samples which were collected from the coastal karstic springs (Kömürlük-16,17, Güvercinlik-18 and Büyükçakıl-19), have high NaCl (consentration) contents reflecting dominant alkalines and strong acid water type. Water samples (Kalkan-1,2) which were collected from the Establishments of Irrigation Water in Kalkan coastline are plotted in the mixed water zone where no cation-anion exceed 50%.

- From Schoeller diagram, the groundwater samples which were collected from (Kalkan 1-2), have higher Na^+, K^+ and Cl^- concentrations than the other samples of the natural springs surrounding the study area. Although, these two samples were collected from wells penetrating the Beydağları limestones, relatively significant decrease in the Ca^{++} concentration is noticed as result of sea water intrusion enfluences.

Table 5.2. Sodium adsorption ratios of the selected water samples.

Sample No	Sample Cod.	% Na	Ec	SAR
1	Kalkan 1	35.0	1150	1.91
2	Kalkan 2	34.0	1200	1.88
3	Yeşilköy	17.2	700	0.72
4	Kaputaş D.	16.4	600	0.53
5	Sidek ad.	16.4	340	0.32
6	Orulca	14.4	390	0.37
7	Pınarbaşı	13.6	460	0.27
8	Köybaşı	23.5	250	0.46
9	Sanbelen	9.8	450	0.30
10	Gökçeören	13.0	230	0.20
11	Üzümlü	13.9	250	0.26
12	İslamlar	9.9	230	0.22
13	Bez K.	16.9	850	0.51
14	Bez 1.	14.9	1400	0.42
15	Bez 2.	20.0	800	0.65
16	Kömürlük 1	88.3	20000	89.90
17	Kömürlük 2	87.4	18700	69.30
18	Güvercin	92.9	11000	123.50
19	B. Çakıl	95.1	12500	143.30
20	Ortaköy	20.7	300	0.45
21	Yeniköy	30.5	350	1.15
22	Sıtma	27.2	340	0.92
23	Bayındır	18.0	200	0.20
24	Gökseki	6.8	390	0.17
25	Gökdere	44.3	370	1.36
26	Dereköy	17.1	450	0.65

