

**EYLUL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED
SCIENCES**

**HYDROGEOLOGY OF LOWER KÜÇÜK
MENDERES RIVER COASTAL WETLAND**

**by
Adile Melis SOMAY**

**December, 2006
İZMİR**

HYDROGEOLOGY OF LOWER KÜÇÜK MENDERES RIVER COASTAL WETLAND

**A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Degree of Doctor of
Philosophy in Geological Engineering, Applied Geology Program**

**by
Adile Melis SOMAY**

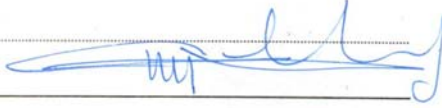
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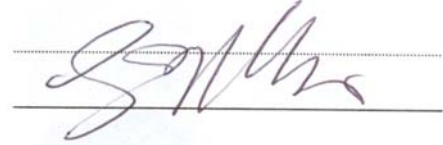
We have read the thesis entitled “HYDROGEOLOGY OF LOWER KUCUK MENDERES RIVER COASTAL WETLAND” completed by ADİLE MELİS SOMAY under supervision of ASSOC.PROF.DR. ÜNSAL GEMİCİ and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor of Philosophy.



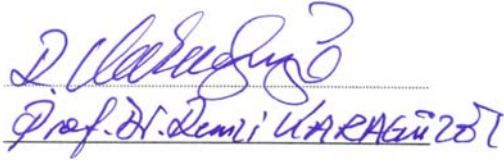
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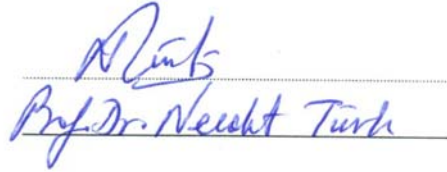
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Adile Melis SOMAY

HYDROGEOLOGY OF LOWER KÜÇÜK MENDERES RIVER COASTAL WETLAND

ABSTRACT

Küçük Menderes River wetland that is inside the Selçuk plain is identified with lakes, swamp and river. These lakes are recharged from precipitation and karstic springs that discharge from marble-schist and marble-alluvium contacts. Lakes are alkaline-slightly alkaline type. Water types are Na-Cl and Na-Ca-Mg-HCO₃-Cl in both seasons. According the perfect correlation between Na-Cl, Na-SO₄ and Cl-SO₄, it can be said that these ions are derived from seawater intrusion. Fe(OH)₃ and MnHPO₄ are oversaturated due to the high biological activities in the lakes. Major species of Se is selenite form due to its relation between Fe and organic matter in the wetland area. In order to compare the wetland waters, recharge areas were sampled. Using the chemical analyze of results, Ca-HCO₃ water type with a neutral-slightly alkaline pH values were determined and the main hydrogeochemical process is weathering of the different types of silicates. There are two different contamination risks for this wetland: (i) Selçuk waste disposal site and (ii) Selçuk treatment water plant where the purified waters release to the river. EC, Al, As, Cd, Cu, Fe and Zn values are very high according to aquatic life standards.

Salinization process was investigated with hydrogeochemical tools to find the origin of salinity in the Selçuk plain that is the wave-dominant delta of Küçük Menderes River. Na/Cl and Cl/Br molar ratios of coastal zone that covers an alluvial aquifer, karstic discharges and full part of a wetland are the similar with seawater ratio. In addition, correlation between Na-Cl and Cl-SO₄ are demonstrated perfect relationship that indicates a seawater intrusion in the plain. According to mixing ratios, seawater addition can be reached 9%-18% in rainy and dry season at the coastal zone especially in karstic springs that are a kind of seawater-freshwater

mixing discharge points and it was proved by ionic ratios. Relationship between Cl and Br, B, Li, Sr gives a perfect correlation that explains the salinization process comes from marine intrusion. Relation with Boron vs. EC values gives reasonable results what the wetland components are clustered as a different group due to their high rate of evaporation potential. But the groundwaters are located on the freshwater-seawater mixing line with a good correlation. Sr/Ca ratio that is over 1‰ characterizes water of evaporitic origin was observed in the coastal zone. From what has been discussed above, we may safely draw the conclusion that the salinization problem mainly arises from seawater intrusion in Selçuk Plain.

The $\delta^{18}\text{O}$ and δD composition of wetland area samples range between -5.40‰ and -2.93‰, and -35.1‰ and -19.55‰, respectively. The lakes and rivers are plotted on the mixing line by slopes of 5.8 and 5.5 because they belong to the open system in the hydrologic cycle and there is a salinization in the plain. To identify which process; evaporation or mixing with seawater, is dominant $\delta^{18}\text{O}$ -Cl relationship was used. River and Lake Kocagöz are plotted on the evaporation line. In addition, for the rainy season lake Akgöl and for the dry season Lake Gebekirse results are plotted between evaporation and mixing line that shows the effect the seawater on the lakes. In the light of the Tritium values, the groundwaters recharge with modern rainfalls with 5-6 TU values and show the short circulation time of groundwaters.

Keywords: Wetland, Hydrogeology, Hydrogeochemistry, Salinization, Environmental Isotopes.

AŞAĞI KÜÇÜK MENDERES NEHRİ KIYI SULAK ALANININ HİDROJEOLOJİSİ

ÖZ

Selçuk ovasında yeralan Küçük Menderes Nehri sulak alanı göller, bataklık ve nehir ile tanımlanmaktadır. Bu göllerin beslenmesi yağıştan ve mermer-şist dokanağından çıkan karstik kaynaklardandır. Göller alkalın-hafif alkalın tiptedirler. Su tipleri hem yağışlı hem de kurak dönemde Na-Cl ve Na-Ca-Mg-HCO₃-Cl dür. Göllerdeki yüksek biyolojik aktiviteden ötürü sular Fe(OH)₃ and MnHPO₄ çe doygunudur. Selenyumun Fe ve organik maddelerle olan ilişkisinden dolayı sulak alanda selenyum selenit formundadır. Sulak alandaki sularla karşılaştırmak için örneklenen dağlık kesim Ca-HCO₃ su tipinde olup nötral-hafif alkalın özellik sunmaktadır. Bu kesimde esas hidrojeokimyasal işlev farklı tipteki silikatların ayrışmasından oluşmaktadır. Sulak alan için iki farklı kirletici riski taşıyan alan mevcuttur: (i) Selçuk çöplüğü ve (ii) Selçuk arıtma tesisi. EC, Al, As, Cd, Cu, Fe ve Zn değerleri sucul hayat standartlarını aşmaktadır.

Dalga baskın bir delta olan Selçuk ovasındaki tuzlanma işlevi major ve minor iyonları kapsayan hidrojeokimyasal araçlar ile araştırılmıştır. Alüvyal akiferi, karstik kaynakları ve tüm sulak alanı kapsayan kıyı bölgesindeki Na/Cl ve Cl/Br oranları deniz suyu ile aynı değerleri vermektedir. Na ve Cl, Na ve SO₄, Cl ve SO₄ arasındaki mükemmel korelasyon, bu suların deniz suyu girişiminden kaynaklandığını göstermektedir. Karışım oranlarına göre, kıyı bölgesinde özellikle deniz suyu-tatlı karışım bölgeleri olan karstik kaynaklarda deniz suyu katkısı %9-%18 lere ulaşmaktadır. Tuzlanma işlevinin denizel etkiden kaynaklandığını gösteren Cl ile Br, B, Li ve Sr minor iyonlarının ilişkisi doğrusaldır. Bor ile EC arasında mantıklı bir ilişki saptanmış olup buharlaşmaya maruz kalan sulak alan bir grup, diğer kesim ise doğrusal ilişkiye sahip diğer bir grup oluşturmuştur. Bu verilere dayanılarak Selçuk Ovası'ndaki ana tuzluluk kaynağının deniz suyu girişimi olduğu söylenilebilir.

Sulak alan örneklerine ait $\delta^{18}\text{O}$ and δD bileşimleri sırası ile -5.40‰ ve -2.93‰, -35.1‰ ve -19.55‰ arasında değişim göstermektedir. Açık hidrolojik sistem ögeleri olan göller ve nehir örnekleri 5.5 ve 5.8 eğimleri ile karışım doğrusu üzerinde yer almaktadırlar. Burada deniz suyu girişi ve buharlaşma işlevlerinin hangisinin etkili olduğunu anlamak için $\delta^{18}\text{O}$ ve Cl diyagramı oluşturulmuş, kurak dönemde nehrin ve Kocagöz Gölü'nün buharlaşma eğrisi üzerinde çıktığı; yağışlı dönemde Akgöl'ün kurak dönemde Gebekirse Gölü'nün buharlaşma ve karışım doğruları arasında kaldığı gözlenmiştir. 5-6 TU değerler veren Trityum radyoizotopu ışığında yeraltı suyunun güncel yağışlarla beslendiği ve yeraltında kısa süreli dolaşım yaptığı söylenebilmektedir.

Anahtar Kelimeler: Sulak alan, Hidrojeoloji, Hidrojeokimya, Tuzlanma, Çevresel İzotoplar.

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CHAPTER ONE

GENERAL OVERVIEW OF WETLANDS

Wetlands are the most important parts of the hydrological cycle due to its importance and functions all around the world. Definition, functions and importance of wetlands; wetlands of Turkey and occurrence of Lower Küçük Menderes coastal wetland are explained in this chapter.

1.1 Definition of Wetlands

Wetlands are difficult to identify as a single definition, largely because their essential elements are so diverse and variable in character that has a lot of definitions for Europe, America, Africa and Australia. A convention was organized on 2 February 1971 in Ramsar city, Iran to use the natural sources sustainable that was named as “The Convention on Wetlands of International Importance especially as Waterfowl Habitats”. Nowadays this convention is told as “Ramsar Convention”.

Wetlands are the areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters according to Ramsar Convention (2004).

Among the most widely accepted definitions is that of Cowardin et al. (1979), which was adopted by the U.S. Fish and Wildlife Service in America:

Land where an excess of water is the dominant factor determining the nature of soil development and the types of animals and plant communities living at the soil surface. It spans a continuum of environments where terrestrial and aquatic systems intergraded. Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by

shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of the year.

The U.S. Army Corps of Engineers (Corps) (1977) and the U.S. Environmental Protection Agency (EPA) (2006) define wetlands as follows:

Those areas that are inundated or saturated by surface or ground water (hydrology) at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation (hydrophytes) typically adapted for life in saturated soil conditions (hydric soils). Wetlands generally include swamps, marshes, bogs, and similar areas (40 CFR 232.2(r)).

The last definition that was published by National Research Council (1992) is as follows:

An ecosystem that depends on constant or an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or recurrent, shallow inundation or saturation at or near the surface of the substrate. The minimum near the surface of the substrate. The minimum essential characteristics are recurrent, sustained essential characteristics are recurrent, sustained inundation or saturation at or near the surface and inundation or saturation at or near the surface and the presence of physical, chemical, and biological the presence of physical, chemical, and biological features reflective of recurrent, sustained features reflective of recurrent, sustained inundation or saturation. Common diagnostic inundation or saturation. Common diagnostic features are features are hydric hydric soils and soils and hydrophytic hydrophytic vegetation.

From the view of all above the definitions, there are three main components of wetlands: (1) existence of water, (2) soil type, (3) biological activity. In this thesis, the component of water and its hydrogeological and hydrogeochemical properties are investigated and discussed.

1.2 Wetland Types

Since 70s' several wetland types have been identified by several scientists and associations. But nowadays mostly two of them are used to classification the wetlands: (1) Ramsar Classification in Europe, Africa and Australia, (2) Cowardin Classification (1979) in America.

Marine/Coastal and Inland wetland type were recognized by Ramsar Convention (Table 1.1). Hydrologic regime, size and geomorphology of wetlands are based upon according to this classification.

On the other hand; Marine, Estuarine, Riverine, Lacustrine and Palustrine are the main systems in Cowardin classification (Table 1.2). Geomorphic origin, broad hydrology and substrate type are the major criteria for this classification.

In addition to these classifications, Novitzki (1979) identified the hydrologic characteristics of Wisconsin's wetlands related to landform and water source. According to Novitzki (1979), there are four wetland types (Figure 1.1):

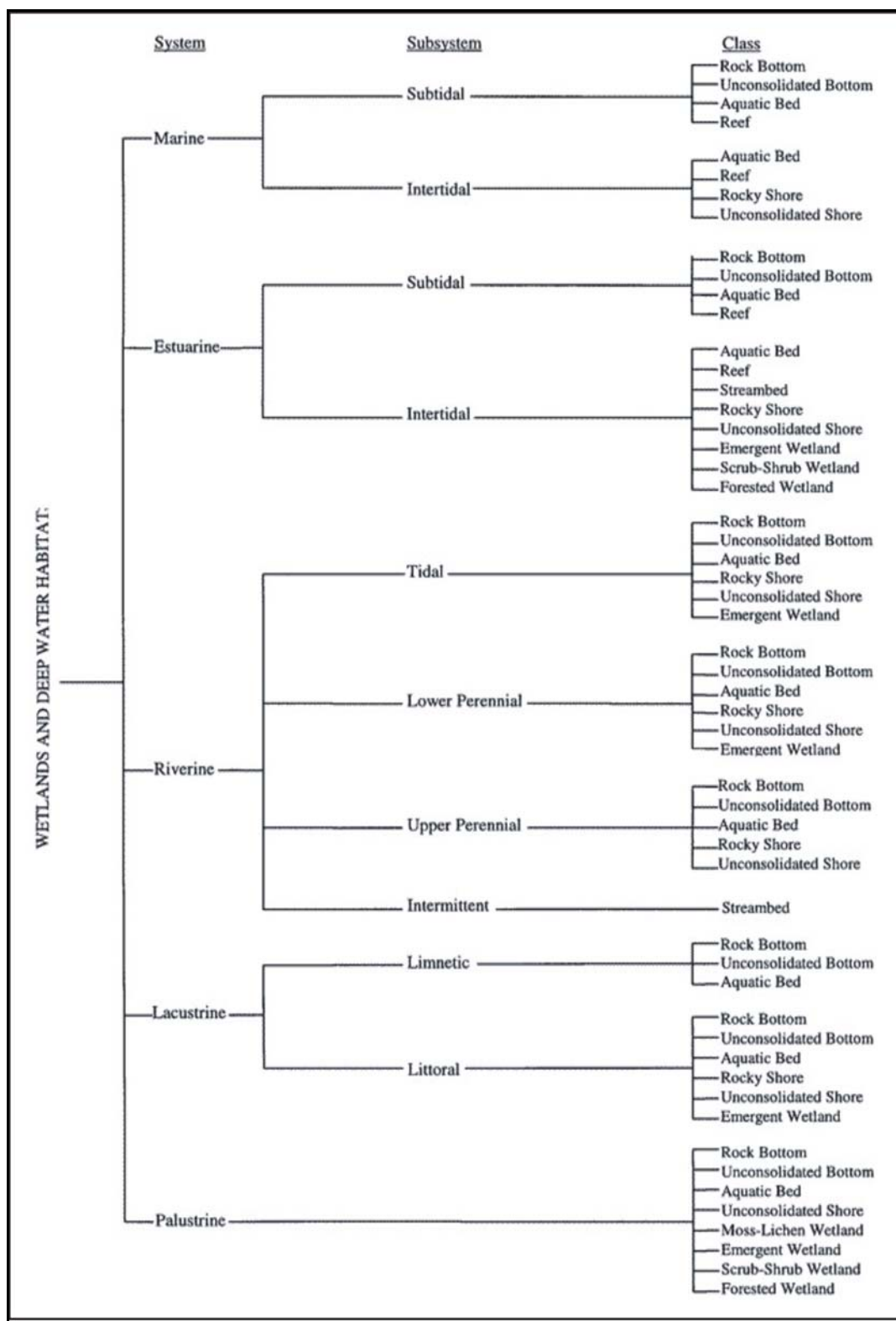
- (1) Surface water depression (Figure 1.1-a); receive precipitation and overland flow,
- (2) Groundwater depression (Figure 1.1-b); receive groundwater, precipitation and overland flow,
- (3) Surface water slope (Figure 1.1-c); receive water from lake or river flooding,
- (4) Groundwater slope (Figure 1.1-d); differ from groundwater depression type by having an outlet.

Table 1.1. Wetland types for Ramsar Convention classification (Ramsar, 2004).

Marine / Coastal Wetlands:				
Saline water	Permanent	< 6 m deep	A	
		Underwater vegetation	B	
		Coral reefs	C	
	Shores	Rocky	D	
		Sand, shingle or pebble	E	
Saline or brackish water	Intertidal	Flats (mud, sand or salt)	G	
		Marshes	H	
		Forested	I	
	Lagoons		J	
	Estuarine waters		F	
Saline, brackish or fresh water	Subterranean		Zk(a)	
Fresh water	Lagoons		K	

Inland Wetlands:				
Fresh water	Flowing water	Permanent	Rivers, streams, creeks	M
			Deltas	L
			Springs, oases	Y
	Lakes and pools	Seasonal/intermittent	Rivers, streams, creeks	N
		Permanent	> 8 ha	O
			< 8 ha	Tp
		Seasonal/intermittent	> 8 ha	P
			< 8 ha	Ts
	Marshes on inorganic soils	Permanent	Herb-dominated	Tp
		Permanent/Seasonal/intermittent	Shrub-dominated	W
			Tree-dominated	Xf
		Seasonal/intermittent	Herb-dominated	Ts
	Marshes on peat soils	Permanent	Non-forested	U
	Forested		Xp	
	Marshes on inorganic or peat soils	High altitude (alpine)		Va
		Tundra		Vt
	Saline, brackish or alkaline water	Lakes	Permanent	Q
Seasonal/intermittent			R	
Marshes & pools		Permanent	Sp	
		Seasonal/intermittent	Ss	
Fresh, saline, brackish or alkaline water	Geothermal		Zg	
	Subterranean		Zk(b)	

Table 1.2. Wetland types of Cowardin classification (Cowardin et al, 1979).



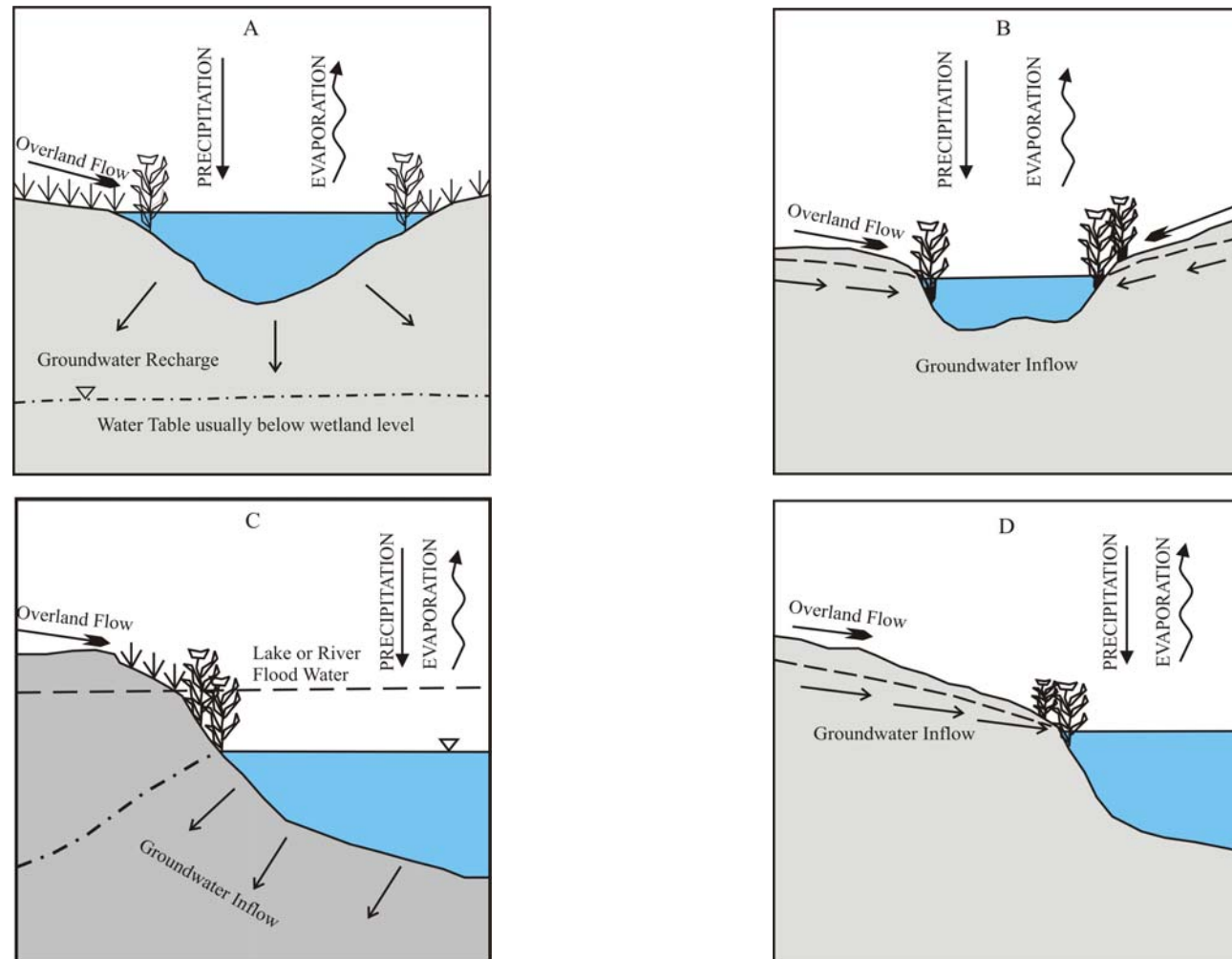


Figure 1.1. Hydrologic classification of Novitzki for wetlands (Novitzki, 1979).

1.3 Functions and Values of Wetlands

Wetlands are amongst the most productive ecosystems in the world, often referred to as “biological supermarkets” because of the extensive food webs and rich biodiversity they support (Mitsch and Gosselink, 1993).

It had been considered that the wetlands were “waste land” in 1970’s due to malaria diseases and unused landscapes. So they dried and filled unconsciously all around the world. But dried processes are given up for 50 years, because wetlands values and functions are understood.

While wetland functions are natural processes of wetlands that continue regardless of their perceived value to humans, the value people place on those functions in many cases is the primary factor determining whether a wetland remains intact or is converted for some other use (National Audubon Society, 1993).

In general there are too many functions of wetlands because of their location on the landscape, the wide variety of functions they perform and uniqueness of their plant and animal communities. Several associations were published these values and functions. In this thesis, Environmental Protection Agency of US (EPA), Ramsar Convention, National Science Foundation (NSF) and Mitsch and Williams, Novitzki et al publications are given.

1.3.1 Wetland Values for Environmental Protection Agency of US (EPA, 2006)

Wetlands values are classified 9 main groups are given as follows:

(1) Fish, wildlife and plant habitats

- (1.1) source of substantial biodiversity
- (1.2) produce great quantities of food
- (1.3) development of organisms that form the base of the food web

- (1.4) birds and mammals rely on wetlands for food, water, and shelter, especially while migrating and breeding
- (1.5) breeding and egg deposition areas (fish, amphibians and reptiles)
- (1.6) estuaries and their coastal marshes serve as important fish nursery areas
- (1.7) some wetlands release cooler water to salmon-bearing streams and rivers
- (1.8) 43% of the federally threatened and endangered species rely directly or indirectly on wetlands for their survival
- (2) Natural water quality improvement and biogeochemical cycling**
 - (2.1) wetlands provide the conditions needed for the removal of both nitrogen and phosphorus from surface water
 - (2.2) improve water/drinking water quality by
 - intercepting surface runoff
 - removing or retaining inorganic nutrients
 - processing organic wastes
 - reducing suspended sediments
 - (2.3) wetlands also reduce environmental problems such as algal blooms, dead zones, and fish kills, that are generally associated with excess nutrients.
- (3) Atmospheric maintenance**
 - (3.1) wetlands world-wide help moderate global climatic conditions
 - (3.2) store carbon within their live and preserved (peat) plant biomass instead of releasing it to the atmosphere as a greenhouse gas
- (4) Hydrologic cycle roles**
 - (4.1) receive, store, and release water in numerous ways
 - (4.2) some wetlands maintain stream flow during dry periods
 - (4.3) some wetlands replenish groundwater
- (5) Flood storage**
 - (5.1) store and slowly release surface water, rain, snowmelt, groundwater and flood waters
 - (5.2) wetland vegetation also impedes the movement of flood waters and distributes them more slowly over floodplains

(5.3) counteract the greatly increased rate and volume of surface-water runoff from pavement and buildings

(6) Shoreline erosion protection

(6.1) protect shorelines and stream banks against erosion

(6.2) hold the soil in place with their roots

(6.3) absorb the energy of waves

(6.4) break up the flow of stream or river currents

(7) Opportunities for recreation, education, research and aesthetic appreciation

(7.1) used to hunt, fish, birdwatch or photograph wildlife

(7.2) nature-based tourism involves birds, many of which are wetland-dependent

(7.3) used for hiking, boating, and other recreational activities

(7.4) studied in conjunction with environmental programs

(7.5) excellent research and teaching sites to learn about vegetation, ecological functions and processes, biodiversity, and plant-animal interactions

(7.6) artists and writers capture the beauty of wetlands on canvas and paper, or through cameras, and video and sound recorders

(8) Economic benefits of natural services and products at little or no cost

(8.1) wetlands filtering function saves us a great deal of money

(8.2) wetlands supporting timber totals about 55 million acres

(8.3) blueberries, cranberries, mints, and wild rice, are produced in wetlands

(8.4) medicines from wetland soils and plants

(8.5) fishing and shellfishing industries harvest wetland-dependent species

(8.6) habitats for commercial fur-bearers like muskrat, beaver, otter, and mink, as well as reptiles such as alligators

(8.7) 3 million migratory bird hunters generated \$1.3 billion in retail sales

(9) Reduce flood damage and protect our health and safety

(9.1) reduce the likelihood of flood damage to homes, businesses, and crops in agricultural areas

(9.2) lower flood heights and reduce erosion downstream and on adjacent lands

(9.3) reduce or prevent water logging of agricultural lands

(9.4) less monetary flood damage (and related insurance costs), as well as greater protection of human health, safety, and welfare.