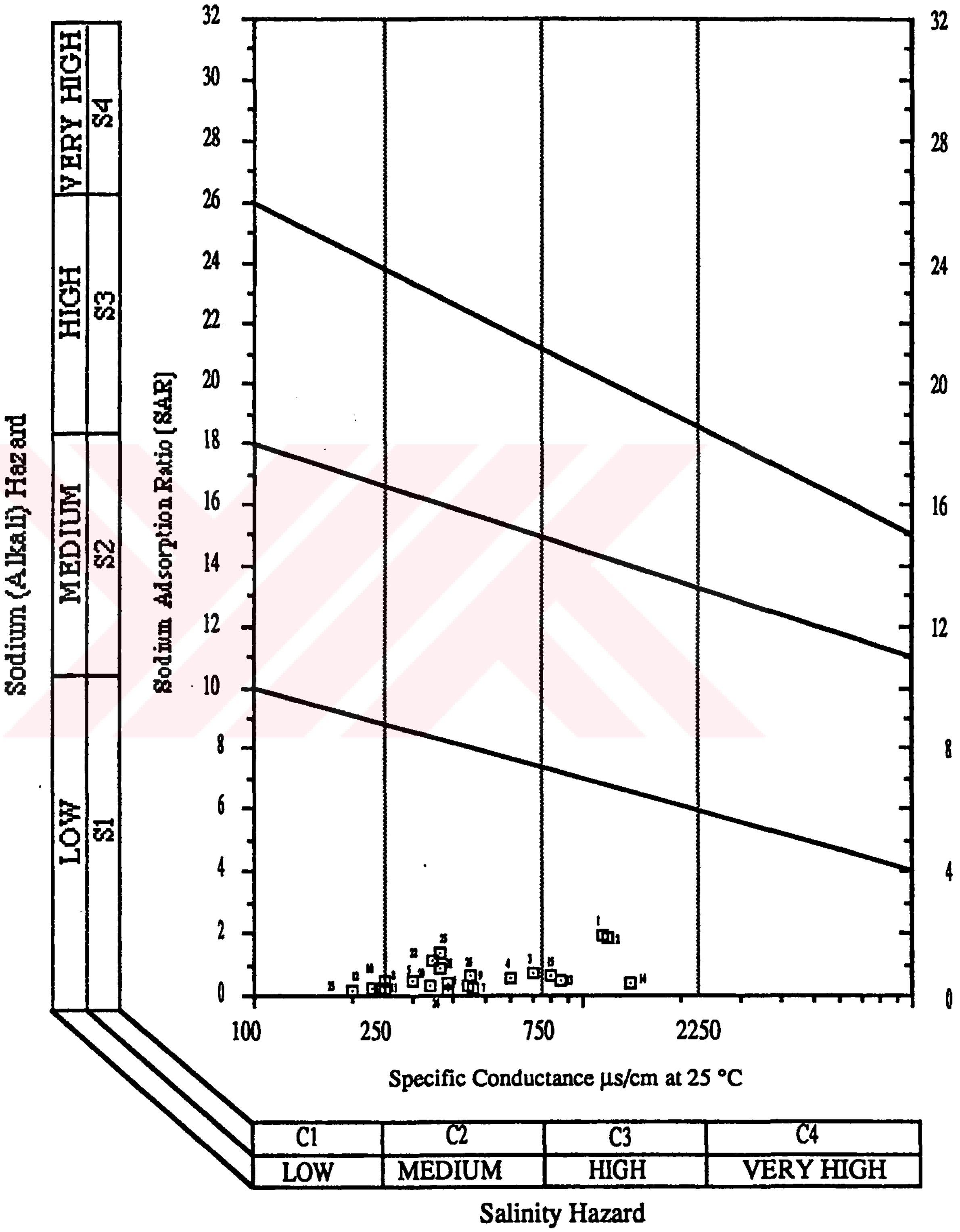

Figure 5.7. Interpreting the analyses of groundwater samples for the agricultural uses by Wilcox diagram

Most of the water samples which were collected from the wells and natural springs discharging from the Beydağları limestones (Ortaköy-20, Yeniköy-21 and Gökdere-25), have higher Na^{+}- K^{+} concentrations than the other surrounded karst springs. This may be related to ionic exchange effects which may take place during long time of groundwater travel throughout this zone.

- As seen in table 5.2, the values of sodium percentages, electrical conductivity and sodium adsorption ratio of the natural surrounding karst springs have the ranges of 7.3 to 44.2, 200 to 1400 mmhos/cm and 0.17 to 1.91 respectively. Whereas, the water samples which were collected from the coastal karst springs (Kömürlük.16-17, Güvercinlik-18 and Büyükçakıl-19), have sodium percentages of > 80 and sodium adsorption ratio ranges between 69.3 to 143.3. Therefore, these samples are not plotted on the Wilcox diagram (Fig.5.7).

However, the water samples of Kalkan.1-2 and Bez.13-14-15 are classified as excellent to good waters for irrigation uses, the graph illustrates that they have low sodium hazard and high salinity hazard enfluences (Fig.5.7). Moreover, the water samples of Ortaköy-20, Yeniköy-21, Sıtma-22 and Gökdere-25, are plotted in the part which has medium salinity hazard and low sodium (alkali) hazard. Therefore, they are also categorized as excellent to good waters for irrigation uses. According to Wilcox quality classification (Table 5.3), the groundwater of the study area is generally considered as an excellent water for agricultural purposes.

Table 5.3. Classification of water for irrigation according to %Na, EC and SAR values

Water Class	% Na	Specific Conductance	SAR
Excellent	< 20	<250	>10
Good	20-40	250-270	10-18
Permissible	40-60	750-2000	18-26
Doubtful	60-80	2000-3000	26-34
Unsuitable	> 80	> 3000	> 34

6. CONCLUSIONS AND RECOMMENDATIONS

Most of the lithological units in the investigation area belong to the Beydağları Carbonate Platform which considered as one of the major tectonostratigraphic units of the Teke Lycian Taurus, the western limb of the Outer Taurus Mountains. The Outer Taurus Mountains also include two main allochthonous units. One is the "Teke Nappes" to the west, and the "Antalya Nappes" to the east. These Tectonostratigraphic Units were emplaced during the Late Mesozoic and Early Tertiary Orogenic events, which caused the unconformity between different lithological units existing in the study area.