1.3.2 Wetland Values for Ramsar Convention (Ramsar, 2004)

According to Ramsar Convention, wetlands values and functions are summarized as follows;

- (1) Groundwater replenishment: The relationship between groundwater and wetlands is rather complicated. Some wetlands, such as peatlands, lie on top of an impermeable layer of rock or soil, preventing the passage of water between the aquifer and the wetland. Other wetlands owe their existence to groundwater that has come to the surface as springs, while still others occur on permeable soils overlying aquifers, allowing water to recharge the aquifer directly.
- (2) Sediment and nutrient retention and export: Wetlands slow the passage of water and encourage the deposition of nutrients and sediments carried in water. Nutrient retention in wetlands makes them among the most productive recorded, rivalling even intensive agricultural systems. Coastal deltas are dependent on riverine sediments and nutrients for their survival; engineered structures that interfere with the natural movement of sediments and nutrients can degrade deltas.
- (3) Water purification: Plants and soils in wetlands play a significant role in purifying water, removing high levels of nitrogen and phosphorous and, in some cases, removing toxic chemicals. High levels of nutrients such as phosphorous and nitrogen, commonly associated with agricultural run-off, are effectively removed by wetlands. This is important in preventing eutrophication further downstream, a process that leads to rapid plant and algal growth followed by depleted oxygen levels that affect other species. It can also be important in preventing high concentrations of these nutrients reaching groundwater supplies or other water sources that may be used for drinking water.

- (4) Flood control: Wetlands “hold” heavy rainfalls, preventing possible flooding downstream. By storing the water in the soil or retaining it in the surface waters of lakes, marshes, etc., wetlands reduce the need for expensive engineered structures. Wetland vegetation also plays a role in slowing down the flow of flood water.
- (5) Shoreline stabilization and storm protection: Salt marshes, mangroves and other forested wetlands act as the frontline defense against incoming storms. They help minimize the impact of storms by reducing wind action, wave action and currents, while the roots of the plants help to hold the sediment in place. Coral reefs also deliver storm protection.
- (6) Climate change and mitigation: Wetlands play at least two critical but contrasting roles in mitigating the effects of climate change: one in the management of greenhouse gases (especially carbon dioxide) and the other in physically buffering climate change impacts.
- (7) Recreation, Tourism: The natural beauty as well as the diversity of animal and plant life in many wetlands makes them ideal locations for tourists. Many of the finest sites are protected as National Parks or World Heritage Sites and are able to generate considerable income from tourist and recreational uses. In some countries the revenue is a significant component of the national economy.
- (8) Wetland products: Wetlands provide a variety of other benefits to humans in the form of products that can be exploited for human use. The range is enormous: fruit, fish, shellfish, deer, crocodile and other meats, resins, timber for building, fuelwood, reeds for thatching and weaving, fodder for animals, etc.
- (9) Reservoir of biodiversity: Wetlands support spectacular concentrations of wetland-depend wildlife.
- (10) Cultural Value: This is a relatively poorly documented function of wetlands, yet there are many instances where wetlands have significant religious, historical, archaeological or other cultural values for local communities, representing a part of a nation’s heritage.

1.3.3 Wetland Values for National Science Foundation (1995) and Mitch and Gosellink (1993)

The other evaluation was done by National Science Foundation (NSF) 1995 and Mitch and Gosellink 1993; is given as Table 1.3:

Table 1.3. Wetland functions and values according to NSF 1995 and Mitch and Gosellink 1993.

FUNCTION	EFFECT	SOCIETAL VALUE
Hydrologic		
Short-term surface water storage	Reduced downstream flood peaks	Reduced property and crop damage from floodwaters
Long-term surface water storage	Maintenance of stream flows, seasonal stream flow moderation	Maintenance of fish habitat during dry periods
Maintenance of high water tables	Maintenance of hydrophytic plants, ground water for tree and crop growth	Maintenance of biodiversity, increased timber and crop production
Biogeochemical		
Transformation and cycling of elements	Maintenance of nutrient stocks within wetland, production of dissolved and partially decayed organic matter	Timber production, food for fish and shellfish downstream, support of recreational and commercial fishing
Retention, removal of dissolved substances	Reduced transport of nutrients and pesticides downstream	Maintenance of water quality. Safer drinking water
Accumulation of peat	Retention of nutrients, carbon, metals, other substances	Maintenance of water quality, reduction of global warming
Accumulation/retention of inorganic sediment	Retention of sediment and attached pesticides, phosphate and other nutrients	Maintenance of water quality, clear water, high quality fish populations in streams
Habitat and Food Web Support		
Maintenance of characteristic plant communities	Food and escape and nesting cover for wildlife; spawning and nursery habitat for fish and shellfish; food for humans	Support for waterfowl and other wild game, furbearers, uncommon and rare and endangered species, fish, and shellfish. Recreational and commercial hunting, fishing and bird watching.
Maintenance of characteristic energy flow	Support for populations of vertebrates and invertebrates	Maintenance of biodiversity, bird watching, aesthetics

1.3.4 Wetland Values for Hydrologic and Water Quality Features

Hydrology and water chemistry are the major themes for this thesis scope. Several scientists and associations have been investigated this subject.

Novitzki et al 1996 concluded that functions that provide internal values are the functions that maintain or sustain the wetland and are essential to the continued existence of the wetland and conversely, many functions have external values that extend beyond the wetland itself (Figure 1.2). From the point view of Figure 1.2 “Water Quality” is the internal value for wetlands. According to Novitzki et al 1996, water-quality functions include the trapping of sediment, pollution control, and the biochemical processes that take place as water enters, is stored in, or leaves a wetland (Figure 1.3).

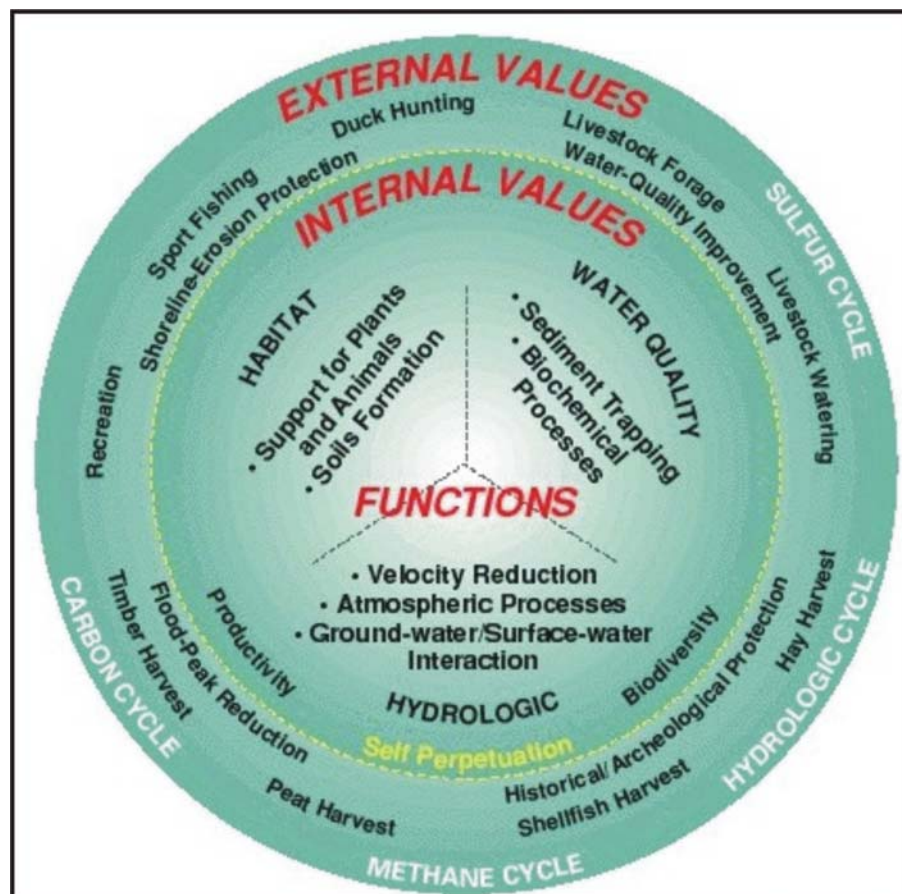


Figure 1.2. Wetland functions and internal and external values (Novitzki et al, 1996).

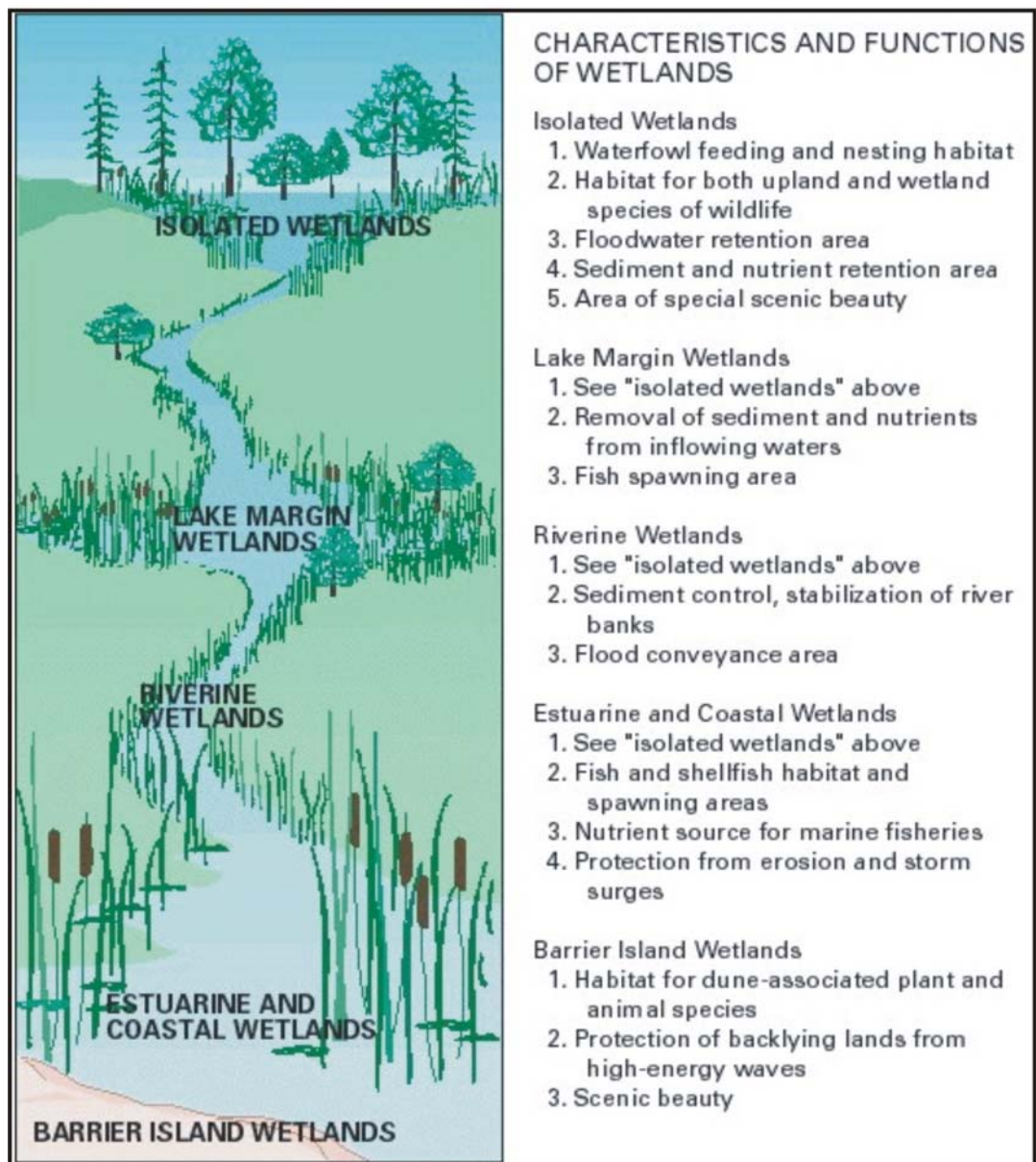


Figure 1.3. Wetland functions depend upon the location of the wetland within a watershed (Notvitzki et al, 1996).

EPA concluded for “Water Quality” that wetlands are valuable to us because they greatly influence the flow and quality of water. They help improve water quality, including that of drinking water, by intercepting surface runoff and removing or retaining inorganic nutrients, processing organic wastes, and reducing suspended sediments before they reach open water. In addition to improving water quality through filtering, some wetlands maintain stream flow during dry periods; others replenish groundwater.

Virginia Carter was published a paper that named as “Technical Aspects of Wetlands: Wetland Hydrology, Water Quality and Associated Functions” in 1996. According to the Carter 1996:

The formation, persistence, size, and function of wetlands are controlled by hydrologic processes. Distribution and differences in wetland type, vegetative composition, and soil type are caused primarily by geology, topography, and climate. Differences also are the product of the movement of water through or within the wetland, water quality, and the degree of natural or human-induced disturbance. In turn, the wetland soils and vegetation alter water velocities, flow paths, and chemistry. The hydrologic and water-quality functions of wetlands, that is, the roles wetlands play in changing the quantity or quality of water moving through them, are related to the wetland's physical setting. The source and movement of water are very important for assessing wetland function and predicting how changes in wetlands will affect the associated basin. Linkages between wetlands, uplands, and deepwater habitats provide a framework for protection and management of wetland resources. Water moving into wetlands has chemical and physical characteristics that reflect its source. Older ground water generally contains chemicals associated with the rocks through which it has moved; younger ground water has fewer minerals because it has had less time in contact with the rocks. Which processes can and will occur within the wetland are determined by the characteristics of the water entering and the characteristics of the wetland itself--its size, shape, soils, plants, and position in the basin. Wetlands are commonly found in topographic depressions, at slope breaks, in areas of stratigraphic change, and in permafrost areas.

The water chemistry of wetlands is primarily a result of geologic setting, water balance (relative proportions of inflow, outflow, and storage), and quality of inflowing water, type of soils and vegetation, and human activity within or near the wetland. The hydrologic and water-quality functions of wetlands are controlled by the following:

- Landscape position (elevation in the drainage basin relative to other wetlands, lakes, and streams)
- Topographic location (depressions, flood plains, slopes)
- Presence or absence of vegetation
- Type of vegetation
- Type of soil
- Local climate
- The hydrogeologic framework
- The geochemistry of surface and ground water.

1.4 Wetlands of Turkey

Turkey is a rich country due to its natural values such as wetlands. According to Environmental and Forrest Ministry of Republic of Turkey inventory, there are more than 70 wetlands (Figure 1.4) (Table 1.4).

Earlier 1990's, wetlands in Turkey had been dried up by authorities due to disaster of malaise like another part of the world. Wetlands have been lost about 236538 ha by interferences to water regime, contamination and excessive/wrong hunting according to Erdem, 2004. But, several investigations have been done since 1990's to expose their wildlife structure by biological surveys. Not only biological values but also hydrologic, hydrogeologic and hydrogeochemical values come into important in Turkey.

Table 1.4. Wetlands of Turkey (Erdem, 2004).

WETLAND NAME	LOCATION AND AREA (HECTARES)	STATUES OF PROTECTION**
1 Meriç Delta	Edirne; 7000	NPA (2369 ha), N/HS
2 İğneada	Kırklareli 5399	WPA, NPA; N/HS
3 Kocaçay Delta	Bursa 4200	WPA
4 Gediz Delta	İzmir 14900	WPA, N/HS, RS
5 Küçük Menderes Delta	İzmir 1500	WPA, N/HS
6 Büyük Menderes Delta	Aydın 9800	NP, N/HS
7 Güllük Delta	Muğla 1400	-
8 Kızılırmak Delta	Samsun 21700	WPA, N/HS, RS
9 Yeşilirmak Delta	Samsun 3000	WPA
10 Göksu Delta	İçel 15000	WPA, N/HS, SEPA, RS
11 Tuzla Lake	Adana 2800	WPA
12 Akyatan Lagoon	Adana 14700	WPA, RS
13 Ağyatan Lagoon	Adana 2200	-
14 Yumurtalık Lagoon	Adana 16430	NPA;N/HS
15 Büyük Çekmece Lake	İstanbul 2850	-
16 Küçük Çekmece Lake	İstanbul 1500	-
17 İznik Lake	Bursa 29880	N/HS
18 Uluabat Lake	Bursa 19900	RS
19 Kuş (Manyas) Lake	Balıkesir 20400	WPA,N/HS,NP,RS
20 Marmara Lake	Manisa 6800	-
21 Bafa Lake	Aydın, Muğla 12281	N/HS, NPA
22 Köyceğiz Lake	Muğla 8000	WPA, SEPA
23 Sapanca Lake	Adapazarı, Kocaeli 4700	N/HS
24 Sarıkum Lake	Sinop 785	NPA, N/HS
25 Gavur Lake	Kahramanmaraş 1500	-

Table 1.4. Contine. Wetlands of Turkey (Erdem, 2004).

WETLAND NAME	LOCATION AND AREA (HECTARES)	STATUES OF PROTECTION**
26 Işıklı Lake	Denizli 7300	-
27 Acı Lake	Afyon, Denizli 836	WPA
28 Yarıklı Lake	Burdur 915	-
29 Burdur Lake	Burdur, Isparta 24800	WPA, RS
30 Karataş Lake	Burdur 1190	WPA
31 Eğirdir Lake	Isparta, 47250	N/HS
32 Eber Lake	Afyon 16800	N/HS
33 Akşehir Lake	Afyon, Konya 35300	N/HS
34 Balıklıdamı	Eskişehir 1470	N/HS, WPA
35 Mogan Lake	Ankara 973	SEPA
36 Samsam Lake	Konya 830	N/HS
37 Kozanlı Lake	Konya 630	N/HS
38 Kulu Lake	Konya 860	N/HS
39 Ereğli Swamps	Konya, Karaman 5600	N/HS, NPA
40 Bolluk Lake	Konya 1150	N/HS
41 Tersakan Lake	Konya 6400	N/HS
42 Tuz Lake	Ankara,Konya,Aksaray 260000	N/HS, SEPA
43 Çorak Lake	Burdur 1150	-
44 Salda Lake	Burdur 4370	N/HS,
45 Karamık Swamp	Afyon 4500	N/HS
46 Çavuşcu Lake	Konya 1200	N/HS
47 Uyuz Lake	Konya 15	N/HS
48 Çöl Lake	Konya 1045	-
49 Tödürge Lake	Sivas 750	-
50 Hazar Lake	Elazığ 7000	-
51 Palas Lake	Kayseri 2720	N/HS
52 Sultan Swamp	Kayseri 17200	WPA, N/HS, NPA, RS

Table 1.4. Contine. Wetlands of Turkey (Erdem, 2004).

WETLAND NAME	LOCATION AND AREA (HECTARES)	STATUES OF PROTECTION**
53 Seyfe Lake	Kırşehir 10700	N/HS, NPA, RS
54 Beyşehir Lake	Konya, Isparta 73000	NP,N/HS
55 Erzurum Plain	Erzurum 3300	-
56 Sarısu Plain	Ağrı 4800	-
57 Haçlı Lake	Muş 2500	-
58 Bulanık Plain	Muş 8000	-
59 Aktaş Lake	Ardahan 2700	-
60 Çıldır Lake	Ardahan 14000	-
61 Kuyucak Lake	Kars 219	WPA
62 Çalı Lake	Kars 25	-
63 Doğu Beyazıt Swamp	Ağrı 8750	-
64 Sodalı Lake	Bitlis 1500	-
65 Erçek Lake	Van 9520	-
66 Van Lake	Van, Bitlis 390000	-
67 Yüksekova Swamp	Hakkari 24900	-
68 Balık Lake	Ağrı 3400	-
69 Nemrut Lake	Bitlis 4500	-
70 Demir Köprü Dam	Manisa 5060	-
71 Sarıyar Dam	Ankara 8400	WPA
72 Hirfanlı Dam	Ankara, Kırşehir 26300	-
73 Yedikır Dam	Amasya 593	WPA, N/HS
74 Keban Dam	Elazığ 12500	-
75 Fırtına Stream	*** Rize	NP
76 Kara Stream	*** Rize	-

* Evaluation is made according to Ramsar Convention Criterias.

** RS: Ramsar Site, N/HS: Natural/Historic Sites, NP: National Park, NPA: Nature Protection Area, WPA: Wildlife Protection Area, SEPA: Special Environment Protection Area

*** Riverine type wetland that have international values.

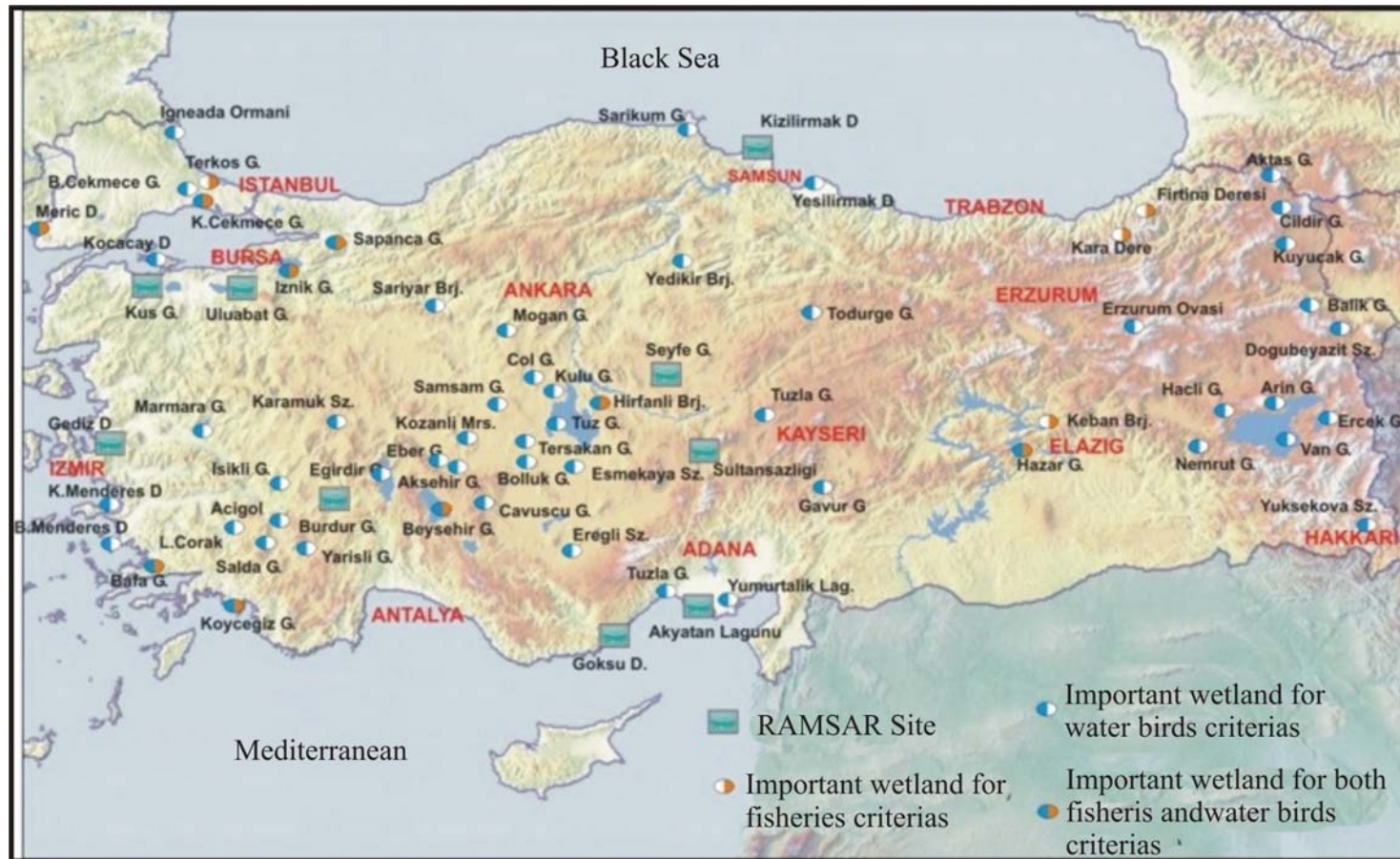


Figure 1.4. Wetlands of Turkey (Environmental and Forrestr Ministry of Republic of Turkey, 2006)

“Turkey is an important area for wetlands, because (i) it is located transition zone between Africa, Asia and Europe (ii) these three continents are having a different character seawater (iii) climate varieties of Turkey due to the differences of elevations” (Erdem, 2004). Erdem 1995 summarized the wetland types of Turkey as given in Figure 1.5 that consist lagoons, lakes, crater lakes, flood plain, marshes and swamps, peatlands, calm parts of the stream and salt pans.

Turkey was participated to RAMSAR Convention in 1994 with Lake Manyas, Lake Burdur, Sultan Sazligi, Lake Seyfe and Goksu Delta. Four years later, Kizilirmak delta, Gediz Delta (İzmir Bird Paradise), Lake Uluabat and Akyatan Lagoon were added to Ramsar sites. In the recent years (2005-2006), Meke Maar, Yumurtalik Lagoons and Kiziloren Obrouk are included the Ramsar sites. All of these wetlands cover 179,482 hectares area.

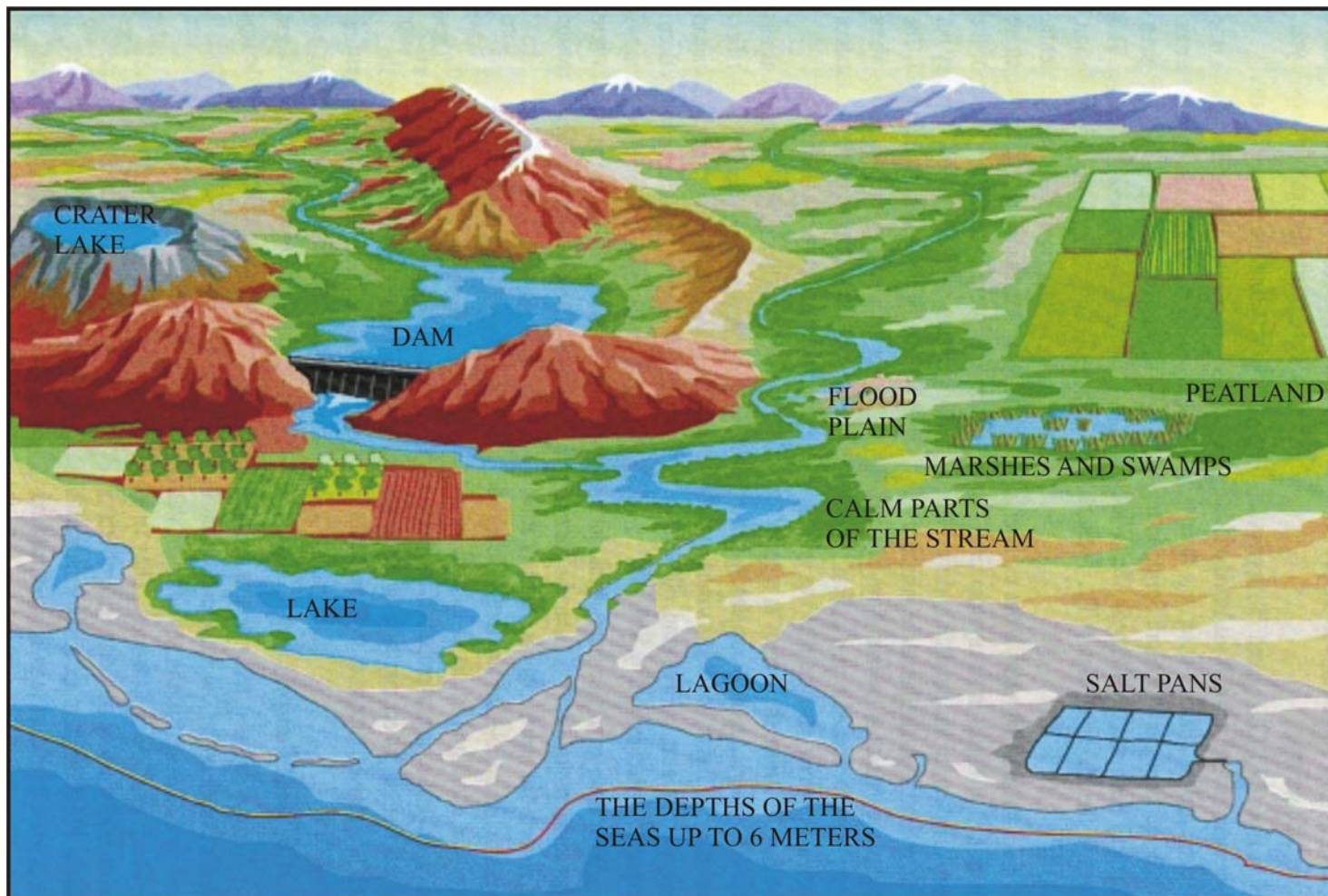


Figure 1.5. Wetland types of Turkey (Erdem, 1995).

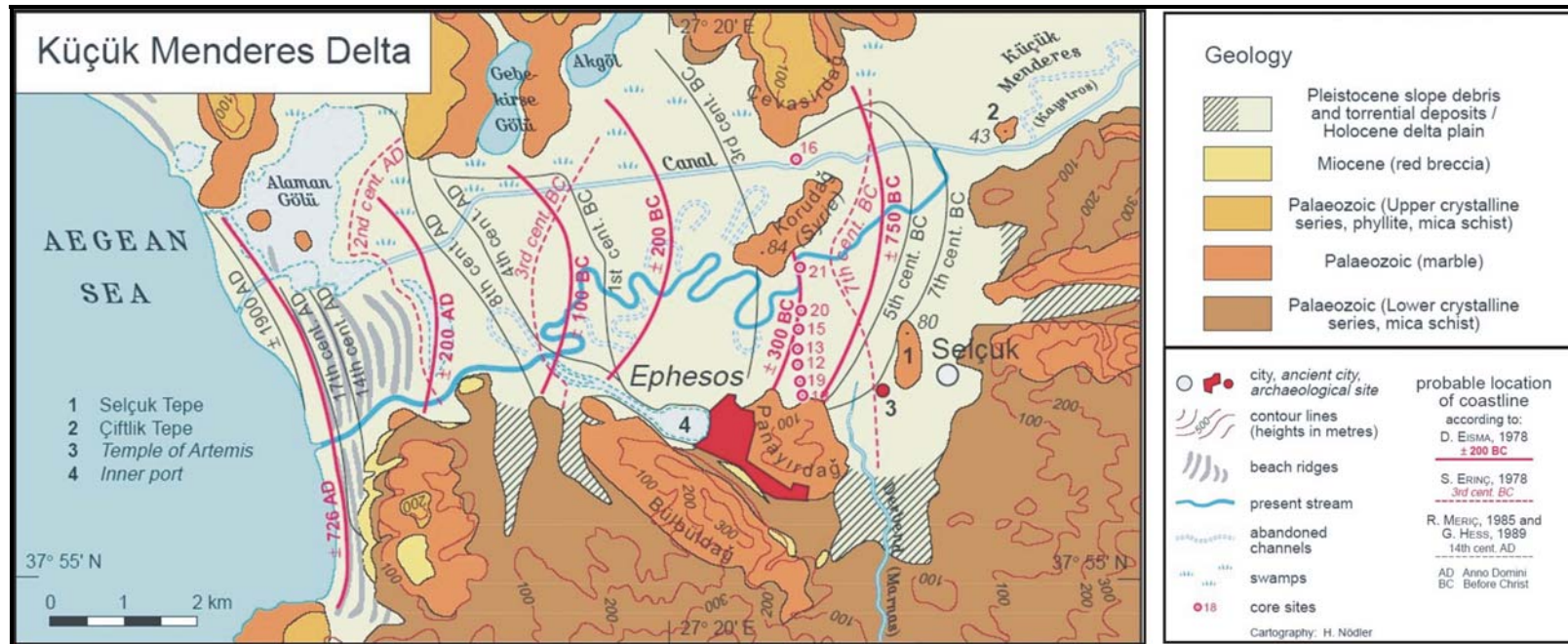
1.4.1 Lower Küçük Menderes River Coastal Wetland

Lower Küçük Menderes River coastal wetland was investigated by some geologists as Erinç, 1955 and Gökçen et al, 1990 and geographer as Kayan, 1999.

“As for the coastal evidence of Quaternary palaeogeography, there are various reasons for vertical and horizontal shoreline changes. Of these reasons, climatic-eustatic sea-level fluctuations are the most important” (Kayan, 1999).

Size and characteristics of sediment differ from Belevi to Aegean Sea. Also in Selçuk plain because of the climatic changes there are both terrestrial and marine deposits (Oner, 1997). According to Kayan and Kraft, 1997; the terrestrial deposits are dominant back part of Belevi; in contrast, in Selçuk Plain when the dynamic of marine and sea-level fluctuations are dominant processes to form the coastal shoreline. Schematic Figure of the sea-level fluctuations and the growing up the delta is given in Figure 1.6 summarized by Brückner 1998.

According to archeological drilling findings that was done in the Ephesus Ancient city by Kayan 1999 (Figure 1.7); the marine sediments which were deposited in the lower parts of the major rivers are generally fine grained and very homogenous. They contain many organic colloids, and therefore they are generally dark colored. These characteristics represent low-oxygen environments and relate to quiet, stable conditions. ^{14}C dating of marine mollusks proves that the rising sea reached its present level in this region about 6000 year ago. However, the rate of sea-level rise became slower in the final stage from 7000 to 6000 BP. When sea-level rise slowed and stopped about 6000 BP, alluvial aggradations and deltaic progradation began to dominate coastal processes.



1.6. Schematic figure of growing up the Küçük Menderes River delta (Brückner, 1998).

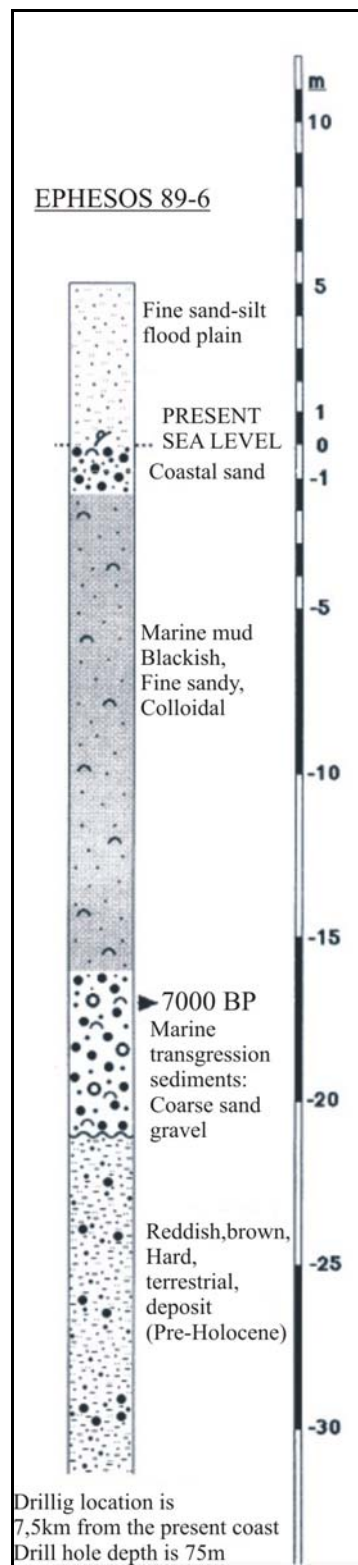


Figure 1.7. 89-6 Bore-hole profile from Ephesus ancient city (Kayan, 1999).

The delta complex of Küçük Menderes River is located on the active tectonic line that effecting the development of the delta according to Gökçen et al, 1990. This delta can be classified as “wave-dominant” by Gallaway (1975). Fine grained wave sediments that are in the oxbow parts of the river form the widespread beaches (Pamucak beach) (Figure 1.8).



Figure 1.8. General view of Pamucak Beach.

Three lakes (Lake Gebekirse, Lake Akgöl and Lake Kocagöz) and one swamp (Eleman Swamp) were occurred in the north of the Küçük Menderes Rivers’ deltatic plain (Figure 1.9).



Figure 1.9. Satellite image from Selçuk (from NASA World Wind program).

Eleman swamp represents coastal lagoon (Erinç, 1955) (Figure 1.10). Decreasing of the topography at somewhere as 0,5 m causes the spreading of this swamp. According to Sıkı 1997, this swamp covers 1500 ha area, but just 1050 ha part of this field is protected as “Bird Paradise”. Expect this area, another part of the swamp that covers about 500 ha lakes take place that consist wildlife habitat. This swamp is used as agricultural area by local people in dry season (from June to September) due to the drying the swamp (Nippon, 1996). This swamp usually floods every winter due to rain and overflowing of the Küçük Menderes River (Figure 1.11) and dries out due to high rate of evaporation every dry season.

Lake Gebekirse covers 75 ha area and has 5m water depth (Figure 1.12). The flooding level is about 2m (Nippon, 1996) (Figure 1.13) and it discharges to Küçük Menderes River with a channel. The recharge processes are both from precipitation and karstic discharges. According to ornithologist Sıkı 1997, there are 97 bird species in Lake Gebekirse.

The second lake located near the Lake Gebekirse and 6km far away from the sea (Figure 1.14) is Lake Akgöl. This lake covers 74 ha area and has 4m water depth. Recharge and discharge processes are the similar with Lake Gebekirse; recharge with both precipitation and karstic discharges and discharges to Küçük Menderes River with a channel. The flooding level is less than 2m. In the rainy season, large swamps occur around the Lake Akgöl (Figure 1.15). This flooding area is used for agricultural purposes as Eleman Swamp.

The last lake is Lake Kocagöz that locates southwestern of Selçuk vicinity (Figure 1.16). This lake is close to Ancient Ephesus that was an ancient harbor before the bay was filled with deposits conveyed by Küçük Menderes River. The topographic elevation is -40cm from the sea-level. The recharging and discharge processes are the similar with other lakes; precipitation and karstic springs (Figure 1.17); evaporation and discharging channel, respectively.



Figure 1.10. General view of Eleman Swamp.

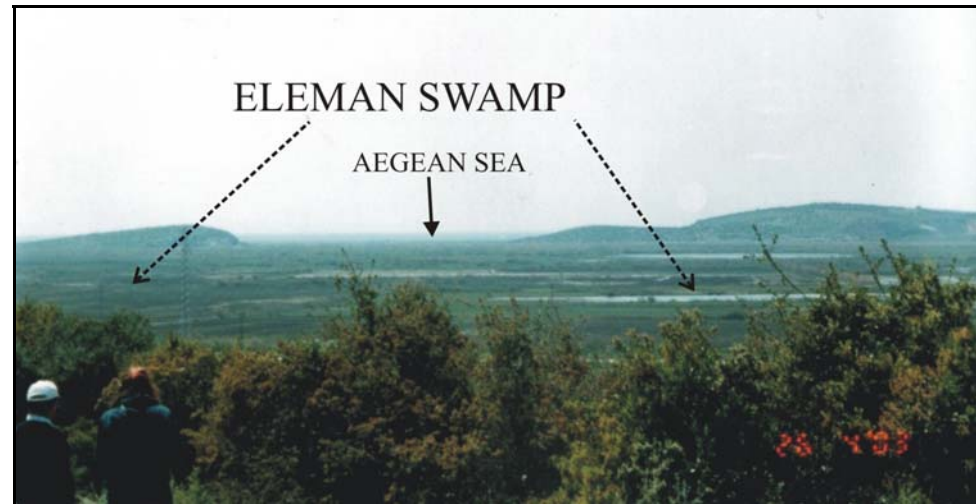


Figure 1.11. A view of Eleman Swamp in rainy season.

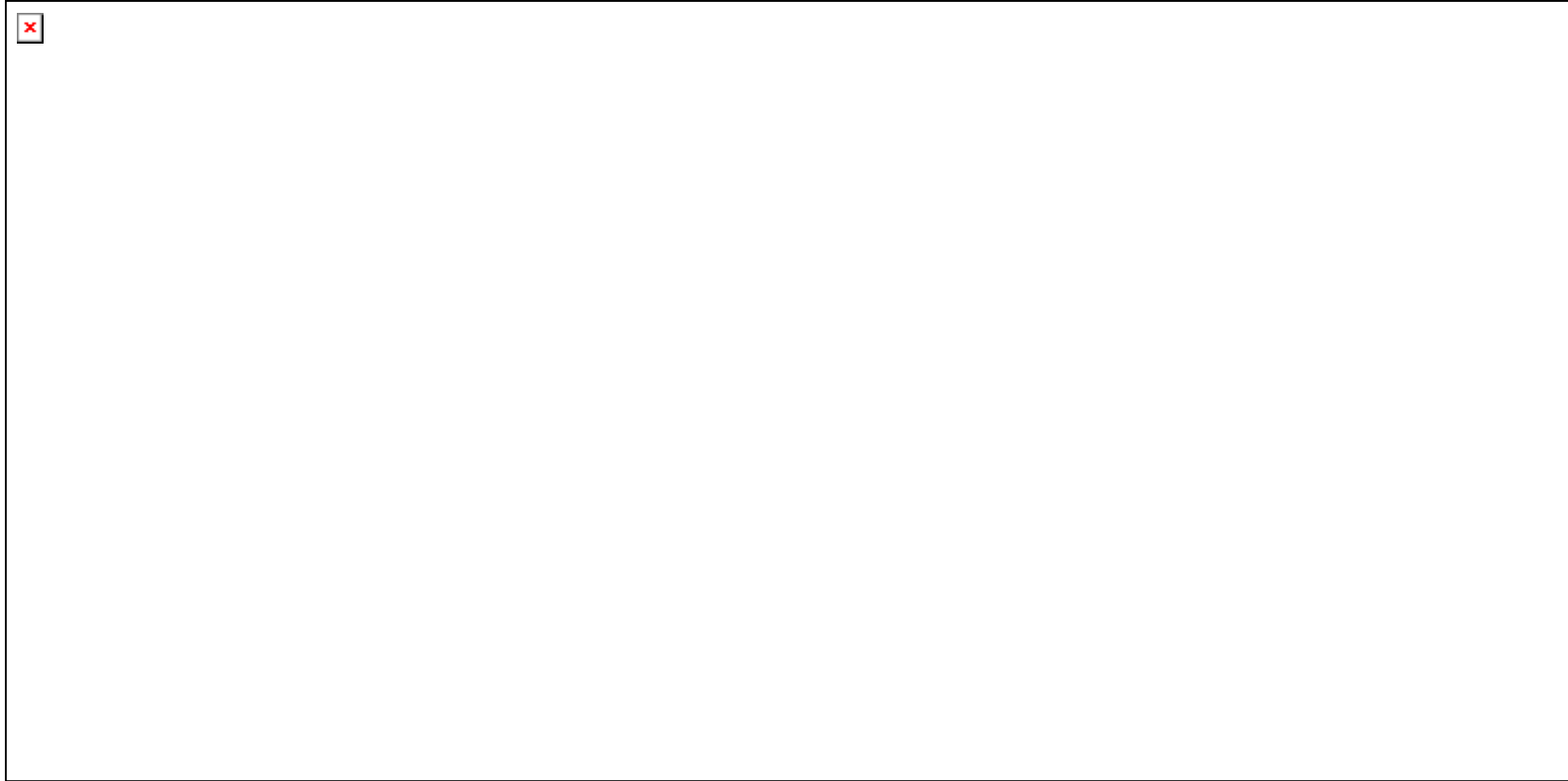


Figure 1.12. Lake Gebekirse.



Figure 1.13. Flooding level rises 1.5m in Lake Gebekirse.

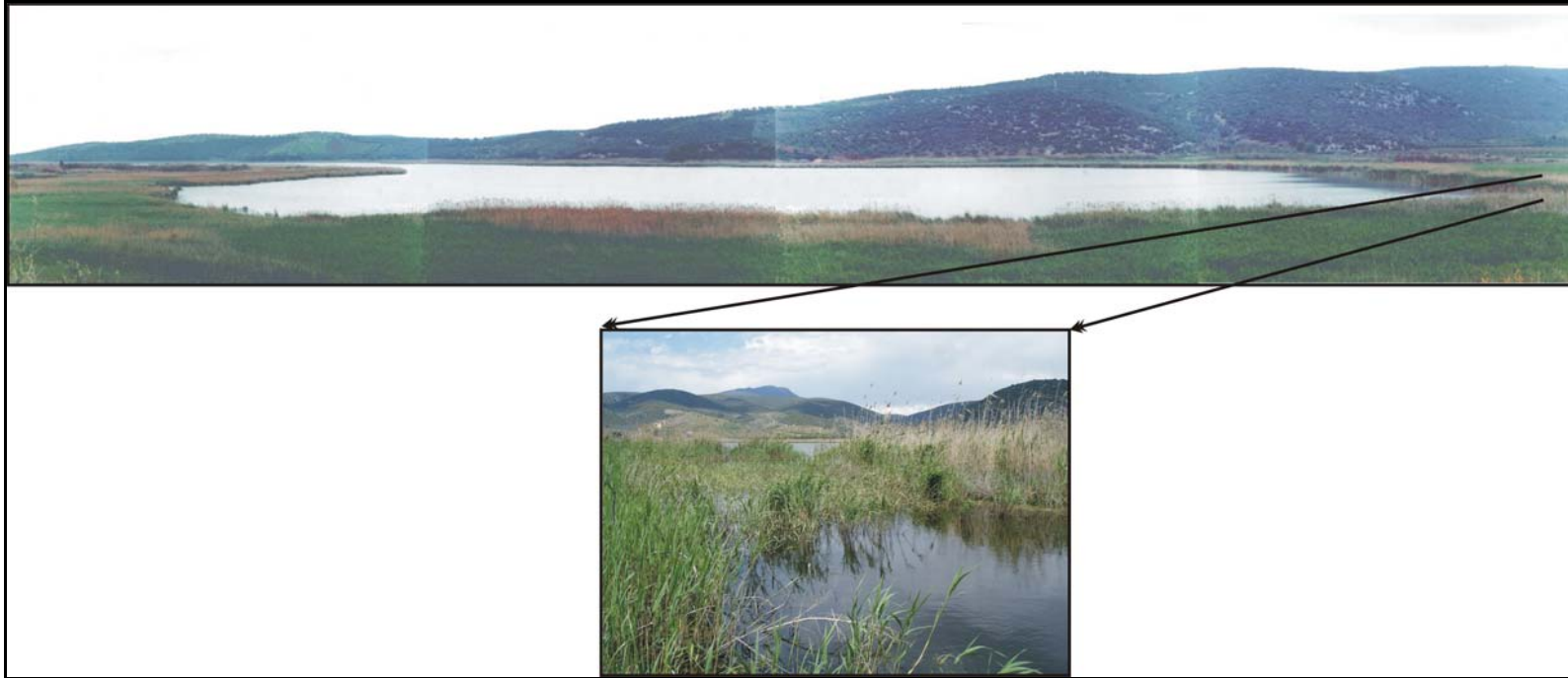


Figure 1.14. General view of Lake Akgöl.



Figure 1.15. Swamp of Lake Akgöl.



Figure 1.16. General view of Lake Kocagöz



Figure 1.17. Karstic structures between Bülbüldağ and Lake Kocagöz.

All these lakes recharge from lots of karstic springs. But in this thesis, just two of them are taken into the consideration: (i) Kazangöl Karstic Spring (Figure 1.18 and 1.19) (ii) Zeytinköy Karstic Spring (Figure 1.20).



Figure 1.18. General view of Kazangöl karstic spring and its pond.

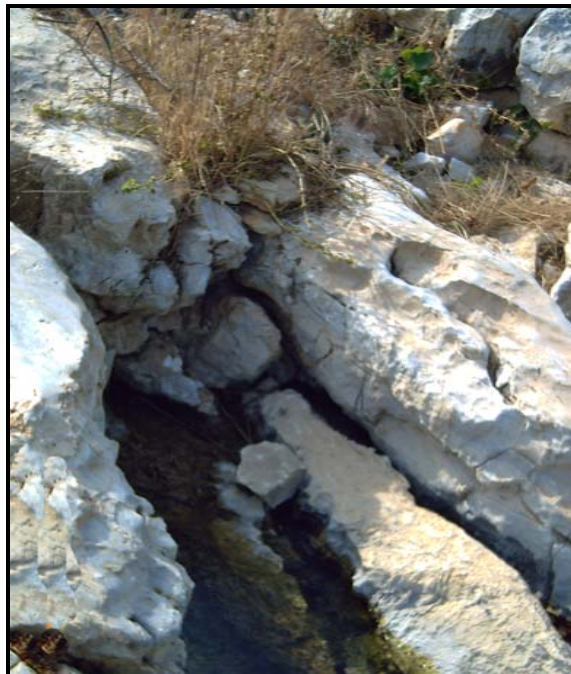


Figure 1.19. Kazangöl karstic spring discharge point.