Generally, the topographical features were exhibited within highly dissected and rugged area due to the intense faulting, folding and different widespread rock weathering along the Kaş-Kalkan Coastline. The general trend of the structural features in the study area is ENE-WSW direction. The widespread remarkable karstic features were generally developed on the foots of the surrounding Beydağları limestones, and also on the contact zone between the Late Miocene Kasaba conglomerates and the Çayboğazı flysch unit.

Analyses of precipitation data have shown that there is reverse proportional relationship between the mean annual precipitation and the topographic elevations above the mean sea level in the study area. Considering that the topographical condition is the main factor that may affect the areal distribution of precipitation over the research site. The average annual precipitation is estimated as 568.0 mm.

Most of the geomorphological features and karstic phenomena are developed either on the foot of the karstic lower units (Beydağları and Susuzdağ limestones) or/and at higher elevations on the upper karstic units which include autochthonous Kasaba Conglomerates and allochthonous Kaymaklı dolomitic limestone. While, some of the karstic features are located on the contact zone with the Impervious lower unit of the Çayboğazı and Kozağacı flysch units. The underground impervious boundry of these units may act as a barrier for the groundwater flow. This may cause the rising of the groundwater level and discharges through the widespread karstic springs at higher elevations.

The coastal springs which extend along the Kalkan coastline are recharged from very deep groundwater flow system, since the average temperature of these springs is about 18.5 °C. On the otherhand, the discharges of karstic springs which are located at high elevation north Kalkan show significantly higher changes than Kaş during the dry periods. Although the number and the extention of the coastal discharge points in Kaş are more than Kalkan. The amount of the coastal discharges and water temperatures in Kaş are lower than in Kalkan. This may also represents that the groundwater flow path in Kalkan follows deeper system throughout highly and deeper karstified aquifers than Kaş.

For identifying the main water sources and the relationship between the expected two groundwater flow paths that recharge the coastal springs extending along the Kaş-Kalkan coastline, about 14 water samples were collected from the coastal and the hinterland sides, for the isotopic analyses. Results of the isotopic analyses have shown that there are mainly two different karst water circulation systems. A shallow groundwater circulation starts at high elevations in the northern part of Kaş and extends toward the Büyükçakıl coastal spring at the Kaş coastline. While, the second groundwater flow system at the northern part of Kalkan is deeper with longer time of travel.

At the study area, there are mainly four major hydrogeological units. These units were differentiated according to their individual structural and hydrogeological characteristics, into karstic Lower and Upper Units, Impervious Lower Unit, and the Quaternary alluvium.

The drainage area of Kaş and Kalkan has a complex hydrological regimen due to the presence of highly variable lithologic units which constitute the unconfined aquifer conditions at the study area. These aquifers include the different autochthonous, allochthonous and Post-tectonic porous units.

Although, the investigation site has a surface drainage area of about **425** km^2, the total catchment area includes the autochthonous, allochthonous porous units and alluvium, which cover areas of about **278.5, 34.5** and **8.0** square kilometers, respectively. Whereas, about **104.0** km^2 of the whole drainage area is covered by autochthonous Çayboğazı flysch (**84.0** km^2) and allochthonous Kozağacı (**20** km^2) impervious units.

Recharge of the groundwater basin is mainly calculated depending on the volumetric determination of the real infiltrated water amounts or percentages throughout the different hydrogeologic units. The autochthonous porous units include the Jurassic-Upper Cretacous Beydağları limestone, Eocene Susuzdağ dolomitic limestone, and the Late Miocene Kasaba (Dirgenler) conglomerates. The total recharge to these porous units is about **75.14 x 10^6** m^3/year. The total recharge to the allochthonous Kaymaklı limestones covering an area of 32.0 km^2 and the Post-Tectonis Çamal porous unit (2.0 km^2) is about **9.8 x 10^6** m^3/ year. Whereas, the recharge to the alluvium which covers an area of 8.0 km^2 is about **0.3 x 10^6** m^3/year. Thus, the total amount of water that may recharge the groundwater basin of the study area is **85.24 x 10^6** m^3/year. This amount of water is calculated depending on different infiltration ratios for the existing porous units.