Figure 1.20. Zeytinköy karstic springs and its pond.

CHAPTER TWO

GEOLOGY, HYDROGEOLOGY AND HYDROGEOCHEMISTRY

2.1 Introduction

Wetlands are the areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters according to the Ramsar Convention (Ramsar Convention, 2004).

In wetlands, water is the primarily necessary factor both occurrence the nutrient for animal and growing up the plants. At this point, water quality effects wild life in wetlands. So not only surface water but also groundwater must be investigated in the recharge and discharge areas of wetlands to understand the water-rock interactions. Water quality in wetlands depends on local geology, distance from sea and industrial zone, agricultural area and urbanization (Somay and Filiz, 2005). Generally, lithology controls the storage capacity, porosity and permeability of rocks, and major and minor ions content. In some special cases lithology causes pollution in and around mining areas. Thus, hydrogeological and hydrogeochemical investigations help us to identify the recharge-discharge areas, wetland water type, water-rock interactions in the wetlands (Somay and Filiz, 2005).

There are 70 wetlands in Turkey according to the inventory of Ministry of Forest and Environment of Turkey. But only nine wetland sites are under protection by Ramsar Convention (Sultan Sazlığı: Kayseri; Lake Seyfe: Kırşehir; Lake Ulubat: Bursa; Manyas Bird Paradise: Balıkesir; Lake Burdur: Burdur; Kızılırmak Delta: Samsun; Gökova Delta: Mersin; Gediz Delta: İzmir (e.g. Somay and Filiz, 2003); Akyatan Lagoon: Adana). In this study, Küçük Menderes River wetland that is between Gediz Delta in north and Büyük Menderes River Wetland in south was investigated by hydrogeological and hydrogeochemical purposes.

This wetland is located in the western part of Selçuk district, approximately 70 km SE of İzmir, Turkey (Figure 2.1). In addition to the presence of wetland landscape at this basin also there are sanctuary places both Ancient Ephesus and Virgin Mary House close to this wetland area. So this area is very important in view of natural sources and historical past, hollow places.

There are a few reports about whole Küçük Menderes River Basin done by General Directorate of State Hydraulic Works alone with (DSİ 1973, 1990a) and cooperation with Middle East Technical University (METU) (Yazicigil et al. 2000) and with Japan International Cooperation Agency (JICA) (Nippon, 1996) and they were mainly carried out to assess the potential of groundwater and agricultural facilities. Only the DSİ 1990a report was focused on how and where to be supplied the fresh drinking water in Selçuk Plain for the tourism purposes. But neither of them were investigated the Küçük Menderes River wetland detailed.

The climate is Mediterranean, with cool, wet winters and warm to hot, dry summers. The average annual temperature for the study area is 16 °C that was assured from Meteorological Station of Güzelyalı-İzmir in 2006. The hottest month is July with an average temperature of 26.4 °C and the coolest month is January with 7.9 °C. The average annual rainfall is 689.2mm and the average annual potential evapotranspiration is 868.4mm that was calculated according to Thornthwaite Method (1948) and it is greatest during July and August and lowest during December and January.

Three lakes, one swamp and Küçük Menderes River are the main components of this wetland. According to Ramsar classification and Cowardin classification; this wetland is “Marine/Coastal, Saline Water Wetland” and “Marine, Lacustrine and Riverien Wetland” respectively (Figure 2.2). All of the wetland covers 1500 ha area (Nippon, 1996) and it is protected by Department of National Park and Wild Life of Forest Ministry. Lake Gebekirse (samples 1, 2) is the nearest lake to

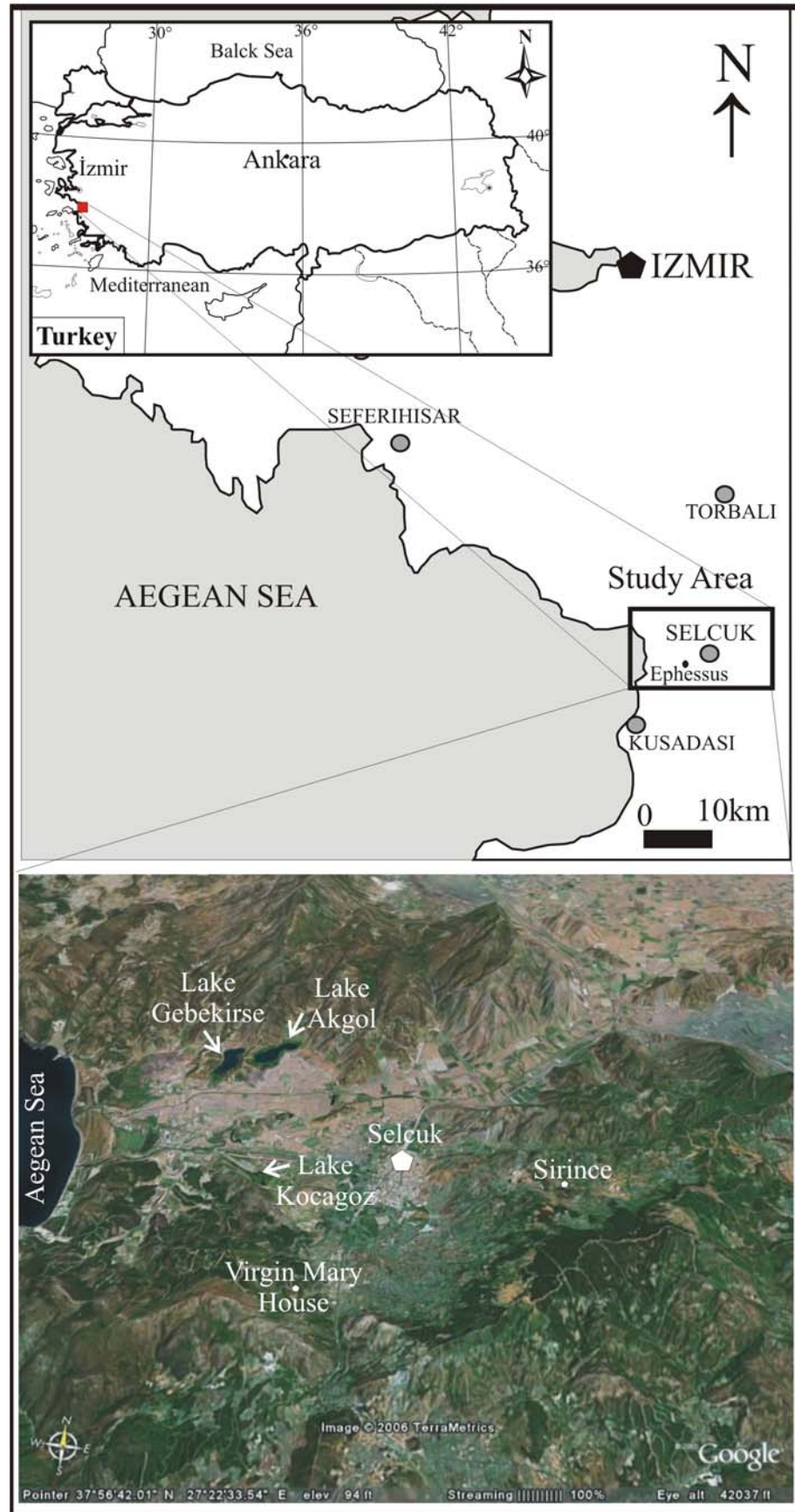


Figure 2.1. Location map of the study area.

the Aegean Sea and is protected due to its ornithological, bestial and vegetation values as “Lake Gebekirse Wild Life Protection Area”. According to Sıkı 1997, there are 97 bird species in this lake. The lakes are fringed with Phragmites: large parts of the marshes are covered with Tamarix (WWF-Türkiye, 2006) that is the indicator for saline water. The second lake is Akgöl (samples 3, 4) that is separated from Lake Gebekirse with a hill. This lake has a large swamp area especially in the rainy season. Lake Kocagöz (sample 5) is close to Ancient Ephesus that was an ancient harbor before the bay was filled with deposits that had been conveyed by Küçük Menderes River. Widely spread swamp that is called “Eleman Swamp” is covering 1000 ha area approximately (samples 6, 7, 8). This swamp usually dries in dry season as a result of high evaporation rate and is used for agricultural purposes by local people (Nippon, 1996). According to Gencer Guler and Zafer Turkyilmaz 2003, this wetland was classification as swamp, shrub and meadow dominated wetland. All of the wetland system is recharged with both precipitation and karstic discharges from marbles towards to sea. In this area there are many karstic spring points that rise from schist-marble and alluvium-marble contacts. But only two of them are formed little pond: Kazangöl karstic spring (samples 13, 14) and Zeytinköy karstic spring (sample 15, 16) that are located between Aegean Sea and Lake Akgöl (Figure 2.8).

The main aim of this study is to characterize the wetland type, such as salt, brackish or fresh water wetland, and to determine the hydrogeochemical properties and the origin of the wetland waters by major and minor ions in both seasons, dry and rainy. And the other aim is to investigate the probable contamination factors and sources in the wetland protection area with its heavy metal contents.

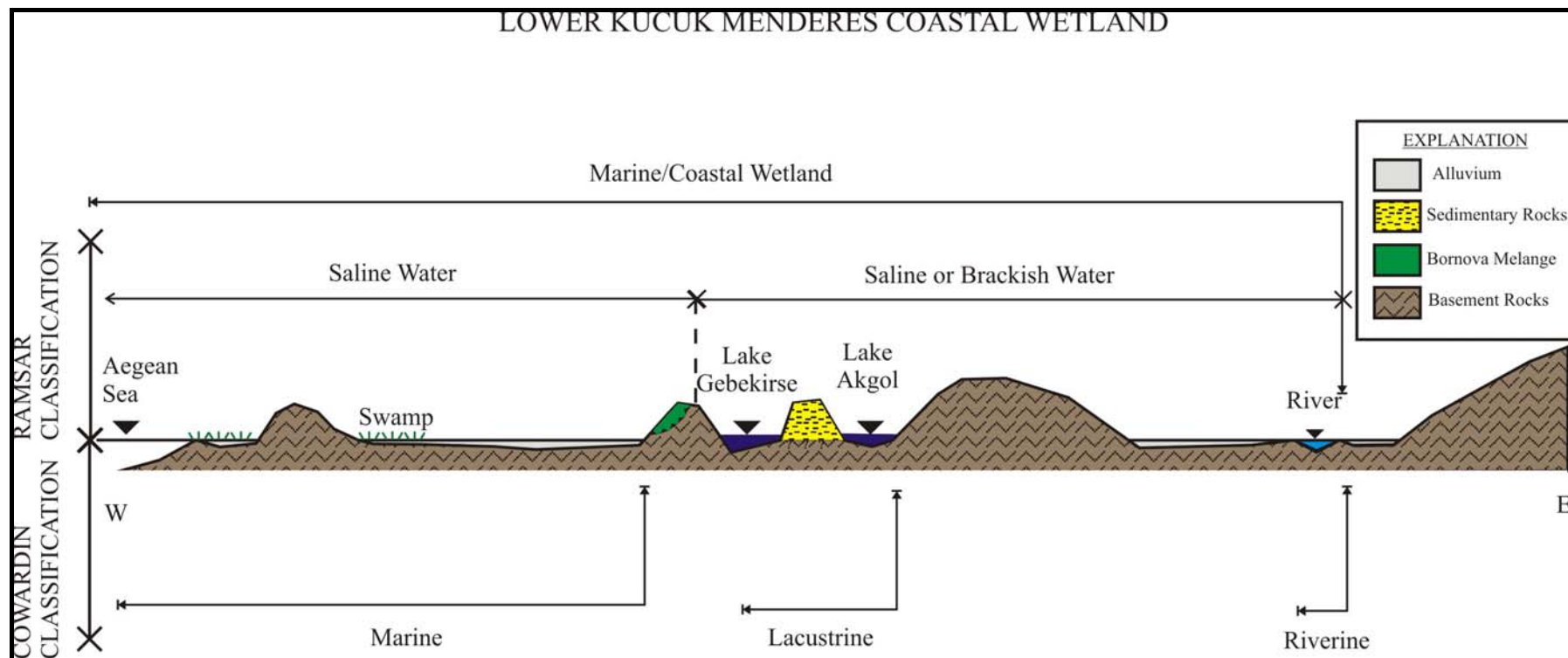


Figure 2.2. Wetland Classification of Küçük Menderes Wetland according to Ramsar, 2004 and Cowardin et al., 1979.

2.2 Materials and Methods

Hydrogeochemical information was gathered from a sampling network of 25 points not only in the wetland but also in the hydrological basin of wetland (recharge area) during 2003-2005 dry and rainy seasons to compare the water types and properties.

pH, temperatures and electrical conductivity (EC) were measured insitu by WTW pH-cond 340i. Water samples were divided into two polyethylene bottles. The parameters were determined by following standard and recommended analysis methods APHA-AWWA-WPCF (1992). The samples taken for cation analysis were acidified using HNO_3 to prevent precipitation. They were kept at 4°C until the analysis was done. Chloride, bicarbonate and carbonate were determined by volumetric methods, and sulfate was determined by gravimetric method in the Dokuz Eylul University Geological Engineering Department Geochemical Laboratory. The cations and all trace elements were analyzed by inductively coupled plasma mass spectrometry (ICP-MS Enhanced) in the ACME Laboratory, Canada.

Canadian Water Quality Guidelines for The Protection of Aquatic Life (CWQG) 2005 was used for wetland area, and TSE 266 (1997) and EPA 2003 drinking water standards were used for the waters from recharge area (Şirince-samples 17-18, Virgin Mary House-sample-20, Andon and İzmir gorges-samples 21-22) to compare the water samples.

The computer program PHREEQCi (Parkhurst and Appelo, 1999) using database llnl was used to calculate the distribution of the aqueous species. The program is designed to perform a wide variety of aqueous geochemical calculations, based on an ion-association aqueous model. This computer program has also been used to evaluate which solid might be precipitating by means of saturation index (SI).

2.3 Geology of the Lower Küçük Menderes River Basin

From a geological point, the Selçuk Plain constitutes an alluvial coastal plain within a group of graben of the western Küçük Menderes Range (Figure 2.3). To the north, the plain is delimited by Paleozoic marbles, while the Paleozoic schist-marble intercalations of Menderes Massif constitute the southern limit. There are four different types of rock units that constitute this basin (Figure 2.4). The basement rock of the study area is Menderes Massif (metamorphic units). Late Cretaceous Bornova mélangé is overlaid this basement rock by unconformity (Güngör and Erdoğan, 2002). Sedimentary rocks overlaid the Bornova mélangé in Neogene that has a small area in the northern part of the plain. The upper unit is the Quaternary alluvium that continues to deposit.

2.3.1 Menderes Massif (Metamorphic Units)

“The Menderes massif in western Anatolia is structurally bounded to the northwest by the Late Cretaceous Bornova flysch zone and to the south by the Mesozoic-Paleogene Lycian nappe complex” (Candan et al, 2001) (Figure 2.3).

Menderes metamorphic (Menderes Massif) units form the basement of the study area (Figure 2.4). The Menderes Massif is represented by an approximately 4-km-thick metasedimentary sequence in the Selçuk area (Güngör and Erdoğan, 2002).

According to Çetinkaplan 2002, the metamorphic rocks in the western Anatolia can be divided into two main rock associations: Marble-schist series and Metaolistostrome unit. Marble-schist series is composed of schists with different mineral compositions, phyllite, metaconglomerates, metabasic rocks and thick bedded platform type marble. The Metaolistostrome unit is made up of blocks embedded in a matrix of albite-phengite schist and garnet-phengite schist.

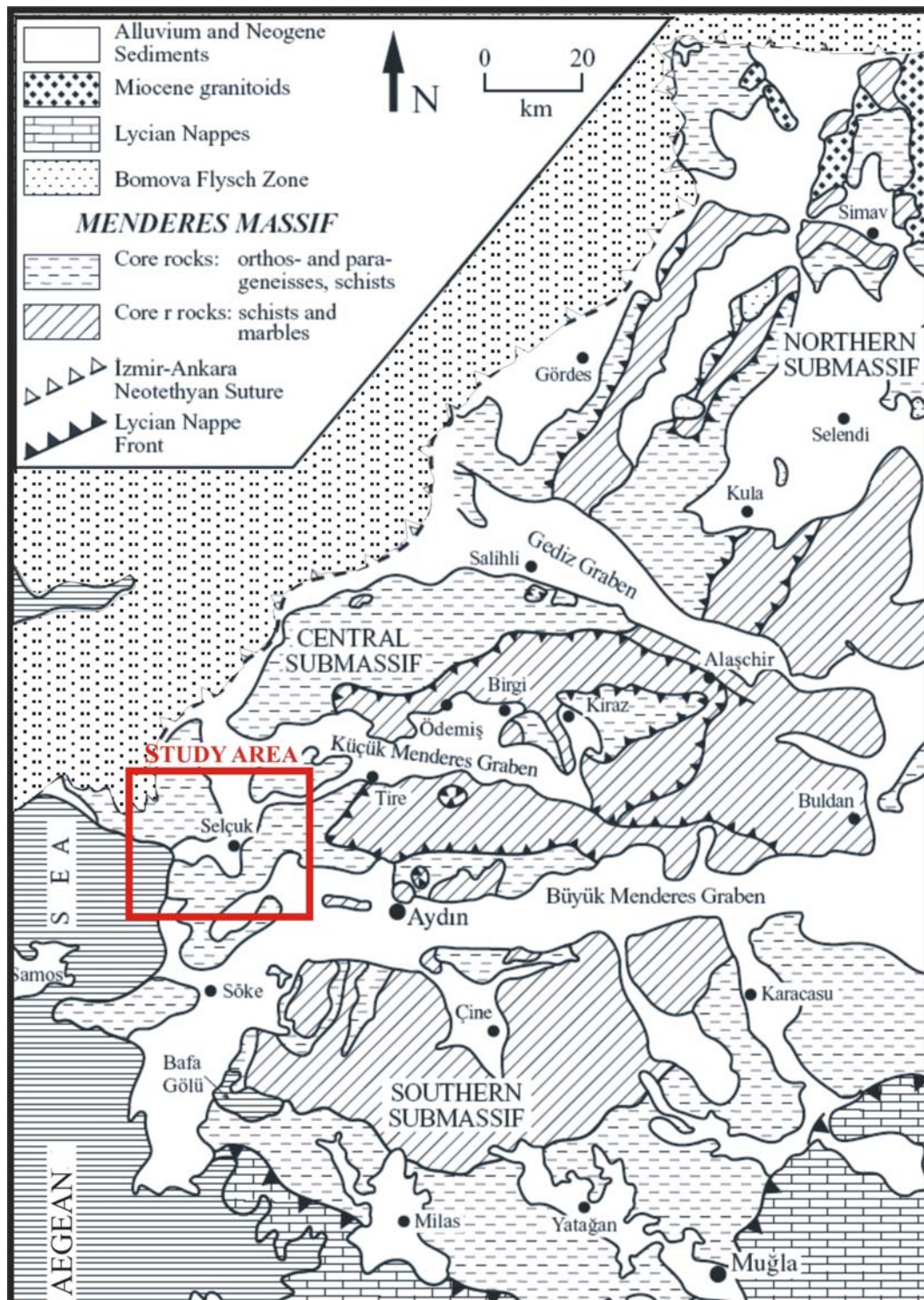


Figure 2.3. Main tectonic belts and the location of the study area (modified from Bozkurt and Oberhansli, 2001; Candan et al, 2001 and Güngör and Erdoğan, 2002).

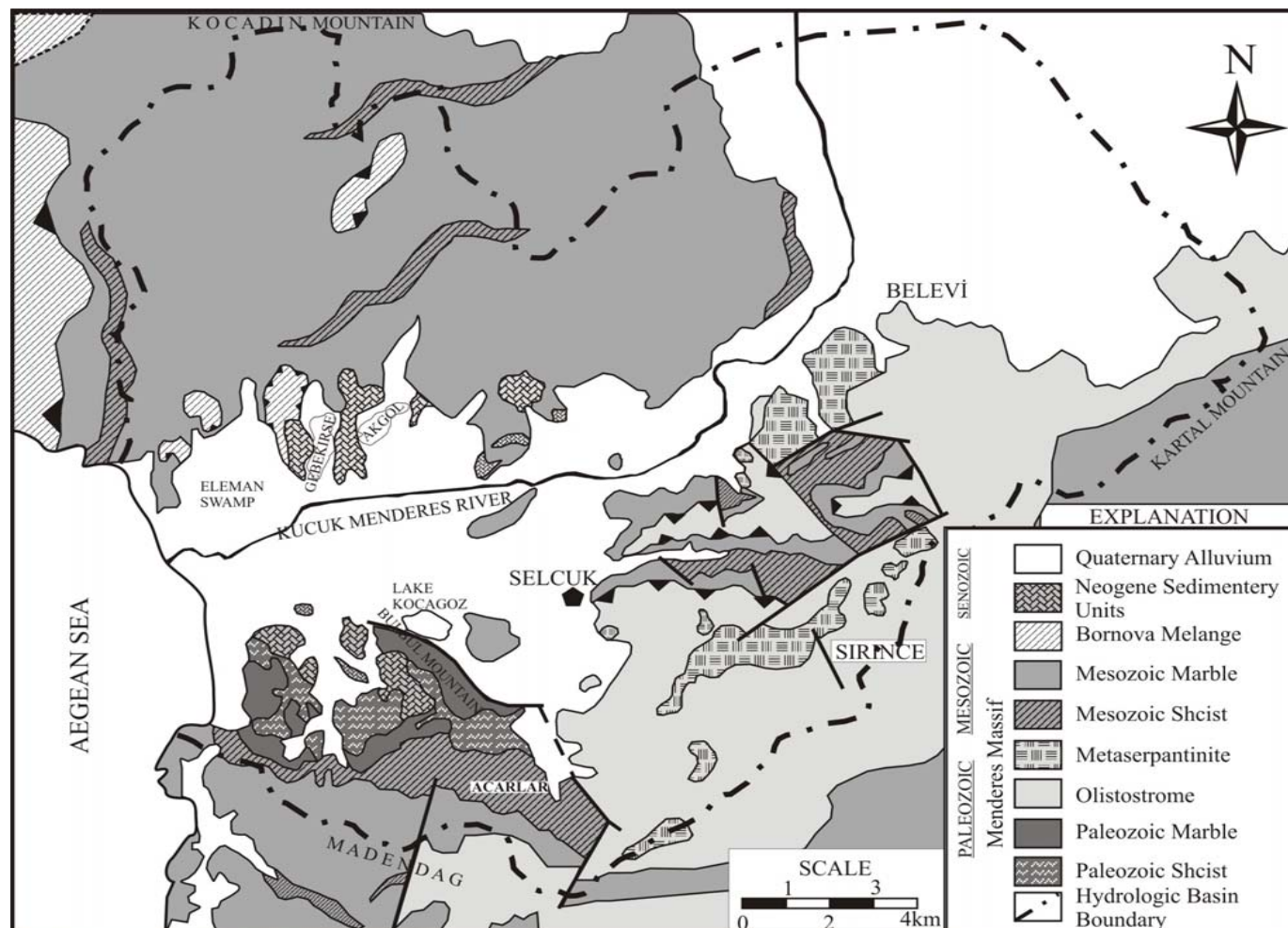


Figure 2.4. Geological map of the study area (modified from Candan and Dora, 1998; Çetinkaplan, 2002)

2.3.1.1. Marble-Schist Series

The general rock succession of the area between Kuşadası and Selçuk can be given in ascending order as follows: i) Marble / schist intercalations, Paleozoic (?) in age, ii) Lower Triassic schist with quartz and carbonate metaconglomerate layers, iii) Jurassic – Upper Cretaceous platform type thick marbles and iv) Metamorphic olistostrome, probably Paleocene (?) in age. In this area, mica schist, metaquartzites are overlain by marbles occur at the base of the metamorphic sequence and are Paleozoic (?) in age. This series can be distinguished from the Mesozoic Marble-schist series by the following features; i) these marbles do not contain metabauxite and are observed as interlayers within the schists, ii) there are no metabasic lenses and layers in this intercalations, iii) this marble / schist series do not contain metaconglomerate horizons. Based on these features, this marble-schist series which can be interpreted as the uppermost part of the Paleozoic (?) series, is separated as a different series from Lower Triassic - Upper Cretaceous sequence. The Marble - schist series Paleozoic (?) in age is conformably overlain by mica schist intercalated with lenses or layers of metaconglomerates, metabasites, metaquartzite and marbles. Quartz and carbonate metaconglomerates occur as lenses or layers showing lateral continuity. The quartz metaconglomerates with fine-grained phyllitic matrix are completely made up of strongly flattened and elongated quartz pebbles and have the characteristic “kyanite + chloritoid + phengite” paragenesis. Like in quartz metaconglomerate, carbonate metaconglomerate has got flattened carbonate pebbles embedded in matrix of quartz and carbonate. Metaconglomerate – schist intercalation is conformably overlain by platform type, metabauxite bearing, thick marbles (Çetinkaplan, 2002) (Figure 2.5).