Since the infiltration rate is controlled by the gentle topographic slopes with rugged surfaces, density of vegetation cover, karstification of these porous units, and duration and intensity of rainfall in the study area. The estimated amounts of water recharging the groundwater basin may slightly decrease or increase according to these factors.

Total discharge of **16.1 x 10^6** m^3/ year may occur due to the artifical pumping, while, the total discharge from karstic springs at the hinterland side is about **21.4 x 10^6** m^3/year. For determining the groundwater potential of the study area, the total discharge of the Coastal springs is estimated as **14.2 x 10^6** m^3/year (450 lt/s). Since the total discharge from the groundwater basin is calculated as **51.7x10^6** m^3/year. Then, the expected discharge of the Kaş-Kalkan submarine springs is about **33.54 x 10^6** m^3/ year (1.06 m^3/sec).

From the lineament map which was prepared using Landsat-MSS and TM (infrared band-5), it is concluded that most of the long lineaments and major structural features are extended along the Kaş-Kalkan coastline after crossing the Beydağları formation in the N70-80E (north of Kaş) and N25-30W directions (north of Kalkan). The relationship between the regional faults (or other major structural elements) shows general parallelism with the karst springs in the hinterlands, whereas they are particularly with small fracture systems.

Comparison of the field observation, geological and lineament maps has shown that most of the widespread karstic features were located at and/or around the northern and northwestern parts of the study area, where most of the intersection images were plotted. Eventually, the availability of the different karstic features along the mainland faultlines may also reflect the main groundwater flow direction through the coastal aquifer (Beydağları limestone).

The hydrochemical analyses of the selected water samples have shown that the groundwater quality in the hinterland side is generally satisfactory for drinking and agricultural purposes. Where the dominant water type is calcium to calcium-magnesium carbonate to sulphate, with high calcite saturation from the autochthonous Beydağları limestones, and high dolomite saturation within the allochthonous Kaymaklı dolomitic limestones.

All the water samples which were collected from the coastal springs discharging throughout the Beydağları limestones along Kaş-Kalkan coastline, have great and sharp decreases in the calcite and dolomite saturation levels, and significant increase in the Na^+ + Cl^- saturation level. The sudden increament of Na^+ and Cl^- concentrations is mainly related to the influences of the sea water intrusion in this part of the study area.

At the study area, there is no boreholes along or nearby the coastline for investigating the structure of the saltwater-fresh water interface (transition zone) within the coastal aquifer. Therefore, the enfluences of the sea water intrusion were studied through the hydrogeological field investigations, depending on the chemical and physical characteristics of the coastal springs during the wet and dry periods.

Although, the groundwater levels in the majority of the coastal regions are slightly above the mean sea level, and pumping is very likely to cause serious seawater contamination problems. This phenomena is not available on the Kalkan coastline where about 60 lt/sec of total artificial discharges of the fresh-water is supplied by the Establishment of Irrigation Water (DSI). This means, there should be barrier or a thick fresh-water column retarding the seawater intrusion to great depth. This also may represent the availability of very deep groundwater flow system along the Kalkan coastline.

Although, the Beydağları coastal aquifer is characterized by a large catchment area, especially during the heavy rain periods. The entense fissures, tectonical damaged and high karstification make the hydrogeological works on capturing the underground karst waters from this terrane linked with many difficulties and risks. Therefore, before the captation works, it is recommended to have detailed geoelectric sounding survey, drilling of exploration boreholes, long term observation of piezometric level of the karst water bodies and periodic sampling for isotope analyses in order to identify the depth of the weak karstic zones (channels) within this coastal aquifer. These studies should be applied for at least one year in order to examine the response of the groundwater within this coastal karstic unit during the wet and the dry periods.