Greenschist metabasites are commonly seen around Selçuk. The general mineral assemblage of these rocks is “epidote - phengite - albite - chlorite - calcite - Ca-amphibole - biotite - zoisite - quartz - sphene - ankerite - opaque oxide”. On the other hand, Phengite-quartz schists are seen in Selçuk. The general mineral assemblage of phengite-quartz schists is “phengite - quartz - albite - biotite - chlorite - tourmaline - opaque oxide”. The general mineral assemblage of the marble is “calcite + albite + phengite + quartz” (Çetinkaplan, 2002).

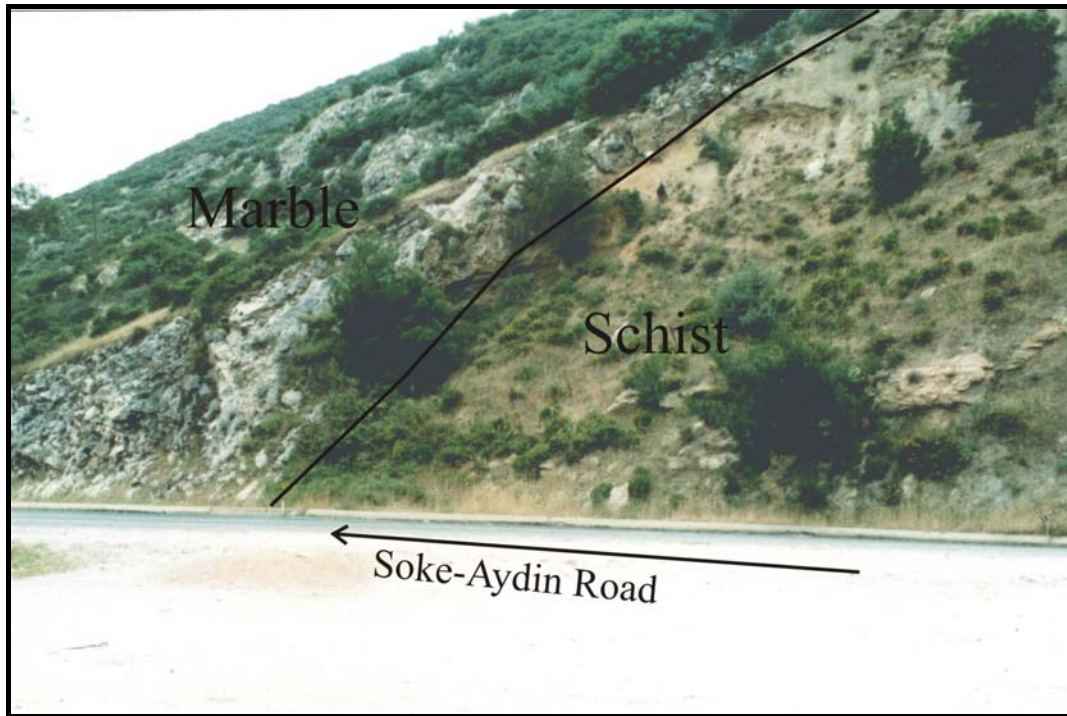


Figure 2.5. Relationship between schist and marble on the Söke-Aydın road (0532450/4194575).

2.3.1.2. *Metaolistostrome Unit*

“The widest outcrop of the Metaolistostrome unit is observed in Selçuk (Şirince) area. Litostratigraphic sequence of this area starts with Lower Triassic (?) – Upper Cretaceous rocks at the base. The uppermost level of the lower sequence is composed of metabauxite bearing, platform type marble. The marbles are tectonically overlain by the Metaolistostrome unit. The matrix of the metaolistostrome is composed of microfolded, strongly foliated garnet-phengite schist and albite-phengite schist. Especially garnet-phengite schists are more dominant in NE of Şirince. The matrix contains numerous blocks of different rock types. These blocks consist of eclogite, omphacite metagabbro, omphacite-epidotite, zoisite metagabbro, Ti metagabbro, blueschist metabasite, metaserpentinite and marble. Typical HP/LT metamorphic rocks in the metaolistostrome are eclogite, omphacite metagabbro, omphacite-epidotite and blueschist metabasites. These metaserpentinite blocks reach up to 3.5 km in size, and are found in different levels of the unit. These metaserpentinite blocks are generally massive. However, especially, the rim of some metaserpentinite blocks are strongly foliated. Metaserpentinites are olive green and yellowish green in colour, and do not contain relict texture of the original igneous rock” (Çetinkaplan, 2002).

2.3.2 Bornova Mélange

Bornova mélange is the main tectonic belts of western Turkey (Güngör and Erdoğan, 2002) and extend between Karaburun belt and the Menderes massif (Erdoğan, 1990). This mélange consists of matrix of flysch-like sedimentary rocks and spilites, separated by strongly sheared serpentinite slices in the Seferihisar region (Güngör and Erdoğan, 2002). The matrix of Bornova mélange is Campanien-Danien in age (Ozer and Irtem, 1982) and includes Triassic-Cretaceous limestone blocks more than 20km in length, which belong to the Karaburun belt (Erdoğan, 1990).

Bornova mélange that is made up of a flysh-type sedimentary matrix with blocks of neritic limestone is overlaid Menderes Massif basement rocks by unconformity (Güngör and Erdoğan, 2002) (Figure 2.3 and 2.4).

2.3.3 Neogene Sedimentary Rocks

Neogene sedimentary rocks that consist of coarse grain conglomerate, limestone and claystone down to up overlay Bornova mélange with unconformity. This unit covers very narrow area in the basin. According to DSİ 1990a, this sedimentary unit contains more clayey levels than conglomerates.

2.3.4 Quaternary Alluvium

Quaternary alluvium that contains clay, sand and gravel with 20-100m thick outcrops all of these units by unconformity. The fill of Selçuk Plain consists of detrital Quaternary sediments that consist of sand, silt and clay that have little vertical or lateral continuity and frequent lateral changes in facies (DSİ, 1973). According to the study of Kayan and Kraft 1997 that explained the archeological aspects of Ancient Ephesus, the alluvium was consisted from marine deposits. The size of these deposits are changed between coarse to fine sand, silt and mud (Figure 2.6).

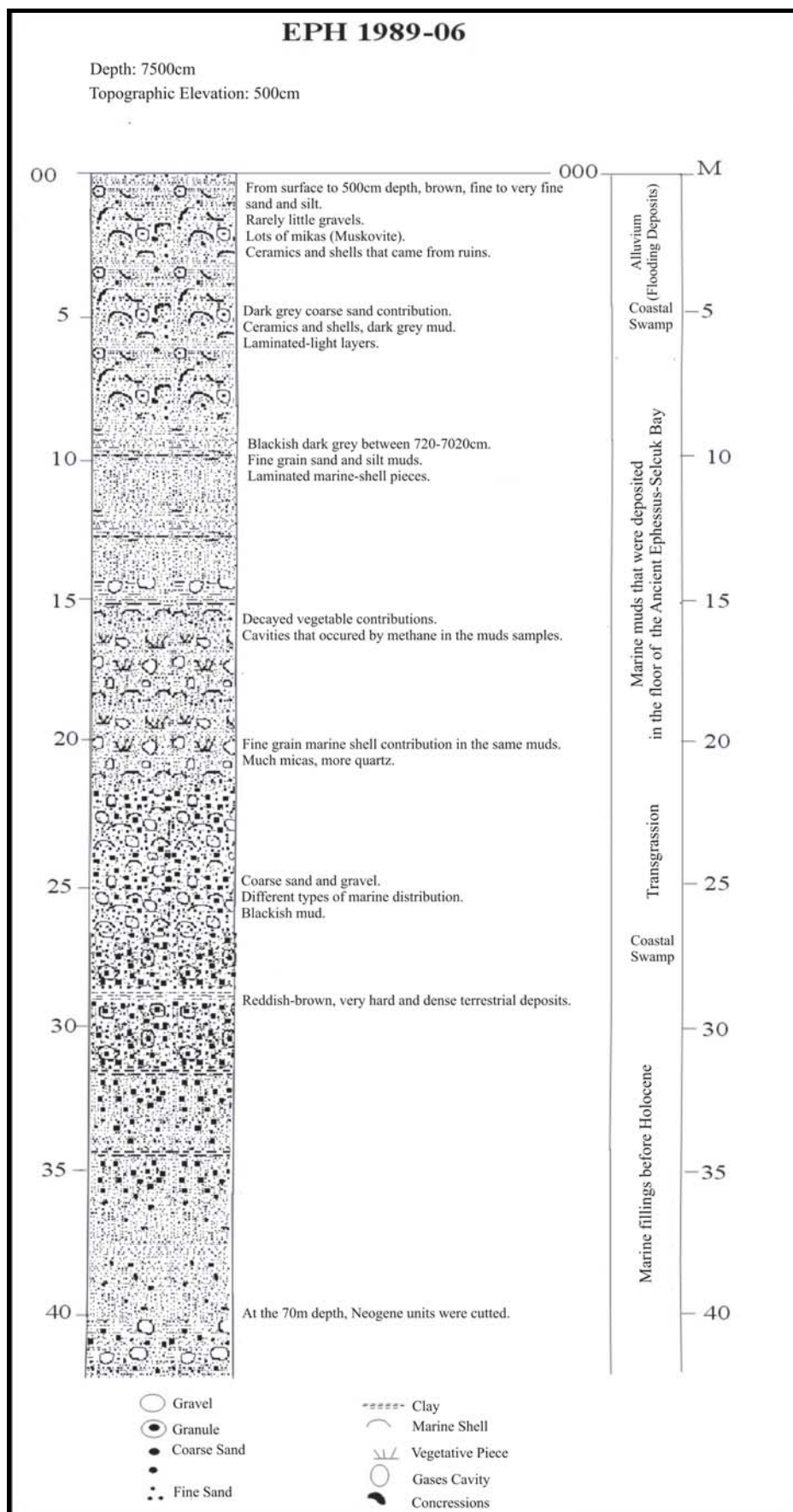


Figure 2.6. Sedimentological profile of EPH 89-06 drilling hole (Kayan and Kraft, 1997).

2.4 Hydrogeology and Occurrence of Küçük Menderes River Coastal Wetland

According to Gökçen et al. 1990; the delta complex of Küçük Menderes River is located on the active tectonic line effecting the development of the delta. This delta can be classified as “wave-dominant” according to Gallaway (1975).

Fine grained wave sediments are in the oxbow parts of the river forming the widespread beaches (Pamucak beach). Size and characteristics of sediment differ from Belevi to Aegean Sea. There are both terrestrial and marine deposits in Selçuk plain because of the climatical changes (Öner, 1997). Terrestrial deposits are seen in the backwards of the Belevi Gorge, but the marine deposits are formed in the area from Selçuk town centre to the coast.

According to the Nippon, 1996; the schist units are practically impervious, while marbles have high porosity and permeability values due to fissures and/or karstification. The intrinsic permeability was found by Yazıcıgil et al., 2000 for the study area. The intrinsic permeability of any porous material is:

$K_i = C * d^2$ where K_i is intrinsic permeability (L²); C is dimensionless constant; d is the average or effective pore diameter (L).

The intrinsic permeability of the marble unit ranges from $0,22 * 10^{-11} \text{ m}^2$ to $497 * 10^{-11} \text{ m}^2$ with an average of $156 * 10^{-11} \text{ m}^2$ (Yazıcıgil et al. 2000) (Figure 2.7). The marbles of the Paleozoic could eventually constitute important aquifers in the northern and southern part of Selçuk Plain. In this area, in fact, there are many karstic discharges points, Kazangöl and Zeytinköy springs, running from the schist-marble contacts towards to the sea. The main point of entry of saline water into the swamp and plain is the inlet of the fractures and karstic structures of Paleozoic marbles. The karstic marbles and springs can be seen in an E-W direction that reaches to the sea. But on the other hand, massive marbles that form the upper level of metamorphic series acts as impermeable layer (Pusatlı, 2000).

An especially shale dominant part of Bornova mélangé is unsuitable for groundwater storage and discharge due to its low permeability and porosity.

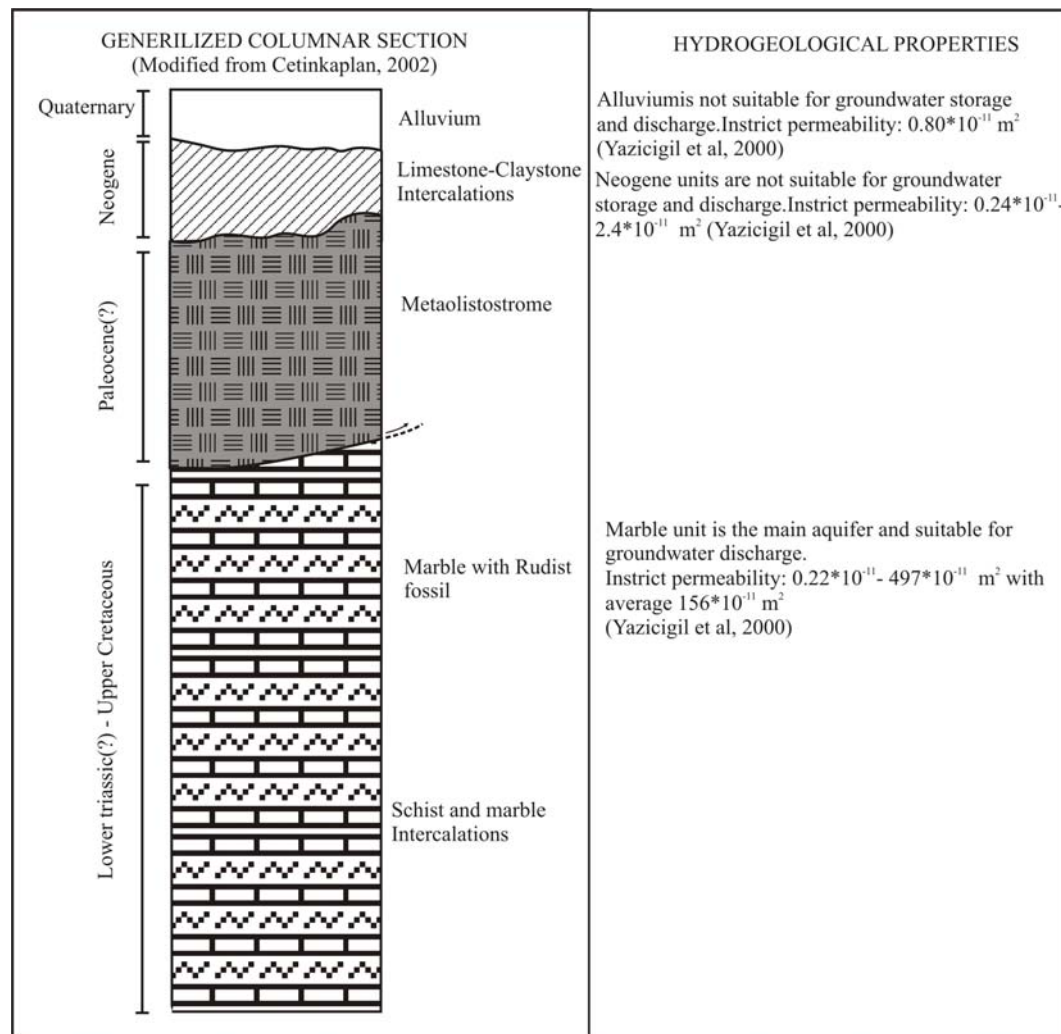


Figure 2.7. Geological and hydrogeological properties of the rocks in the study area

Limestone levels of this unit act as an aquifer and claystone-mudstone alternates are impermeable layer of this aquifer. The intrinsic permeable of the Neogene sedimentary units range from $0,24 \cdot 10^{-11} \text{m}^2$ to $2,4 \cdot 10^{-11} \text{m}^2$ (Yazicigil et al., 2000).

Although the lithology of Quaternary alluvium of Selçuk plain is basically sand and gravel, there are lots of clay lenses and salt soil that make the alluvium impermeable layer especially in and around swamp. Due to salt soil potential that is occurred by sea-water intrusion and high evaporation, a large part of alluvium acts as impermeable layer. Its intrinsic permeability is measured as $0,80 \cdot 10^{-11} \text{m}^2$ by Yazicigil et al., 2000.

The recharge of alluvium comes from direct infiltration of rain and lateral inflow from Paleozoic marbles, Küçük Menderes River and return flow irrigation water. The discharge of the aquifer is a result of excessive pumping, outflow to the sea and swamp.

2.5 Hydrogeochemical Properties

The water chemistry of wetlands is primarily a result of geologic setting, water balance (relative proportions of inflow, outflow, and storage), and quality of inflowing water, type of soils and vegetation, and human activity within or near the wetland. Wetlands dominated by surface-water inflow and outflow reflect the chemistry of the associated rivers or lakes. Those wetlands that receive surface-water or ground-water inflow, have limited outflow, and lose water primarily to ET have a high concentration of chemicals and contain brackish or saline (salty) water (Carter, 1996).

97 samples were taken from the study area during 2001 to 2005, in both dry and rainy seasons (Appendix II and Appendix III). But in this chapter, only 25 samples taken between 2003 to 2004 were evaluated (Figure 2.8). Some sample points were chosen from recharge area that consists of Şirince settlement and Virgin Mary House, Andon and İzmir Gorges, and sea water (Aegean Sea) to compare with wetlands' waters. The hydrogeochemical characteristics and the processes which determine the mineralization of groundwater have been established for these arid-semi humid conditions on the basis of analysis of the main physico-chemical parameters. These parameters are presented in Table 2.1.

Hydrogeochemical analysis of the water samples revealed two distinct groundwater environments: a) wetland area that consists of lakes, swamp and Selçuk Plain, b) recharge area.

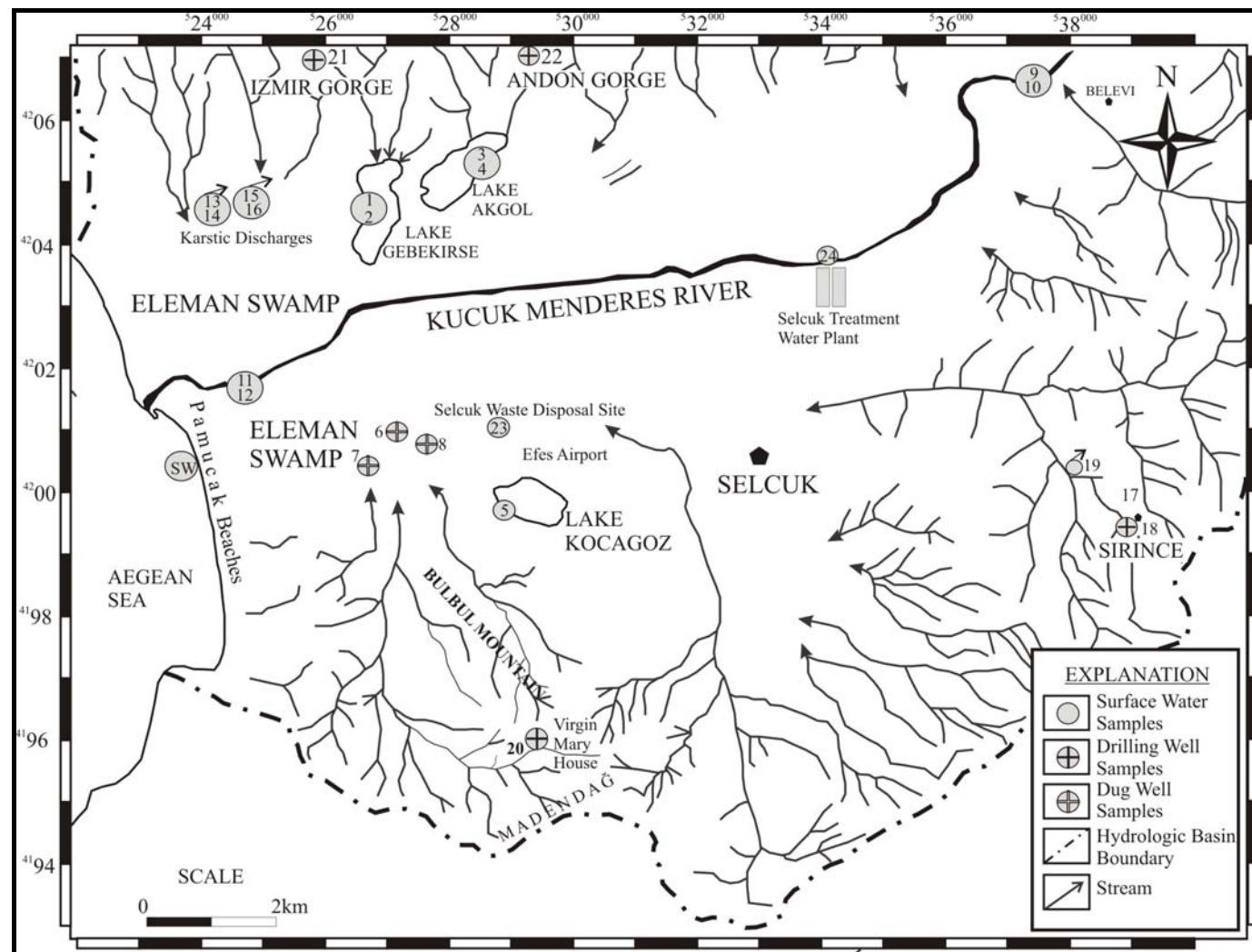


Figure 2.8. Sample location map of the study area.

Table 2.1. Chemical analyses of the waters (EC=Electrical Conductivity; “d” represents dry season (December 2003), “r” represents rainy season(July 2004)).

Location	Coordinate X Y	EC μS/cm	pH	Na ⁺ (mg/l)	K ⁺ (mg/l)	Ca ⁺² (mg/l)	Mg ⁺² (mg/l)	Cl ⁻ (mg/l)	HCO ₃ ⁻ (mg/l)	SO ₄ ⁻² (mg/l)	Water Type (IAH, 1979)
1 (Lake Gebekirse ^d)	0526560/4204600	11510	8.1	1873.2	66.1	217.4	199.6	3340	266.0	471.0	Na-Cl
2 (Lake Gebekirse ^r)		2255	7.7	1107.4	34.5	130.4	105.0	1720	235.9	290.0	Na-Cl
3 (Lake Akgöl ^d)	0528600/4205153	2020	7.4	202.5	7.4	142.5	33.3	391	446.0	75.0	Na-Ca-Cl-HCO ₃
4 (Lake Akgöl ^r)		1586	8.0	740.0	19.0	135.0	74.0	1125	300.0	250.0	Na-Cl
5 (Lake Kocagöz ^d)	0529121/4199618	1488	6.7	158.2	13.9	90.3	48.0	206	453.8	104.8	Na-Ca-Mg-HCO ₃ -Cl
6 (Eleman Swamp ^d)	0527214/4200599	5790	7.9	1126.9	37.2	39.8	54.1	1500	671.0	174.0	Na-Cl
7 (Eleman Swamp ^d)	0526440/4200259	5490	7.4	533.2	12.1	337.9	147.2	1580	312.2	192.0	Na-Ca-Mg-Cl
8 (Eleman Swp. ^r)	0527197/4200633	5360	7.6	1267.7	35.0	14.4	15.6	1090	556.3	114.4	Na-Cl
9 (River-Belevi ^d)	0538210/4207313	2460	7.7	121.4	9.9	321.2	78.6	235	706.9	498.0	Ca-Mg- HCO ₃ -SO ₄ -Cl
10 (River-Belevi ^r)		1600	7.9	92.1	7.9	192.0	11.4	103	305.0	356.2	Ca-Na-SO ₄ -HCO ₃
11 (River-Pamucak ^d)	0524839/4201836	2900	7.9	506.8	16.1	145.1	59.2	745	522.2	175.6	Na-Ca-Cl-HCO ₃
12 (River-Pamucak ^r)		2850	8.0	431.8	15.3	104.0	53.5	450	458.7	109.5	Na-Cl-HCO ₃
13 (Kazangöl Krst. ^d)	0524126/4204452	10250	7.2	1489.1	56.2	183.7	193.8	2980	276.5	432.0	Na-Cl
14 (Kazangöl Krst. ^r)		5800	7.1	1070.8	25.9	134.0	121.0	1270	778.4	190.2	Na-Cl-HCO ₃
15 (Zeytinköy Krst. ^d)	0524605/4204525	4150	6.8	672.0	19.6	153.6	90.8	1290	366.0	168.5	Na-Cl
16 (Zeytinköy Krst. ^r)		4020	7.1	638.0	19.0	136.7	83.1	1107	366.0	168.0	Na-Cl
17 (Şirince ^d)	0538151/4199552	305	8.0	5.8	0.4	43.6	9.5	15	160.6	15.0	Ca-Mg-HCO ₃
18 (Şirince ^r)		472	7.4	8.6	1.5	60.8	19.4	15	236.7	26.6	Ca-Mg-HCO ₃
19 (Şirince Spring ^d)	0536564/4201383	773	7.2	21.3	2.1	76.9	46.3	39	430.0	61.2	Ca-Mg-HCO ₃
20 (Virgin Mary H. ^r)	0529328/4196129	645	7.3	8.9	0.3	74.8	32.8	131	356.2	40.6	Ca-Mg-HCO ₃

Table 2.1. Chemical analyses of the waters (EC=Electrical Conductivity; “d” represents dry season (December 2003), “r” represents rainy season(July 2004)).

Location	Coordinate X Y	EC μS/cm	pH	Na ⁺ (mg/l)	K ⁺ (mg/l)	Ca ⁺² (mg/l)	Mg ⁺² (mg/l)	Cl ⁻ (mg/l)	HCO ₃ ⁻ (mg/l)	SO ₄ ⁻² (mg/l)	Water Type (IAH, 1979)
21 (İzmir Gorge ^d)	0524643/4206425	977	6.8	80.6	2.1	97.6	24.5	151	356.2	29.1	Ca-Na-HCO ₃ -Cl
22 (Andon Gorge ^d)	0530456/4205808	780	6.9	25.8	1.8	121.6	17.5	57	419.7	21.1	Ca-HCO ₃
23 (Disposal Site ^d)	0528409/4200943	4550	8.5	657.8	42.5	132.5	115.7	1230	480.7	84.0	Na-Mg-Cl
24 (Treatment Water ^r)	0530240/4203222	565	7.8	43.9	100.8	54.0	19.7	120	295.2	24.0	Ca-K-Na-HCO ₃ -Cl
25 (Sea water-Pamucak)	0524140/4199607	58800	8.3	12720.0	398.8	476.0	48.1	17800	156.2	2920.7	Na-Cl

2.5.1 Hydrogeochemical Properties of Wetland Area

Lakes with their clear-cut boundary represent one of the most versatile ecosystems on the earth. There is limited mobility of lake materials as compared to rivers and oceans (Chakrapani, 2002).

The lakes are mostly alkaline in nature with pH values range between 7.8 and 9.00. Lake Gebekirse and Akgöl are more alkaline (pH 8.00-7.5) than that of Lake Kocagöz (pH 6.69 in dry season, whereas the pH value is 7.5 in rainy season). All of the lakes and swamp waters have high EC values ($>1000 \mu\text{S/cm}$) with a maximum value of $11510 \mu\text{S/cm}$ for Lake Gebekirse because of sea-water intrusion by the karstic structures through to the lake. On the other hand, the leaching of salts during subsequent rainfall events, in combination with evaporation losses, increases the concentration of Na and Cl in the soil and groundwater (Malcolm and Soulsby, 2001). So there is a salinization problem in the plain due to not only from sea-water but also from evaporation losses.

Among the major cations, Na dominates over Ca and Mg, among the major anions Cl dominates followed by HCO_3 , SO_4 that differ remarkably from those of all the other waters (recharge area). Especially, Lake Gebekirse is characterized by high Na and Cl values because of the proximity to the Aegean Sea. The sea water exhibits the typical chemistry ($\text{Na} > \text{Mg} > \text{Ca} > \text{K}$ and $\text{Cl} > \text{SO}_4 > \text{HCO}_3$) of the Aegean Sea in the close vicinity of the study area. The seasonal changes of the major ions of the wetland components were given in Figure 2.9. From this figure, it is clearly seen that there is a mineralization in dry season due to evaporation. Also, from Figure 2.9 the ionic composition of the lake water samples suggests that they could be formed by mixing of karstic discharge and sea-water. As expected, in the rainy season, the great quantities of meteoric water dilute the surface waters both lakes and rivers. In addition, the duration times between surface waters and outcropping rock are limited, which results in minimum salt concentrations. Conversely, during periods of drought, low rainfall, low flow rates and high temperatures all combine to favor the evaporation of waters, which reach peak salinity in summer in addition to sea-water intrusion especially in the Lake Gebekirse.

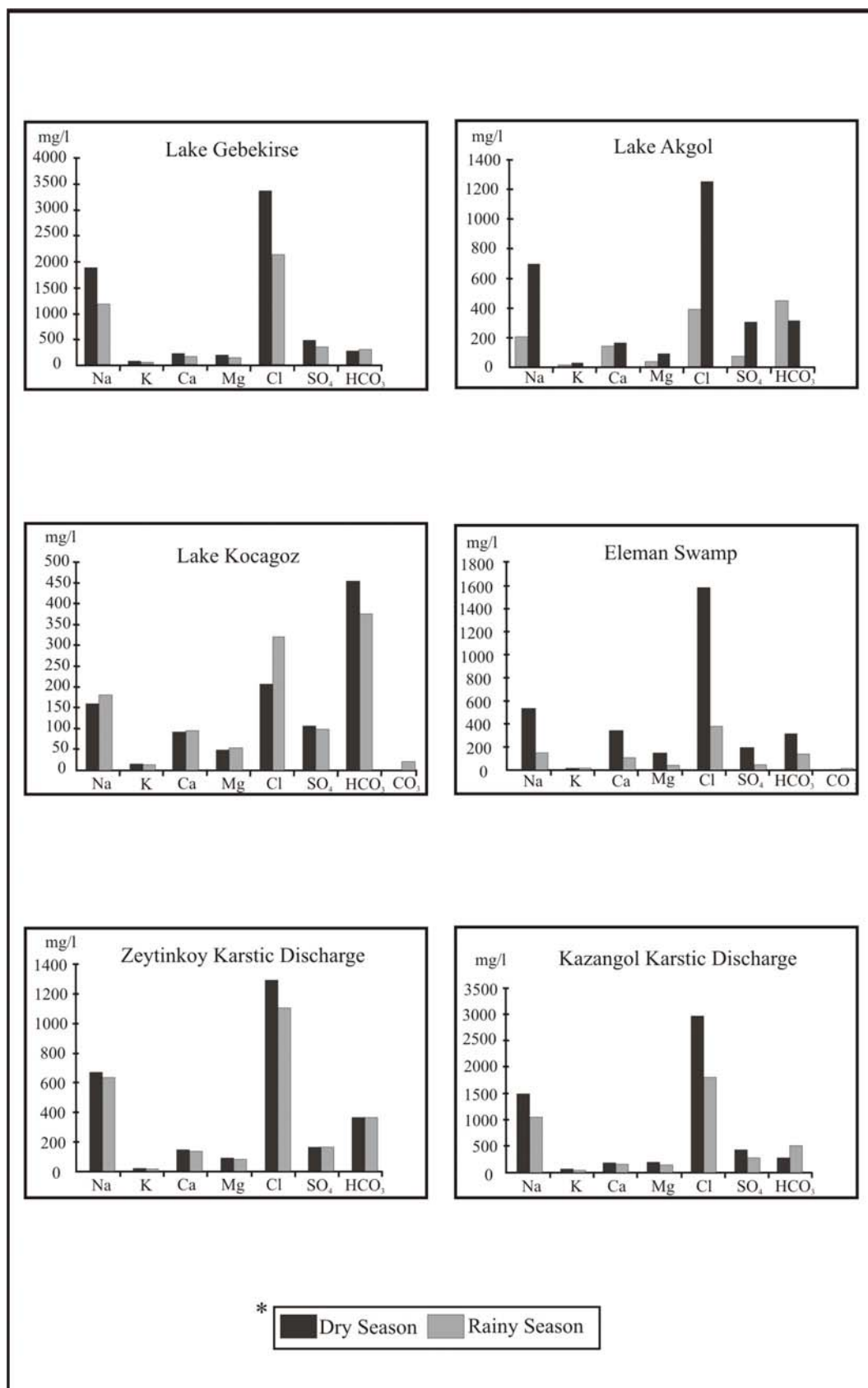


Figure 2.9. Seasonal changes of the major ions in wetland area.

The samples from lakes and swamp occupy a distinct position among the recharge area waters on the Chadha Diagram, 1999 (Figure 2.10). In order to classify the groundwater and to identify the hydrochemical process, Chadha Diagram, 1999 was used. This diagram is a somewhat modified version of the Piper diagram, 1944 and the expanded Durov diagram, 1948. The difference is that the two equilateral triangles are omitted. The water samples plot along the mixing line between sea water and fresh water from recharge area, which are assumed to be typical salt waters in the basin. The relationship between different water bodies and processes influencing their chemical composition was investigated through the use of major ions concentrations versus Cl^- concentration because chlorine is the good indicator for mixing phenomena. Deviation from evaporation line indicates addition or removal of solutes as result of chemical reactions, such as mineral dissolution or precipitation (Marimuthu et al., 2005). It can be clearly seen that there is a good positive correlation between Na and Cl ions ($r^2=0.9$) and between SO_4 and Cl ions ($r^2=0.9$), too (Table 2.2). On the other hand there is a poor correlation between Ca and HCO_3 ions ($r^2=0.02$), Ca and Cl ions ($r^2=0.3$).

The evaluation of the Na contents with respect to Cl contents show, for the majority of the investigated samples, an excess of sodium contents, indicating an external source of sodium, provided there is no halite in the sequence that may have dissolved. At this stage, it should be pointed out that the sodium, chlorine and sulfate are derived from primarily from sea-water intrusion.

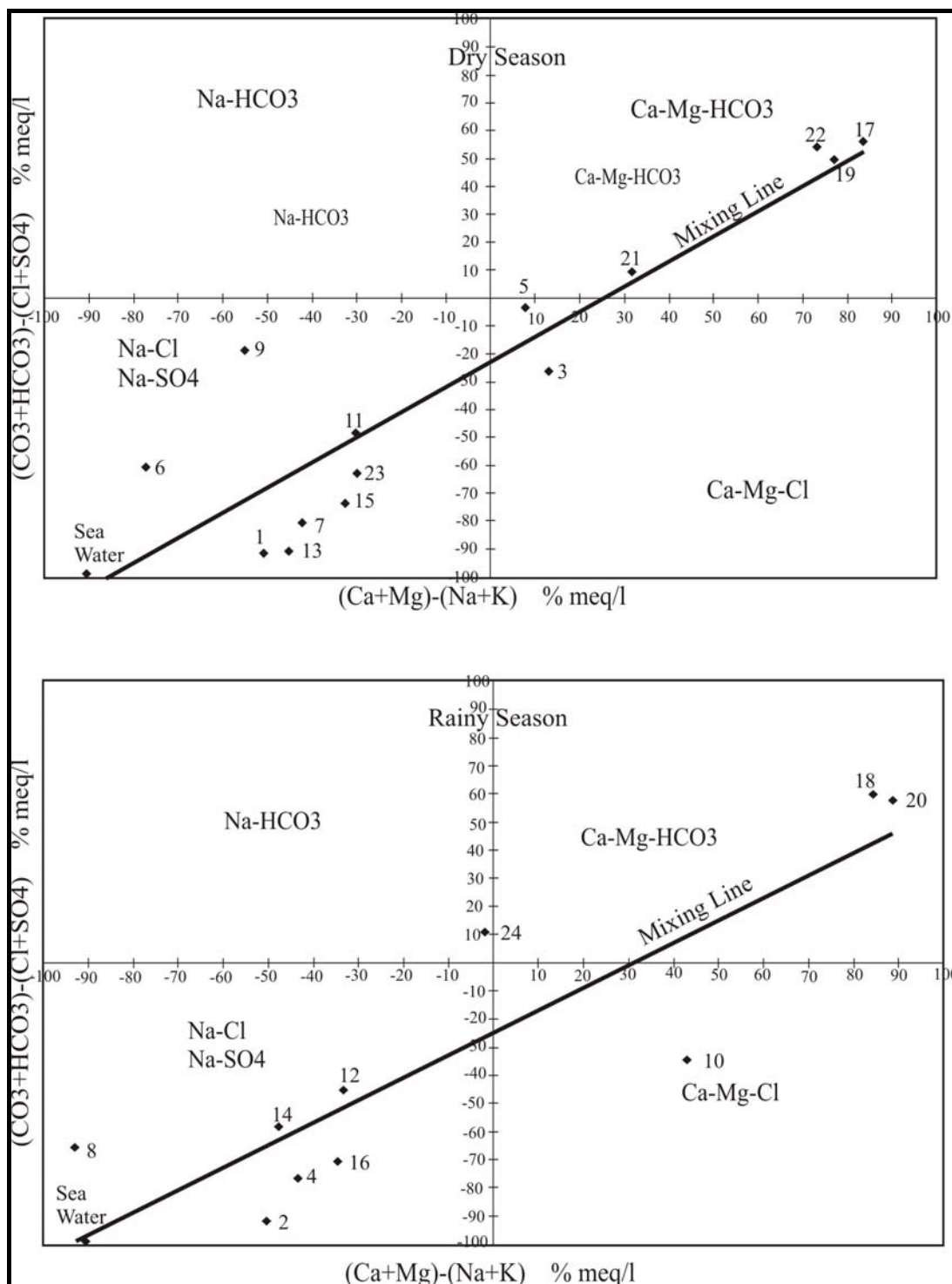


Figure 2.10. Water chemical facies in the study area: (1) Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively. (2) Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. (3) Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. (4) Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions.

* Dry Season: December 2003; Rainy Season: July 2004.

Table 2.2. Correlation matrix of the major ions for wetland area in both dry and rainy seasons.

Dry Season	pH	EC	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻²
pH	1.000								
EC	0.473	1.000							
Na ⁺	0.482	0.998	1.000						
K ⁺	0.504	0.997	0.998	1.000					
Ca ⁺⁺	0.313	0.735	0.708	0.701	1.000				
Mg ⁺⁺	-0.030	0.013	-0.048	-0.023	0.241	1.000			
Cl ⁻	0.467	1.000	0.997	0.996	0.730	0.018	1.000		
HCO ₃ ⁻	0.019	-0.515	-0.495	-0.485	-0.349	-0.286	-0.531	1.000	
SO ₄ ⁻²	0.480	0.986	0.985	0.983	0.787	-0.030	0.983	-0.428	1.000

Rainy Season	pH	EC	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻²
pH	1.000								
EC	0.400	1.000							
Na ⁺	0.386	0.994	1.000						
K ⁺	0.436	0.995	0.991	1.000					
Ca ⁺⁺	0.224	0.769	0.789	0.750	1.000				
Mg ⁺⁺	0.074	0.073	0.094	0.066	0.206	1.000			
Cl ⁻	0.410	0.995	0.995	0.994	0.780	0.133	1.000		
HCO ₃ ⁻	-0.310	-0.333	-0.371	-0.345	-0.212	-0.022	-0.368	1.000	
SO ₄ ⁻²	0.420	0.979	0.987	0.979	0.828	0.133	0.987	-0.390	1.000

2.5.2 Hydrogeochemical Properties of Recharge Area

These water samples were taken from Şirince district (sample 17-18), Virgin Mary house (sample 20) that discharged from both schist and metaolistostrome units and also İzmir and Andon Gorges (samples 21, 22 respectively) that rises from marbles to compare with wetland waters. The pH of waters from marbles and metaolistostrom-schist units are range between 6.83 and 7.77. EC values are under the tolerance limits of both Türk Standartları Enstitüsü (TSE 266, 1997) and Environment Protection Agency (EPA, 2003) drinking water standards with an average 723 μ S/cm value. The major cation is Ca and/or Mg, and the major anion is HCO₃ in itself. The water type of the waters is Ca-HCO₃ type according to International Association of Hydrogeologists (IAH, 1979) except İzmir Gorge due to the proximity of Aegean Sea (Ca-Na-HCO₃-Cl) (Table 2.1).

At the Chadha diagram these waters are plotted in Ca⁺²-Mg⁺²-HCO₃ type in both dry and rainy seasons (Figure 2.10). The correlation between Na and Cl ions show a perfect linear relationship with $r^2 = 0.93$. Also Na and SO₄ ions are a good positive correlation ($r^2 = 0.78$). Ca-HCO₃ and Mg-HCO₃ correlations are given positive relationship, $r^2 = 0.51$ and $r^2 = 0.62$, respectively. Except İzmir Gorge, there is no sea water influence at the recharge area due to the high elevation and formation. The waters are oversaturated with respect to boehmit, calcite, corundum, diaspor, dolomite, gibbsite, illite, K-Feldspar, kaolinite, quartz. All of these results show that the main hydrogeochemical process is weathering the different types of silicates in the recharge area.

According to the TSE 266 (1997) and EPA (2003) drinking water standards all of the recharge area waters do not exceed the tolerance limits except the Zn value of Virgin Mary House drilling well. This is probably a result of the corrosion of metal pipes, because there is no zinc mineralization in and around this site.

2.5.3 The Heavy Metal Distribution and Species of the Wetland Area Waters

All of the wetland waters exceed tolerance limits of CWQG (2005) with high levels of Al, As, Cu, Fe and Se. Zn values are high in the sample 6. In the Eleman Swamp the waters were taken from shallow drilling wells that cause the pipes corrosive so the Zn values are high. The distribution of the different species is explained as follows while the mineral saturation indexes are presented in Table 2.4.

The major species of Al in the wetland area include $\text{AlO}_2^- > \text{HAIO}_2 > \text{Al}_{13}\text{O}_4(\text{OH})_2^{4+7}$ in the lakes, and $\text{AlO}_2^- > \text{HAIO}_2 > \text{Al}(\text{OH})^{+2}$ in the karstic discharges and swamp waters. The waters are saturated with respect to alunite, boehmit, diaspor, gibbsite. The low concentration of Al (mean value in summer: 52.1 ppb, in winter: 84.1 ppb) that not exceed the CWQG (2005), saturated mineral phases that can immobilize and species causing Al to pose no threat to the groundwater and lake waters.

Arsenate ((As(V))) and arsenite ((As(III))) are the main inorganic forms of arsenic. As(V) is more strongly sorbed on to soil and sediment components by $\text{Fe}(\text{OH})_3$ than As(III), making it less mobile (Şahinci, 1991; Ryu et al. 2002). Generally, As(V) dominates in the oxic water, while As (III) is more likely to occur in anoxic water (Rahman et al, 2006). The major specie of As in the wetland area is HAsO_4^{-2} . Under oxidizing conditions, H_2AsO_4^- is dominant at low pH ($\text{pH} < 6.9$); while at higher pH ($\text{pH} > 6.9$), HAsO_4^{-2} becomes dominant (Edet et al. 2003). Because of this situation all alkaline waters are HAsO_4^{-2} type in the study area. On the other hand, total dissolved As concentrations ranged between 0.1 and 183.9 ppb in the study area. As concentrations were strongly correlated with EC values ($r^2 = 0.98$ in both dry and rainy seasons) (Figure 2.11). Arsenic concentrations and EC values suggest that subsurface inflow and evaporation are major factors influencing arsenic distribution in the Lower Küçük Menderes River Basin. The higher arsenic concentration and EC values near the surface further indicate that evaporation is active in concentrating solutes in near surface groundwater (Ryu et al. 2002).

Table 2.3. Some trace and heavy metal content of the water samples (unit=ppb; wetland waters compare with CQEG (2005); n.d: not detected; d: dry , r: rainy season).

Location	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	P	Pb	Sb	Se	U	Zn
1	50	<u>12.8</u>	n.d.	0.53	2.2	<u>37.9</u>	138	36.08	0.6	n.d.	43	6.3	0.32	<u>17.2</u>	1.64	9.9
2	<u>180</u>	<u>8.7</u>	<u>0.35</u>	0.53	1.8	<u>16</u>	137	47.09	0.7	0.3	98	4.7	3.55	<u>31.3</u>	1.52	24.3
3	39	3.6	n.d.	0.26	0.7	<u>5.3</u>	103	41.33	1.1	n.d.	34	2.3	0.37	1.9	1.36	25.7
4	<u>160</u>	<u>7.7</u>	n.d.	0.79	2.6	<u>10.7</u>	<u>464</u>	135.16	1.2	0.2	108	3.9	1.97	<u>20.4</u>	1.58	6.7
5	76	<u>11.1</u>	n.d.	1.31	1.5	<u>7.4</u>	<u>500</u>	549.52	2.6	4	209	2.8	0.42	<u>4.8</u>	0.8	5.8
6	20	5.7	<u>0.22</u>	0.11	3.6	<u>15.6</u>	95	8.32	11.5	n.d.	95	4.2	0.19	<u>8.8</u>	1.3	<u>123.1</u>
7	24	<u>8.2</u>	<u>1.12</u>	0.97	1.8	<u>7.9</u>	<u>325</u>	392.78	0.6	n.d.	64	<u>11.3</u>	0.2	<u>7.3</u>	2.45	19.4
8	38	5.1	<u>0.94</u>	n.d.	0.7	<u>13.4</u>	<u>303</u>	9.6	16.4	0.5	99	6.4	0.2	<u>16.1</u>	1.52	<u>989.3</u>
9	<u>154</u>	<u>28.2</u>	n.d.	3.47	1.4	<u>5.3</u>	<u>1049</u>	2374.1	2.9	11.4	357	1.5	2.58	1.9	5.81	9.1
10	<u>187</u>	<u>6.6</u>	0.08	1.3	1.9	<u>8.0</u>	<u>858</u>	502.65	2	4.9	157	2.5	1.5	2.4	4.84	16.1
11	<u>199</u>	<u>44.2</u>	n.d.	0.96	3.9	<u>11.7</u>	<u>1247</u>	630.36	1.2	0.6	1815	1.2	4.17	<u>11.1</u>	1.69	8.4
12	72	<u>23.1</u>	n.d.	0.74	2.4	<u>4.6</u>	<u>1035</u>	309.73	1.5	2.9	1469	1.5	1.87	<u>6.3</u>	1.22	11.6
13	15	<u>10.6</u>	n.d.	0.51	2.4	<u>20.2</u>	n.d.	1.45	0.6	n.d.	39	4.2	0.2	<u>13.7</u>	1.31	10.6
14	49	<u>7.2</u>	n.d.	n.d.	8.7	<u>4.5</u>	118	0.95	0.6	n.d.	n.d.	n.d.	0.13	<u>16</u>	0.26	0.3
15	19	4.9	n.d.	n.d.	2.9	<u>8.9</u>	16	0.64	0.4	n.d.	94	1.5	0.29	<u>19.4</u>	1.2	6.6
16	14	n.d.	n.d.	n.d.	n.d.	<u>4.9</u>	n.d.	3.46	n.d.	n.d.	n.d.	n.d.	n.d.	<u>19.5</u>	1.18	7.9
*17	1	0.5	0.15	n.d.	0.7	4.5	n.d.	0.4	n.d.	n.d.	n.d.	1.5	0.14	0.4	0.64	6.4
*18	13.5	0.5	n.d.	n.d.	1.2	10.3	130	0.5	n.d.	0.5	n.d.	0.9	0.09	0.4	0.67	21.7
*19	8	1.3	n.d.	n.d.	0.8	2.3	n.d.	0.68	0.4	1.4	34	1.1	0.17	0.7	1.69	3
*20	9	0.5	n.d.	0.05	0.9	10.6	225	2.32	n.d.	2.8	n.d.	1.2	0.15	0.4	0.47	1019.6
*21	11	2.3	n.d.	n.d.	1.1	2	n.d.	0.57	n.d.	0.7	21	0.4	0.14	2.5	0.75	3.1

Table 2.3. (Continue). Some trace and heavy metal content of the water samples (unit=ppb; wetland waters compare with CQEG (2005); n.d: not detected; d: dry , r: rainy season).

*22	20	1.1	n.d.	n.d.	1.0	3.9	n.d.	1.24	n.d.	2.0	43	2.6	0.15	0.9	0.68	7.5
23	<u>250</u>	<u>22.4</u>	<u>0.51</u>	1.05	3.8	<u>13.3</u>	<u>893</u>	262.13	1.4	2.9	655	4.5	1.42	<u>5.8</u>	2.22	<u>356.4</u>
24	<u>1097</u>	<u>10.2</u>	0.10	2.89	3.5	<u>8.9</u>	<u>1604</u>	245.09	0.2	8.1	2456	5.8	4.92	1.2	0.83	22.3
SW	<u>121</u>	<u>84.1</u>	n.d.	n.d.	n.d.	<u>75.3</u>	n.d.	n.d.	10.6	n.d.	n.d.	<u>13.3</u>	n.d.	<u>223.4</u>	3.49	13.2
CWQG,2005	5-100	5	0.12	-	1-8.9	2-4	300	-	73	25-150	-	1-7	-	1.0	-	30
*TSE, 1997	50-200	50	5		50	20-50	50-200	20-50		50		10	10	10	-	100-5000
*EPA, 2003	50-200	10	5	-	100	1300	300	50	-	-	-	15	6	50	30	5000

Table 2.4. The mineral saturation indexes of the wetland area waters (all abbreviations* for minerals follow Kretz, 1983).