The recommended captage will consist of a vertical mine shaft with a horizontal water catchment gallery (collector) extending within the underground karstic channels at elevations above the mean sea level. From the present study, two main sites are recommended for capturing fresh groundwater from the coastal Beydağları karstic aquifer. One is the area behined the Büyükçakıl coastal spring in Kaş and behind the Kömürlük coastal springs (Kaputaşdere) nearby Kalkan town.

In long run, the groundwater may have an adverse effects on such coastal water supplying structures. Thus, it is recommended that the foundation of the coastal structure must be protected against the chemical effects of the groundwater and the sea water intrusion.

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APPENDIX - 1

RESULTS OF THE WATEQB - MODEL PROGRAM

EXAMPLE GİVEN FOR YEŞİLCE (LAPAZ-2) SPRING

SUMMARY OF ANALYTICAL EXPRESSIONS OF THE FORM
LOG K = A +B*T+C/T+D*T**2+E/T**2

I	NREACT	A	B	C	D	E
13	CALCITE	13.5430	-.0401	-3000.0000	.0000E+00	.0000E+00
14	KH3SIO4	6.3680	-.0163	-3405.9000	.0000E+00	.0000E+00
15	KH2SIO4	39.4780	-.0659	-12355.1000	.0000E+00	.0000E+00
25	KMGOH	.6840	.0051	.0000	.0000E+00	.0000E+00
26	KH3BO3	28.6059	.0121	1573.2100	.0000E+00	.0000E+00
27	KNH3	.6322	-.0012	-2835.7600	.0000E+00	.0000E+00
36	KH2CO3	-14.8435	.0328	3404.7100	.0000E+00	.0000E+00
69	KHCO3	-6.4980	.0238	2902.3900	.0000E+00	.0000E+00
73	KKSO4	3.1060	.0000	-673.6000	.0000E+00	.0000E+00
74	KMGCO3	.9910	.0067	.0000	.0000E+00	.0000E+00
75	KMGHCO3	2.3190	-.0111	.0000	2.2981E-05	.0000E+00
78	KCAHCO3	-2.9500	.0133	.0000	.0000E+00	.0000E+00
79	KCACO3	-27.3930	.0562	4114.0000	.0000E+00	.0000E+00
90	KHSO4	-5.3505	.0183	557.2461	.0000E+00	.0000E+00
92	KH2S	11.1700	-.0239	-3279.0000	.0000E+00	.0000E+00

INITIAL SOLUTION

TEMPERATURE = 13.00 DEGREES C PH = 7.76
ANALYTICAL EPMCAT = 2.142 ANALYTICAL EPMAN = 2.851

***** OXIDATION - REDUCTION *****

DISSOLVED OXYGEN = 8.800 MG/L
EH MEASURED WITH CALOMEL = 9.9000 VOLTS
MEASURED EH OF ZOBELL SOLUTION = 9.9000 VOLTS
CORRECTED EH = 9.9000 VOLTS
PE COMPUTED FROM CORRECTED EH = 100.000

*** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

TOTAL SPECIES		LOG MOLALITY	TOTAL MOLALITY	TOTAL MG/LITRE
CA	2	7.701426E-04	-3.1134	3.086160E+01
mg	2	2.850528E-04	-3.5451	6.928920E+00
NA	1	2.000370E-05	-4.6989	4.597960E-01
K	1	1.200222E-05	-4.9207	4.692240E-01
CL	-1	1.000185E-03	-2.9999	3.545300E+01
SO4	-2	7.501389E-05	-4.1249	7.204620E+00
HCO3	-1	1.700315E-03	-2.7695	1.037294E+02

*** CONVERGENCE ITERATIONS ***

ITERATION	SI-ANALCO3	S2-SO4TOT	S3-FTOT	S4-PTOT	S5-CLTOT
1	-3.091567E-11	7.193179E-13	.000000E+00	.000000E+00	1.517883E-18
2	-1.712701E-10	-2.312475E-13	.000000E+00	.000000E+00	-6.722053E-18
3	-1.887665E-10	-4.087379E-13	.000000E+00	.000000E+00	-3.252607E-18
4	-3.371098E-10	-2.591271E-13	.000000E+00	.000000E+00	-1.496199E-17
5	-2.779619E-10	-3.105714E-13	.000000E+00	.000000E+00	1.127570E-17

****DESCRIPTION OF SOLUTION ****

	ANALYTIC AL	COMPUTED	PH	ACTIVITY H2O = .9999
EPMCAT	2.142	2.114	7.76	PCO2 = 7.326605E-03
EPMAN	2.851	2.822		LOG PCO2 = -1.788
TEMPERATURE		13.00		PO2 = .000000E+00

EH= 9.9000 PE = 100.000 13.00 DEG C PCH4 = .000000E+00
PE CALC S = 1.000000E+02 CO2 TOT = 2.022490E-03
PE CALC DOX= 1.000000E+02 IONIC STRENGTH DENSITY = 1.0000
PE SATO DOX= 1.000000E+02 3.571410E-03 TDS = 585.1 MG/L

IN COMPUTING THE DISTRIBUTION OF SPECIES,
PE = 100.000 EQUIVALENT EH = 5.748 VOLTS

<u>DISTRIBUTION OF SPECIES</u>

I SPECIES		PPM	MOLALITY	LOG MOL	ACTIVITY	LOG ACT	ACT. COEFF.	OG A COF
1 CA	2	3.02959E+01	7.56027E-04	-3.1215	5.88171E-04	-3.2305	7.77976E-01	-.1090
2 mg	2	6.78208E+00	2.79012E-04	-3.5544	2.17611E-04	-3.6623	7.79936E-01	-.1079
3 NA	1	4.59280E-01	1.99812E-05	-4.6994	1.87494E-05	-4.7270	9.38350E-01	-.0276
4 K	1	4.69067E-01	1.19982E-05	-4.9209	1.12463E-05	-4.9490	9.37336E-01	-.0281
64 H	1	8.49108E-05	8.42525E-08	-7.0744	7.94328E-08	-7.1000	9.42795E-01	-.0256
5 CL	-1	3.54530E+01	1.00018E-03	-2.9999	9.37509E-04	-3.0280	9.37336E-01	-.0281
6 SO4	-2	6.47085E+00	6.73739E-05	-4.1715	5.23270E-05	-4.2813	7.76666E-01	-.1098
7 HCO3	-1	1.02800E+02	1.68508E-03	-2.7734	1.58274E-03	-2.8006	9.39265E-01	-.0272
18 CO3	-2	5.86091E-02	9.76846E-07	-6.0102	7.60289E-07	-6.1190	7.78310E-01	-.1088
86 H2CO3	0	2.00856E+01	3.23890E-04	-3.4896	3.24186E-04	-3.4892	1.00091E+00	.0004
27 OH	-1	1.13824E-03	6.69384E-08	-7.1743	6.27361E-08	-7.2025	9.37221E-01	-.0282
19 MGOH	1	8.81477E-05	2.13372E-09	-8.6709	2.00653E-09	-8.6976	9.40389E-01	-.0267
23 MGSO4	0	2.21578E-01	1.84110E-06	-5.7349	1.84261E-06	-5.7346	1.00082E+00	.0004
22 MGHCO3	1	3.46415E-01	4.06050E-06	-5.3914	3.80782E-06	-5.4193	9.37772E-01	-.0279
21 MGCO3	0	1.15840E-02	1.37404E-07	-6.8620	1.37517E-07	-6.8616	1.00082E+00	.0004
29 CAOH	1	5.28760E-05	9.26400E-10	-9.0332	8.70708E-10	-9.0601	9.39883E-01	-.0269
32 CASO4	0	7.88065E-01	5.78964E-06	-5.2373	5.79440E-06	-5.2370	1.00082E+00	.0004
30 CAHCO3	1	7.87637E-01	7.79232E-06	-5.1083	7.32388E-06	-5.1353	9.39883E-01	-.0269
31 CACO3	0	5.33294E-02	5.32918E-07	-6.2733	5.33356E-07	-6.2730	1.00082E+00	.0004
44 NASO4	1	6.15863E-04	5.17404E-09	-8.2862	4.85980E-09	-8.3134	9.39265E-01	-.0272
43 NAHCO3	0	1.40021E-03	1.66740E-08	-7.7780	1.66877E-08	-7.7776	1.00082E+00	.0004
42 NACO3	-1	1.46176E-05	1.76150E-10	-9.7541	1.65452E-10	-9.7813	9.39265E-01	-.0272
94 NACL	0	2.56600E-05	4.39143E-10	-9.3574	4.39504E-10	-9.3570	1.00082E+00	.0004
46 KSO4	-1	5.06084E-04	3.74493E-09	-8.4266	3.51748E-09	-8.4538	9.39265E-01	-.0272
95 KCL	0	2.04186E-05	2.73924E-10	-9.5624	2.74149E-10	-9.5620	1.00082E+00	.0004
63 HSO4	-1	3.26244E-05	3.36155E-10	-9.4735	3.15419E-10	-9.5011	9.38313E-01	-.0277
96 H2SO4	0	3.23488E-15	3.29890E-20	-19.4816	3.30161E-20	-19.4813	1.00082E+00	.0004
93 HCL	0	8.09736E-13	2.22124E-17	-16.6534	2.22307E-17	-16.6530	1.00082E+00	.0004