Location	Ab	Alun	Bar	Boe	Cal	Cha	Crn	Daw	Dsp	Dlt	Fe(OH) ₃	Gbs	Goe	Gy	Ill	Kfs	Kaol	Qtz	Tlc
1	-2.33	-7.78	-0.07	0.99	1.15	-1.35	-1.03	0.21	1.38	3.71	1.18	0.74	6.17	-1.18	-0.42	-1.14	0.08	-1.08	1.25
2	1.83	-1.18	0.33	2.38	0.25	-0.06	1.31	1.94	2.80	1.73	-0.05	2.28	5.26	-1.39	6.32	3.38	5.60	0.23	-0.54
3	2.41	-2.02	0.49	2.41	0.65	0.10	1.34	1.96	2.84	2.36	0.41	2.32	5.74	-1.35	7.04	3.90	5.99	0.39	1.02
5	0.39	1.14	0.13	2.67	-0.30	-0.10	2.08	1.52	3.08	0.50	0.96	2.50	6.12	-1.69	5.59	2.19	6.03	0.17	-5.73
6	0.77	-7.26	0.37	1.05	0.66	-0.16	-1.02	0.67	1.44	2.87	0.76	0.83	5.81	-2.08	3.31	2.03	2.62	0.11	2.32
8	1.53	-5.20	0.27	1.58	0.01	-0.04	-0.04	1.28	1.98	1.46	1.06	1.39	6.17	-2.55	4.64	2.78	3.95	0.23	-0.03
13	0.20	-1.15	-0.03	1.87	-0.12	-0.32	-6.29	1.25	2.27	1.19	-1.54	1.67	3.56	-1.23	3.78	1.56	3.96	-0.05	-2.94
14	1.18	0.30	-0.17	2.50	0.15	-0.17	1.69	2.17	2.91	1.65	-0.28	2.34	4.91	-1.39	5.71	2.62	5.56	0.11	-2.82
15	0.43	0.14	-0.20	2.29	-0.23	-0.18	1.31	1.62	2.70	0.69	-1.91	2.12	3.25	-1.46	4.63	1.77	5.12	0.10	-5.12
16	0.39	-1.39	-0.24	2.04	-0.03	-0.19	X	1.38	2.45	1.10	X	1.89	X	-1.51	4.31	1.77	4.62	0.09	-3.83
17	-3.19	-11.4	-1.59	0.63	0.44	-0.59	-1.81	-2.38	1.03	1.70	X	0.41	X	-2.52	-0.35	-1.41	0.91	-0.33	-1.12
18	0.19	-4.46	-1.18	2.05	-0.16	0.30	0.67	-0.52	2.47	0.38	-0.10	1.94	5.19	-2.37	5.47	2.39	5.66	0.59	-2.76
20	-0.43	-3.98	-1.12	2.04	-0.02	0.14	0.61	-0.16	2.47	0.91	0.11	1.95	5.43	-2.04	4.41	1.14	5.34	0.43	-3.71

(*Abbreviations: Ab=Albite, Alun=Alunite, Bar=Barite, Boe=Boehmite, Cal=Calcite, Cel=Celadonite, Cha=Chalcedony, Crn=Corundum, Daw=Dawsonite, Dlt=Dolomite, Gbs=Gibbsite, Gy=Gypsum, Ill=Illite, Kfs=K-Feldspar, Kaol=Kaolinite, Qtz=Quartz, Tlc=Talc.)

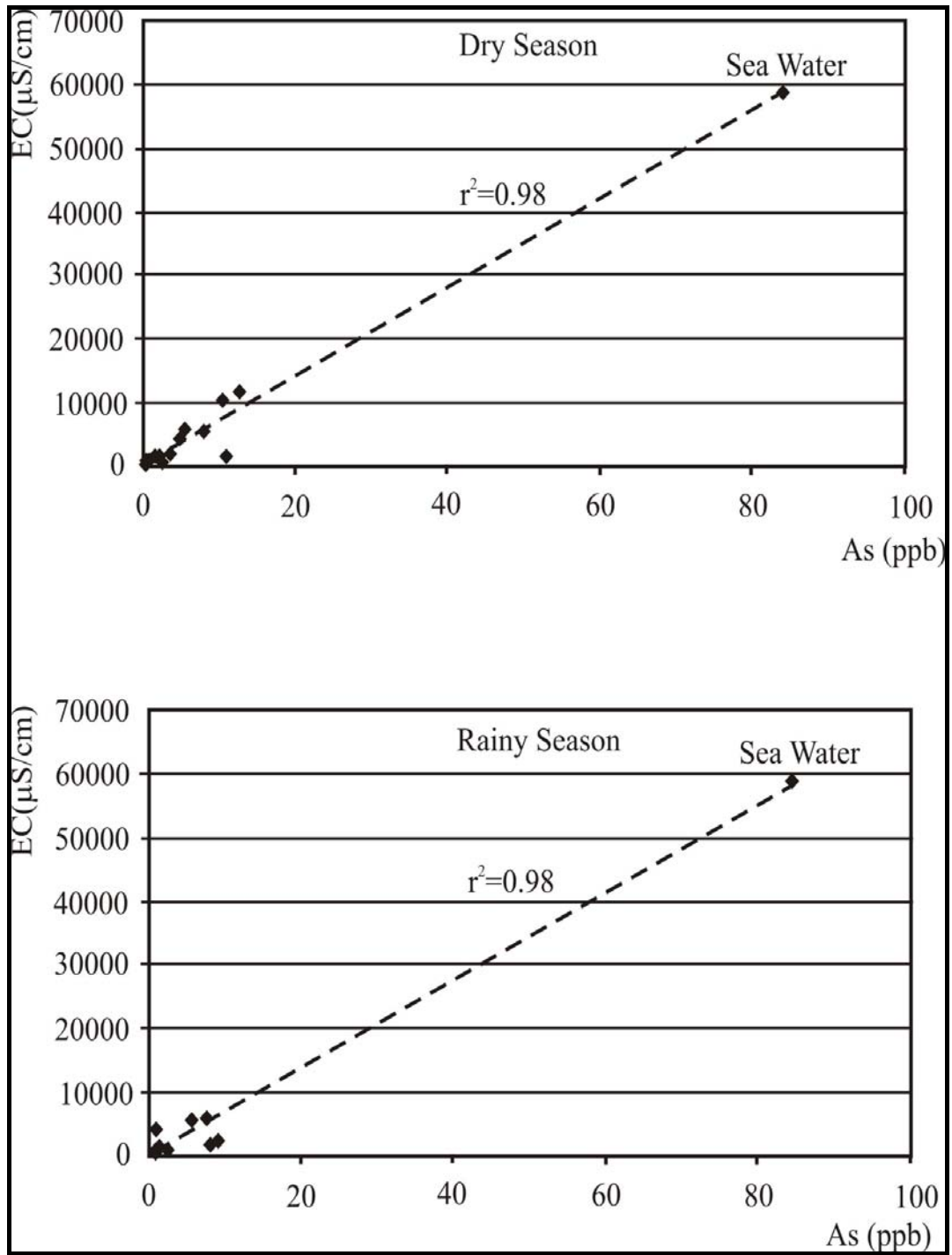


Figure 2.11. Relationship between arsenic and EC in dry and rainy seasons.

Cu^{+2} that is formed as CuCO_3 is the main ionic species in the area. Cu can be interacted with organic matters (Şahinci, 1991). The waters are saturated with CuCr_2O_4 and ferrite Cu (CuFe_2O_4). Cu values for the wetland waters' exceed the CWQG (2005) with an average of 15 ppb. In fact, it is well established that iron and manganese oxy-hydroxides can absorb Cu and Zn. Cu is known to form strong dissolved organic complexes and organic matter was shown to play an important role in complexing Cu elsewhere (Stumm and Morgan, 1996; Elbaz-Paulichet et al. 1999).

It is a known fact that Fe^{+2} components are more abundance than Fe^{+3} components in the groundwater. In the surface waters, due to the existent of O_2 , Fe is soluble more less and it is seem to be supersaturated to Fe^{+3} -hydroxides and hematite (Şahinci, 1991). Fe^{+3} ions are present in oxic waters (Rahman et al. 2006). Dissolved Fe^{+2} ions are oxidizing with iron bacteria and $\text{Fe}(\text{OH})_3$ is precipitated. Although the solubility products of Fe-oxides do not allow explaining how the reductive dissolution of these phases may have occurred in the wetlands undergoing such physico-chemical conditions, organic compounds favor the reduction of Fe(III) oxy-hydroxides (Deng and Stumm, 1993), and so the Fe release in solution (Olivie-Lauquet, et al. 2001). The over saturation of the mineral phases containing iron includes CuFeO_2 , goethite, hematite, and magnetite. In the wetland area except karstic discharges, the major species of Fe is Fe^{+3} representing more than Fe^{+2} . On the other hand, the concentration of Fe clearly exceed the tolerance limit of CWQG (2005) (>300ppb) in the Küçük Menderes River, Eleman Swamp and Lake Kocagöz.

The chemistry of Mn is somewhat like that of iron in that both metals precipitate in redox processes in weathering environment (Hem, 1985). In the wetland area, Mn is more than 80% is in the ionic form as Mn^{+2} with about %10 MnCO_3 and 5% MnSO_4 . Especially in the lakes dissolved organic matters may emancipate Mn^{+2} . According to Aguilar and Nealson 1998; in the lakes Mn is removed from the water column in the spring via conversion to particulate form and deposited in the bottom sediment and this removal is due to biological factor. During summer months the Mn from microbial reduction moves from the sediment to the water column. So in the Lake Gebekirse and Akgöl sediments'

content Mn is more abundance than other elements such as Cu, Zn, Pb, Ni (Figure 2.12) and in addition the sediment and water trends are similar. From what has been discussed above, we may safely draw the conclusion that Mn^{+2} is not mobile in the present condition, it does not pose a problem in the wetland area.

Selenium transformation and transitioning in natural aquatic systems are influenced by site-specific hydrogeochemical and biological processes including the source and removal pathways, biological productivity in the water (Fan et al. 1997) and sediment (Oremland, 1994) compartments, and alkalinity and oxidization potential (Masscheleyn et al. 1991). Selenium occurs in oxidizing solutions as selenite (SeO_3^{-2}) or selenate (SeO_4^{-2}) ionic species in the groundwater (Hem, 1985). Selenium is mobile as the selenate oxyanion under oxidizing conditions but is immobilized under reducing conditions either due to the stronger adsorption of its reduced form, selenite, or due to its reduction to the metal (Smedly and Kinniburgh, 2002) and Selenium concentrations are in a linear proportion with organic matters and iron (Şahinci, 1991). So the major species of Se is Se^{+4} with a selenite form in the wetland area.

On the other hand, dissolved selenium speciation as a function of salinity (EC: $\mu\text{S}/\text{cm}$) in the both wetland and recharge area, with straight lines showing perfect linear regression given in Figure 2.13. In addition it is clearly seen that the selenium concentrations decrease while the temperature and EC values increases.

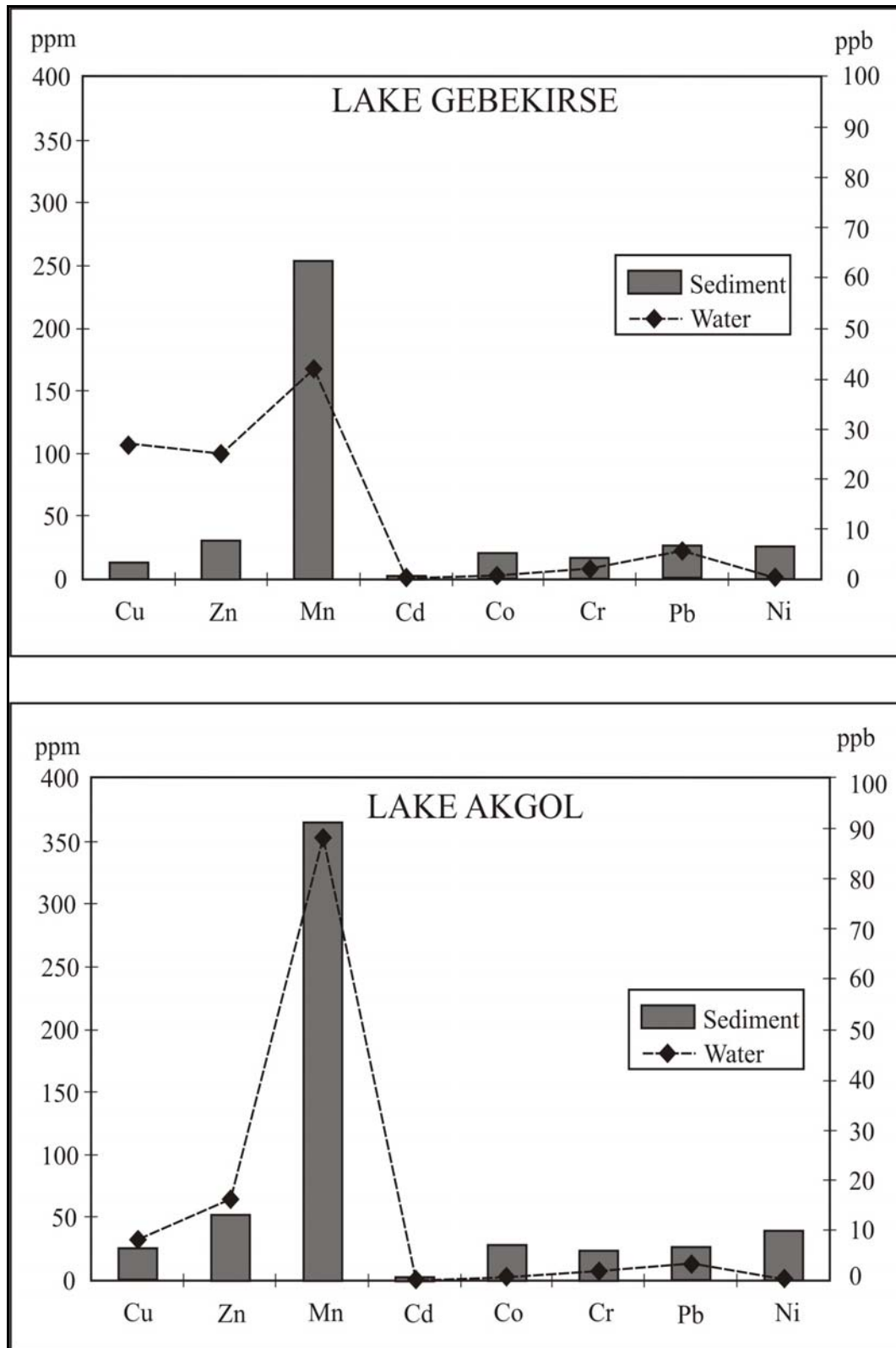


Figure 2.12. Some metal contents of both sediment and waters in Lake Gebekirse and Akgöl. (sediment data was taken from Egemen, 2005).

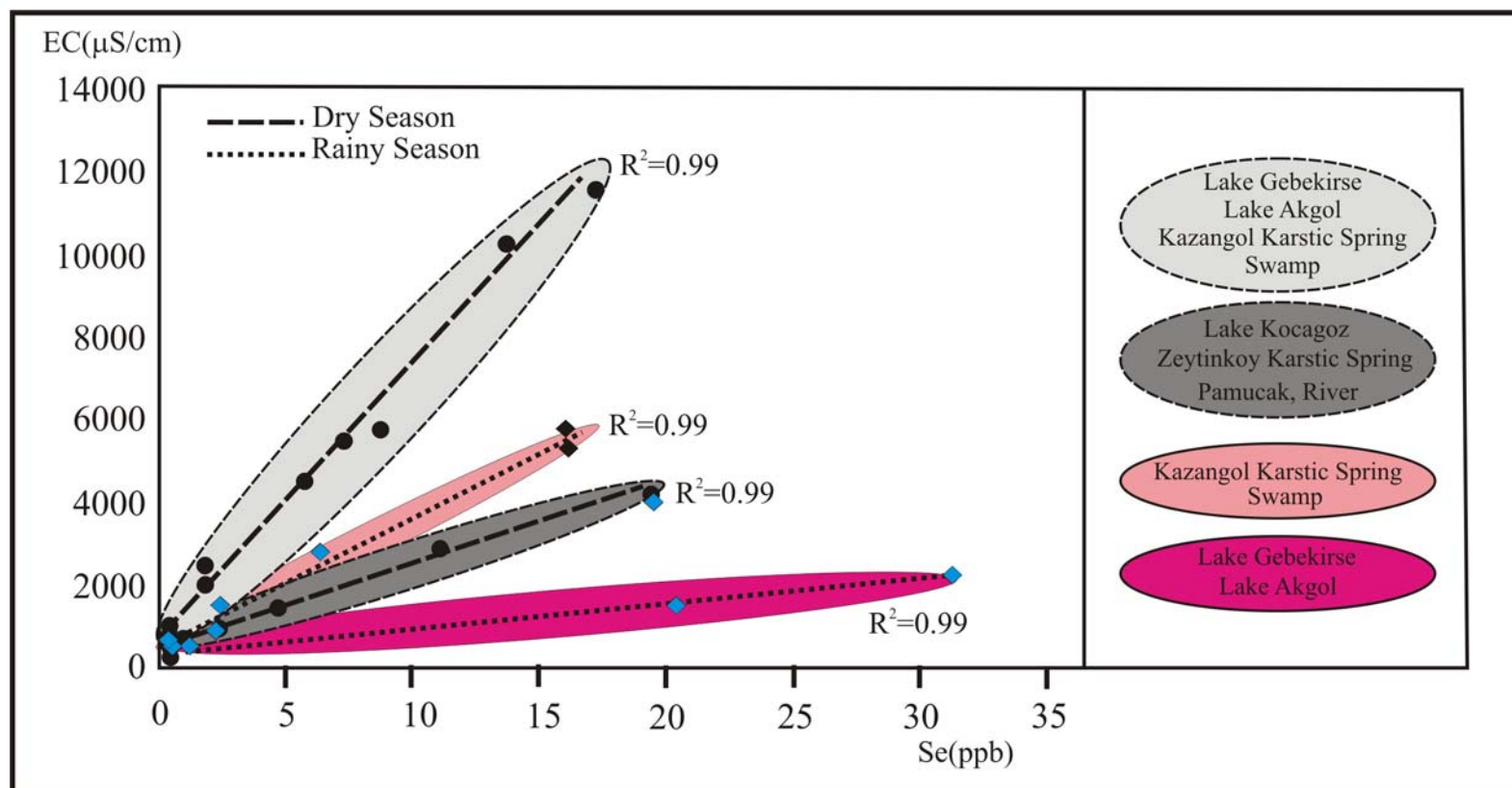


Figure 2.13. Relationship between total selenium and EC in dry and rainy seasons.

2.6 Contamination Risk of Selçuk Plain

Selçuk Plain is the last sub-basin of Küçük Menderes River Basin. River rises from Beydağ and passes through Ödemiş, Tire, Torbalı and Belevi. Belevi is the last settlement that the river passes. But this river is collected very different types of contamination from the industrial zones (e.g. Tire, Torbalı etc.). To investigate the contamination level of Küçük Menderes River 8 additional samples were taken (Figure 2.14 and Table 2.5).

According to these data, the water type is changed from Mg-Ca-HCO₃-SO₄ to Na-Ca-HCO₃-Cl (from Beydağ to Torbalı). pH values are 8.0 approximately known as slightly alkaline waters. The EC values are increased from the rising point, Beydağ to Belevi such as from 537 to 1534 µS/cm due to the releasing waters from the industrial zones in Tire and Torbalı.

There are several industrial zones around Küçük Menderes River. Due to the lack of treatment systems at these factories, the waste waters are released to the river and an environmental problem occurs (Figure 2.15). The heavy metal contents of the river waters are given in Table 2.6.

Aluminum, arsenic, cadmium, chrome, copper, iron, manganese, lead and antimony content of the river waters were analyzed. Al content of the river waters are exceeds the tolerance limits of both TSE 266 (1997) and EPA (2003) drinking water standards. Sources of Al can be from both industrial and from mining activity near the Küçük Menderes River (e.g. Beydağ and Tire Hg mining etc.). Arsenic levels of the waters are range between 5.6 to 75.8 ppb and the high levels are seen from Tire to Torbalı. High arsenic levels are caused by mining byproduct, pesticides and chemical wastes (Manahan, 2000) and it is valid for the Küçük Menderes River waters. Arsenic is a toxic element that damages the living organism. Iron values of the river waters are exceeded the drinking water standards more ten times. The sources of iron are; industrial wastes and microbial action and also mining products. In addition to high iron level, manganese levels are exceeded the standards with twelve times. Mn is caused by industrial wastes and microbial actions, too.

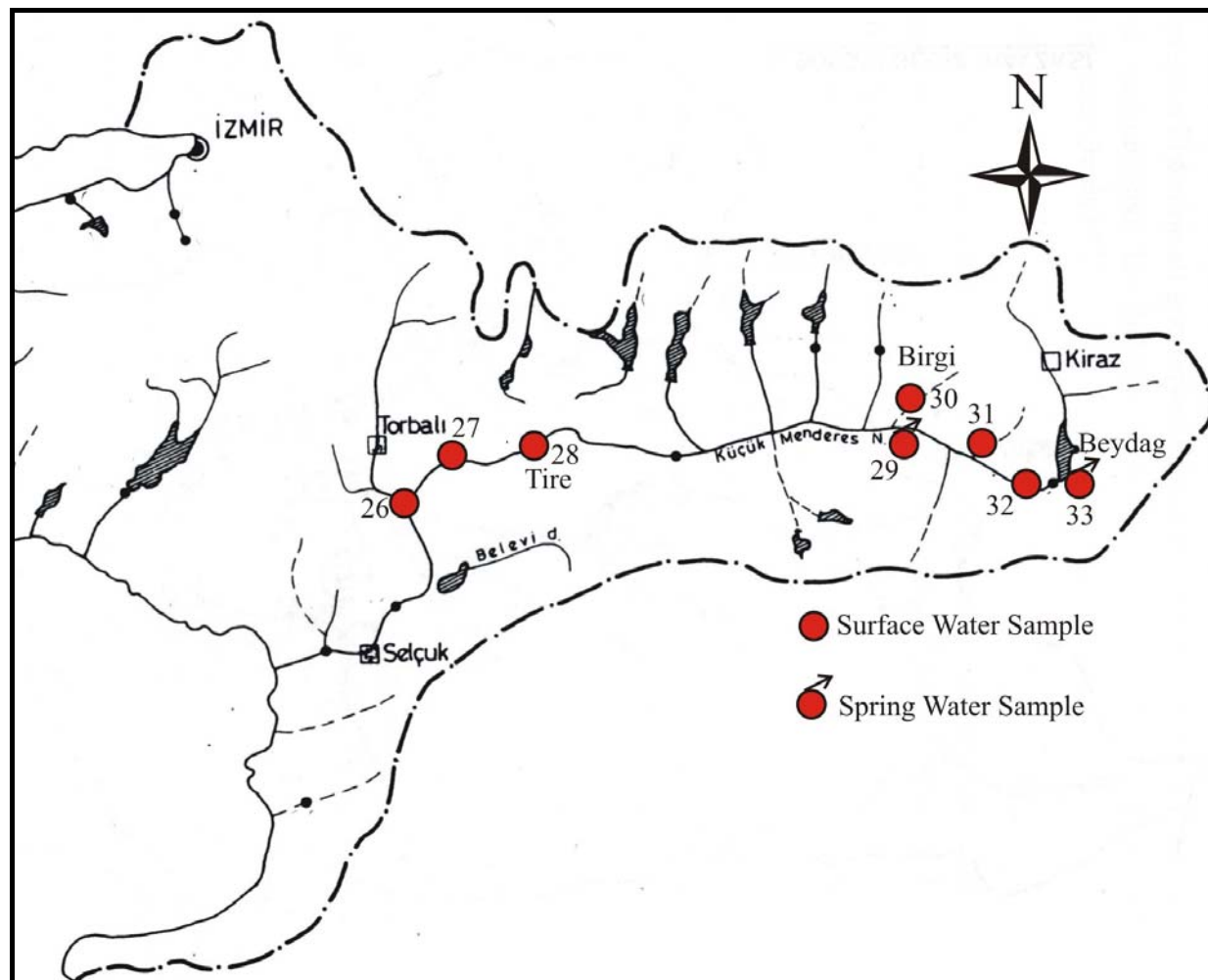


Figure 2.14. Sample location map of the Küçük Menderes River.

Table 2.5. Some chemical and physical properties of Küçük Menderes River (KMR).