MOLE RATIOS FROM ANALYTICAL MOLALITY MOLE RATIOS FROM

COMPUTED MOLALITY	LOG ACTIVITY	RATIOS
CL/CA = 1.2987E+00	CL/CA = 1.3229E+00	LOG CA/H2 = 10.9695
CL/MG = 3.5088E+00	CL/MG = 3.5847E+00	LOG MG/H2 = 10.5377
CL/NA = 5.0000E+01	CL/NA = 5.0056E+01	LOG NA/H1 = 2.3730
CL/K = 8.3333E+01	CL/K = 8.3361E+01	LOG K/H1 = 2.1510
CL/A1 = 1.0002E+27	CL/AL = 1.0002E+27	LOG AL/H3 = 21.3000
CL/FE = 1.0002E+27	CL/FE = 1.0002E+27	LOG FE/H2 = 14.2000
CL/SO4 = 1.3333E+01	CL/SO4 = 1.4845E+01	LOG CA/MG = .4318
CL/HCO3 = 5.8824E-01	CL/HCO3 = 5.9355E-01	LOG NA/K = .2220
CA/MG = 2.7018E+00	CA/MG = 2.7097E+00	
NA/K = 1.6667E+00	NA/K = 1.6654E+00	

RESULTS TAKEN FOR SATURATİON AND EVOLUTION STUDIES :

Sample	pH	EH	LogPCO2	SiCa	SiMg
Yeşilköy	7.64	5.74	-2.14	-.92	-2.3
Sarıbelen	7.8	5.7	-2.06	-.32	-.93
Dereköy	7.48	5.72	-1.81	-.69	-2.16
Pınarbaşı	7.65	5.75	-1.79	-.9	-1.98
Ikizce	7.24	5.78	-1.96	-.48	-1.44
Ortaköy	7.38	5.8	-1.8	-.64	-2.17
Lapaz-2	7.76	5.65	-1.82	-.9	-2.46
Yeniköy	7.32	5.72	-1.79	-.53	-2.12
Bezirgan	7.28	5.68	-1.88	-1.06	-2.57
Gökçeören.1	7.15	5.74	-1.72	-.38	-.84
Gökçeören.2	7.18	5.73	-1.94	-.61	-1.63
Arapyrdu.sp.	7.54	5.78	-2.04	-.98	-1.75
Değirmenbaşı	7.82	5.71	-1.91	-.69	-1.04
Üzümlü	7.12	5.65	-1.89	-.19	-2.37
Sıtma	7.1	5.72	-1.96	-.9	-2.65
Çukurbağ	7.28	5.68	-1.8	-.87	-1.63
Köybaşı	7.12	5.78	-1.85	-.69	-1.85
Yarımdam	7.86	5.82	-2.11	-.67	-1.92
Islamlar	7.12	5.82	-1.61	-.22	.26
B.Çakıl	6.85	5.65	-	-	-
orulca	7.1	5.71	-	-	-
Güvercinlik	6.8	5.68	-	-	-
Likye.p.	6.92	5.7	-	-	-
Kömürlük	6.75	5.66	-	-	-