NO	Coordinate		EC $\mu\text{S/cm}$	pH	Na^+ (mg/l)	K^+ (mg/l)	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	Cl^- (mg/l)	HCO_3^- + CO_3^{-2}	SO_4^{-2} (mg/l)	Water Type (IAH, 1979)
	X	Y										
26	0536870	4218585	1534	8.0	179	13	91.0	36.0	198	478.2	100	Na-Ca- HCO_3 -Cl
27	0546505	4219269	1853	7.8	193	35	105.5	27.1	250	507.5	12	Na-Ca- HCO_3 -Cl
28	0562770	4221771	1524	7.6	1356	30	85.8	23.3	178	517.7	21	Na-Ca- HCO_3 -Cl
29	0590692	4233682	230	7.3	9	3	18.6	8.9	10	87.8	27	Ca-Mg- HCO_3 - SO_4
30	0593324	4235146	393	7.9	16	5	34.9	18.3	12	178.1	60	Ca-Mg- HCO_3 - SO_4
31	0605508	4218090	759	6.6	69	21	57.0	14.3	96	231.8	33	Na-Ca- HCO_3 -Cl
32	0606314	4216874	537	7.9	21	7	37.9	28.3	23	229.4	66	Mg-Ca- HCO_3 - SO_4
33	0606041	4216101	236	6.9	11	3	21.6	6.4	12	93.2	24	Ca-Mg-Na- HCO_3 - SO_4

Table 2.6. Heavy metal contents of the Küçük Menderes River waters (units are ppb; italic and underlined numbers represent the exceeded values; n.d. not detected).

Locations	#	Al	As	Cd	Cr	Cu	Fe	Mn	Pb	Sb
Torbalı Bridge KMR	26	<u>472</u>	<u>75.8</u>	0.10	8.4	11.6	<u>2066</u>	<u>970.9</u>	3.1	0.90
Rahmanlar Bridge KMR	27	<u>683</u>	<u>39.5</u>	0.07	14.8	6.3	<u>3029</u>	<u>277.1</u>	2.2	3.88
Tire KMR	28	<u>103</u>	<u>19.6</u>	0.09	9.0	<u>40.1</u>	<u>462</u>	<u>294.6</u>	3.2	2.31
Küçükavulcuk Spring	29	14	1.9	0.06	3.0	4.7	63	2.8	0.9	n.d.
Birgi KMR	30	<u>989</u>	6.6	n.d.	4.9	4.7	<u>2403</u>	<u>94.7</u>	1.0	0.60
Beydağ KMR	31	43	9.5	0.07	3.5	<u>32.8</u>	<u>2114</u>	<u>404.1</u>	5.0	0.44
Tasavra KMR	32	<u>299</u>	5.6	0.06	4.6	5.4	<u>1027</u>	<u>121.6</u>	1.4	0.36
Beydağ Spring	33	29	0.9	n.d.	2.9	2.3	20	3.0	0.6	0.09
	TSE 266 (1997)	50-200	50	5	50	20-50	50- 200	20-50	10	10
	EPA 2003	50-200	10	5	100	1300	300	50	15	6

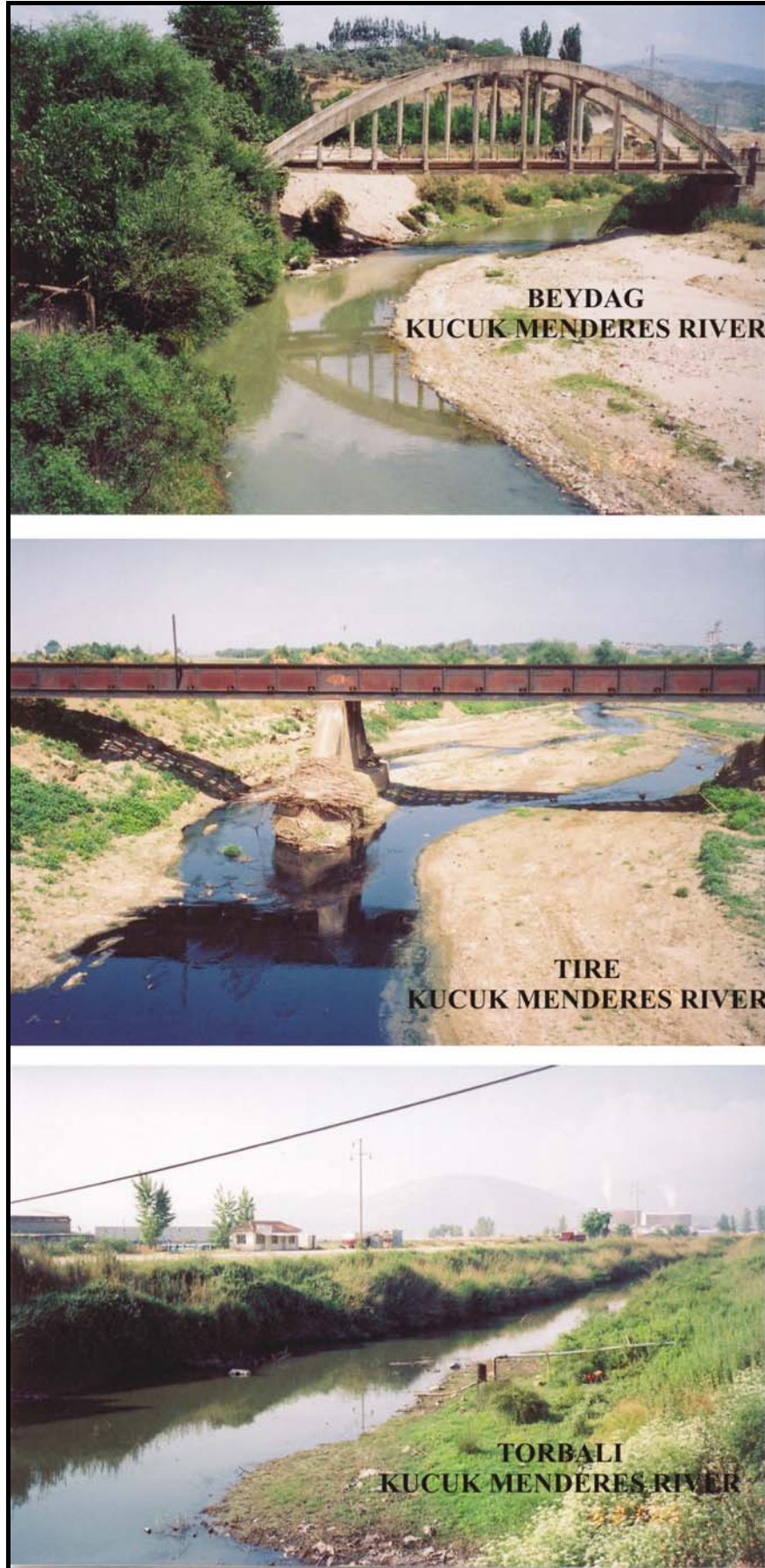


Figure 2.15. Küçük Menderes River.

Heavy metal content of the wetlands waters not only lakes, swamp and karstic discharges but also the irregular waste disposal site of Selçuk and treatment waters that release to Küçük Menderes River were investigated. This site is located in between Lake Gebekirse and Selçuk airport near the Ancient Ephesus (Figure 2.16). All of the domestic wastes were storage in the one of the oxbow channel of the Küçük Menderes River. In the disposal site, all of the domestic wastes of Selçuk are laid up in one of the oxbow channel of Küçük Menderes River, center of the plain (Figure 2.8). There has been no study about this site.

The second risk factor is treatment water plant of Selçuk Municipality. This site is located between Andon Gorge and Küçük Menderes River. There are 2 ponds for precipitating the heavy metals of waters. After this process this purified water releases to the river. According to analyses of Environment Protection Foundation of Environment Laboratory results, chemical oxygen demand (COD) values are 106-111 mg/l (max: 100 mg/l), biologic oxygen demand (BOD) values are 48-76 mg/l (max: 50 mg/l), and suspended solute matter values are 72-73 mg/l (max: 45 mg/l) in dry season of 2004. All of the values are exceeded the tolerance limits of Water Regulations of Turkey (Su Kirliliği Yönetmeliği, 2004). Two of these sites are sampled due to these reasons. The results are represented in Table 2.3. These waters are appraised with CWQG (2005) because they are in wetland system. Al, As, Cd, Cu, Fe, Se, and Zn values of these sites are clearly exceeded the tolerance limit.

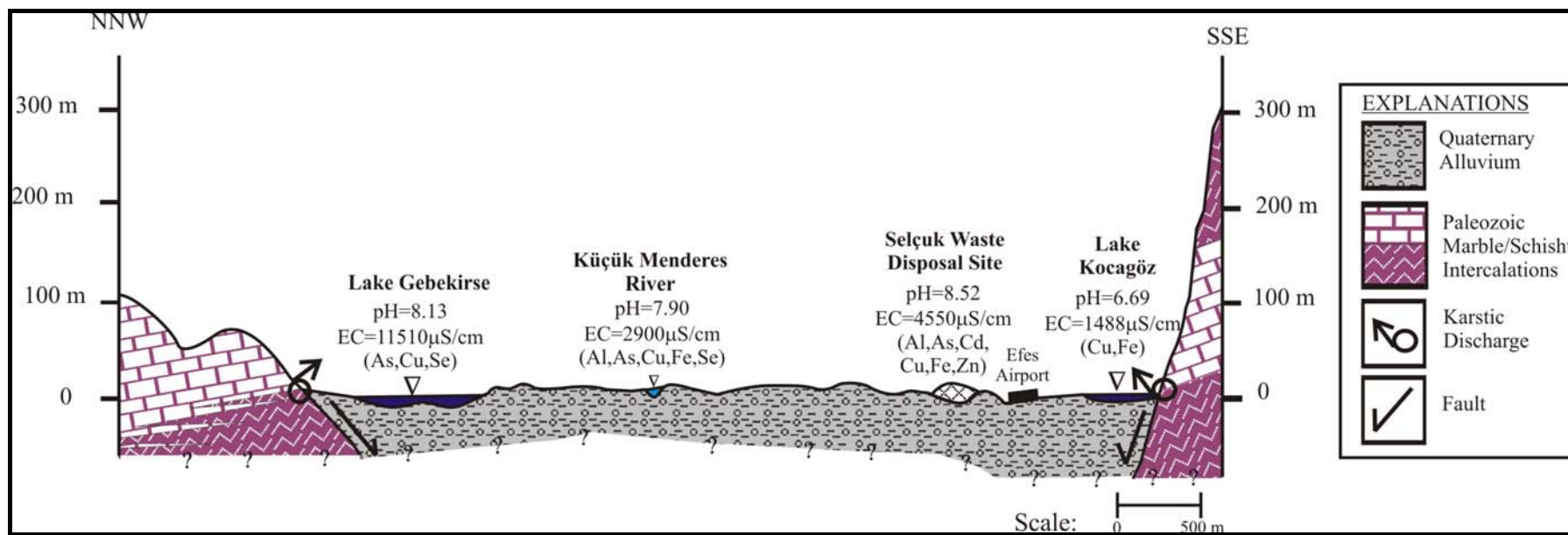


Figure 2.16. A cross-section from the study area that represent some chemical properties.

2.7 Conclusion

Küçük Menderes River wetland is a coastal wetland that consists of 3 lakes (Lake Gebekirse, Lake Akgöl and Lake Kocagöz) and swamp (Eleman Swamp) in Selçuk district, İzmir, Turkey. Not only presence of wetland but also presence of Ancient Ephesus and Virgin Mary House have raised the value of this site.

The lakes, swamp, karstic springs that recharge the lakes and recharge-hilly area (Şirince, Virgin Mary House, İzmir and Andon Gorges) are sampled to determine the recharge and discharge boundaries, and to compare with waters in a hydrological basin.

In the Selçuk district average annual precipitation is about 689.2mm while the mean annual evapotranspiration is 868.4mm, which is estimated as “drought” according to Thornthwaite Method (1948) and the mean temperature is 16 °C that indicates a Mediterranean climate.

The lakes are alkaline type with 8.00-7.50 pH values. EC values are more than recharge area that can be reached 11510 µS/cm for Lake Gebekirse because of seawater intrusion from karstic structures to the lake. The water types (according to IAH 1979) from sea to the recharge area change from Na-Cl to Na-Ca-Cl-HCO₃, Ca-Mg-HCO₃-SO₄-Cl and Ca-Mg-HCO₃. At the Chadha diagram wetland waters are plotted on the mixing line. According to the correlation coefficient between Na-Cl, Na-SO₄ and Cl-SO₄ ($r^2=0.99$) it can be clearly said that these ions are derived from seawater intrusion and evaporation in the wetland. The recharge area waters are characterized with their low EC values (<1000 µS/cm), neutral pH and Ca-Mg-HCO₃ water types except İzmir Gorge (Ca-Na-HCO₃-Cl) due to the proximity to the Aegean Sea. These waters are oversaturated with respect to boehmit, calcite, corundum, diaspor, dolomite, gibbsite, illite, K-Feldspar, kaolinite, quartz that show the main hydrogeochemical process is weathering of the different types of silicates in the recharge area.

According to heavy metal ion species that was calculated by PhreeqCi computer code (Parkhurst and Appelo, 1999), the major species of Al include AlO_2^- > HAlO_2 > $\text{Al}_3\text{O}_4(\text{OH})_2^{4+7}$ in the lakes; the major species of As is HAsO_4^{2-} ; Cu^{+2} that is formed as CuCO_3 is the main ionic species; the major species of Fe is Fe^{+3} ; Mn is more than 80% is in the ionic form as Mn^{+2} with about %10 MnCO_3 and 5% MnSO_4 ; major species of Se is Se^{+4} with a selenite form in the wetland area. These species are similar properties with other studied same characterized lakes. Also wetland waters are saturated with respect to albite, barite, boehmite, calcite, chromite, CuCr_2O_4 , dawsonite, dolomite, $\text{Fe}(\text{OH})_3$, gibbsite, goethite, illite, k-feldspar, kaolinite, MnHPO_4 , quartz, witherite. It can be clearly understood that the main components of the wetlands waters are Na-Al silicates, Na-Al carbonates, Ba sulfate are due to sea-water intrusion processes, and $\text{Fe}(\text{OH})_3$ and MnHPO_4 that are due to the high biological activities. According to heavy metal values in whole wetland, copper, selenium and iron (except Lake Gebekirse) ions are exceed the tolerance limits of CWQG (2005) aquatic life standards (Table 2.3). In addition to these sample points two different locations were sampled the risk of high heavy metal content: i) Selçuk waste disposal site that is located on the oxbow channel of Küçük Menderes River, center of the Selçuk plain; ii) Selçuk municipality water treatment foundation is located Küçük Menderes River and discharged the treatment water to the river. In the highlight of the heavy metal values the aluminum, arsenic, copper, iron and zinc concentrations exceed the standards limits in both places.

CHAPTER THREE

SALINIZATION PROCESS IN THE SELÇUK PLAIN

Salinization is the major problem for supplying the fresh water to the local people. In this chapter the salinization process or processes have been discussed by hydrogeochemical data as major and minor ion ratios.

3.1 Introduction

Salinization of the groundwater is the major problem in the coastal aquifers of Turkey especially due to excessive pumping of groundwater for agricultural purposes. When development for agriculture or public water-supply are based on water extracted from a coastal aquifer in a semiarid area, other sources of salinity can contribute to salinization of extracted groundwater (Carnoda et al, 2004). In the coastal plains, understanding of the origin of salinization it is necessary to differentiate sources and establish their importance in the salinization process.

Selçuk plain is located in 65 km south of İzmir city, in the western part of Turkey (Figure 3.1). It is the wave-dominant delta of Küçük Menderes River. One swamp (Eleman swamp) is covered 45% of this plain. This swamp has saline soil in itself (DSİ, 1990a). On the other hand, another part of Selçuk plain is used for agricultural purposes.

Salinization is the most widespread form of water contamination, and leads to an increase in the content of certain dissolved chemical species, as well as the overall chemical water composition (Richter and Kreitler, 1993). Salinization in the Selçuk Plain may be caused by a single process or combination of different processes; sea water intrusion (Aegean Sea), high rate of an evapotranspiration 868.4mm, return flow from irrigation water and leakage waste water from disposal site that is located center of the plain, and/or treatment waters of Selçuk municipality. On the other

hand, existence of an extensive wet zone (Küçük Menderes River Coastal Wetland: Eleman swamp, Lake Gebekirse, Lake Akgöl, Lake Kocagöz); the silt clay deposits that make up the zone, as well as water with a high salt content, are clearly determinants in the hydrogeochemical situations of the system. This is temporary inundated area, with abundant vegetations that are published by Kara, 1997 and Secmen & Gemici, 1997; *Salicornia europea*, *Juncus acutus*, *Chenopodium* sp., and *Limnium bellidifolium*, *Ammophillia arenaria*, *Sporobolus virginicus*, *Pancratium maritimum*, *Glyceria distans*, *Elymus elongates* ssp., *Glycyrrhiza globra*, and these vegetations are a kind of indicator for the salinization.

Use of natural tracers has been revealed as one of the most efficient tools to understand the mechanism of groundwater mineralization in coastal aquifers (Morell et al, 1986; Fidelibus and Tulipano, 1986; Vengosh et al, 1996; Andreasen and Fleck, 1997; Fakir, 2002). In general using the major ions to characterize the salinization sources are common all around the world. In addition, in the recent years the minor ion composition of the waters (Li, Br, B, Sr etc) can be used for the identification of salinization process by some authors as Petalas and Diamantis, 1999; Sanches-Martos and Pulido-Bosch, 1999; Cruz and Silva, 1999; Sanches-Martos et al, 2002; Faye et al, 2004. In this paper; Na/Cl, SO₄/Cl, Mg/Ca, Na/Ca, Br/Cl, Sr/Ca ionic ratios were used to distinguish different salinization sources. Two end members were chosen to determine the sea water intrusion and/or hydrogeochemical evaluation. The progressive salinity increases from hilly area (Şirince, Acarlar, Belevi) to coastal area and the occurrence of sea water in the Selçuk Plain suggests a mixing modal between these two end members: a low salinity groundwater (hilly area) and a high salinity water (local seawater). As information regarding the composition of local sea water was taken for this study in Aegean Sea of Pamucak beach.

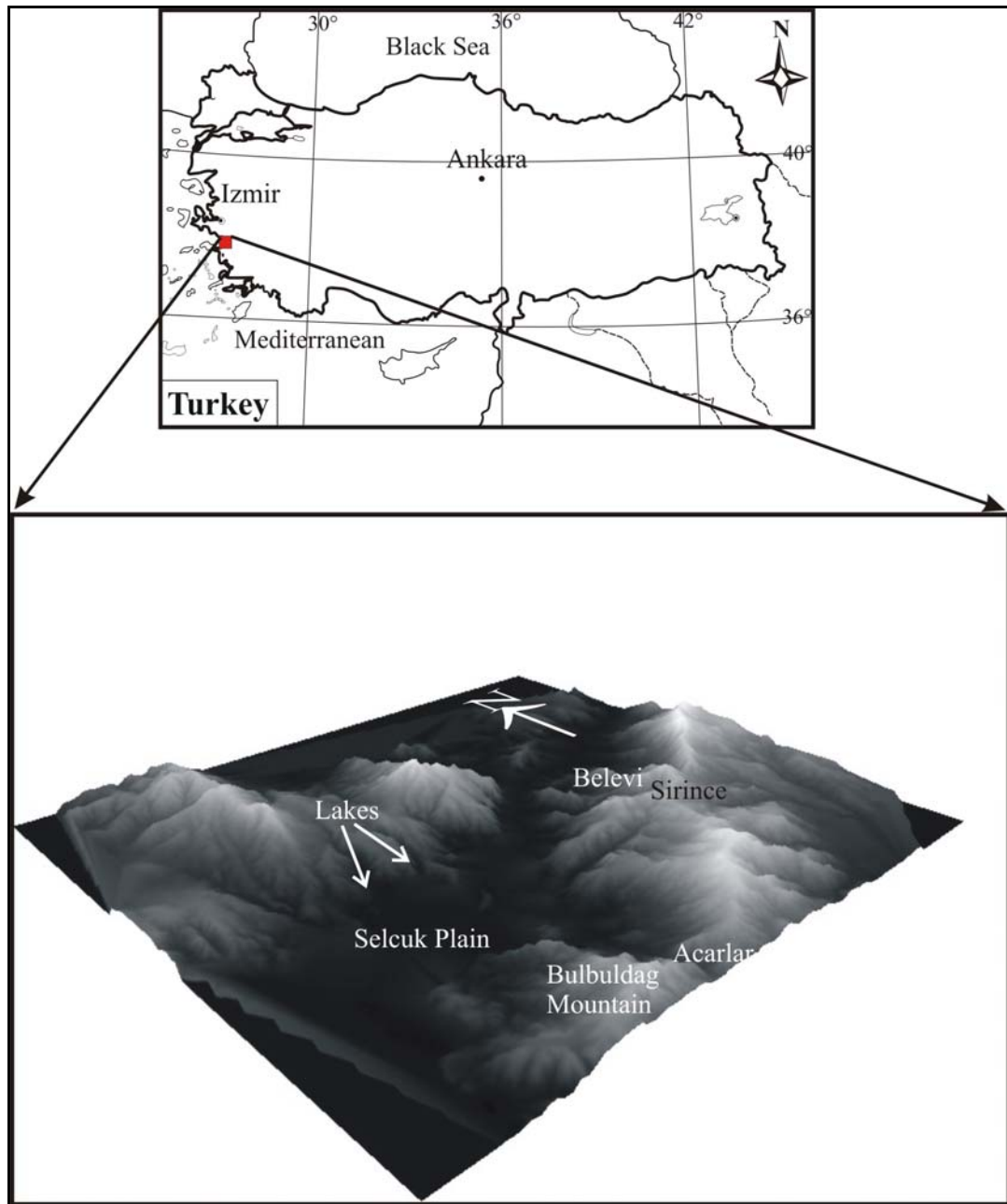


Figure 3.1. Location map of the study area.

3.2 Materials and Methods:

The data sets, comprising 60 water samples, 6 river samples, 6 lake water samples, 2 disposal site waters, 1 treatment water, local seawater and 44 groundwater samples, upon which the current study is based, were collected during two periods of sampling, dry and rainy seasons in 2004 and 2005.

One sample filtered (0.45 μ m) in the field was taken at each site in an acid-washed, well-rinsed low density polyethylene bottle and acidified with 1% HNO₃ to a pH of <2 to assure major cations (Na, K, Ca, Mg) and trace metals (Li, Br, B, Sr). Other sample was taken unfiltered and no acid was added for HCO₃, CO₃, Cl, SO₄ analyses. Samples were stored at 4⁰C for no more than 1 week prior to laboratory analyses, which were carried out in ACME laboratory (Canada).

3.3 Climate and Rainfall

Selçuk Plain is dry–sub humid, with a forth mesothermal season of deficiency, with a large seasonal surplus and a temperature-efficiency regime third mesothermal (C1 B'4 S2 d) according to the Thorntwaite classification system (1948) (Table 3.1). The dry season occurs in summer (July through October) and the wet season occurs in winter (November through May). According to the data of İzmir Guzelyali Meteorological Station, the mean yearly temperature has been 16.4 °C in long-years period. June is the hottest month with 26.4 °C temperatures and January is the coolest with 7.9 °C temperatures. Average yearly rainfall in Selçuk Plain is estimated to be about 689.2 mm. Average yearly actual evapotranspiration is about 868.4 mm according to the Thorntwaite method.

Evapotranspiration was calculated using the Thorntwaite method and an evapotranspiration–rainfall diagram is shown in Figure 3.2.

According to Figure 3.2, the amount of rainfall is greater than potential evapotranspiration in January, February and March; therefore, potential evapotranspiration is equal to real evapotranspiration. Excessive water from rainfall (water surplus) recharges the surface and groundwater. From Figure 3.2, it can be seen that soil moisture utilization responds to water deficiency in April, May and June. Potential evapotranspiration is greater than rainfall; therefore, there is a water deficiency from June to September. From Figure 3.2, it can be seen that in November and December, potential evapotranspiration is equal to real evapotranspiration as the rainfall is greater than potential evapotranspiration. Soil moisture is recharged by excess water. Other water recharges the surface and groundwater.

Table 3.1. Table of Thornthwaite Water Balance (T (Temperature-°C); TI (Temperature Indice); PE (Potential Evapotranspiration-mm); CF (Correction Factor); CPE (Corrected PE-mm); P (Precipitation-mm); DS (Storage Change);S (Storage); ETR (Real Evapotranspiration-mm); WD (Water Deficiency); EW (Excessive Water); RO (Runoff-mm);MR (Moisture Ratio))

Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
T	7.9	8.7	10.8	14.6	19.3	24.1	26.4	25.4	21.3	16.7	12.4	9.5	
TI	1.9	2.4	3.2	5.1	7.7	10.8	12.4	11.7	9.0	6.2	4.0	2.6	77.0
PE	16.7	19.7	28.6	48.2	77.9	114.3	133.7	125.1	92.4	60.7	36.3	23.0	776.7
CF	0.9	0.8	1.0	1.1	1.2	1.2	1.3	1.2	1.0	1.0	0.9	0.8	
CPE	14.2	16.6	29.5	53.0	95.9	141.7	167.2	146.4	96.1	58.3	30.5	19.1	868.4
P	118.4	105.7	84.1	50.8	25.3	6.1	1.4	1.5	17.6	40.6	97	140.5	689.2
DS	0.0	0.0	0.0	2.2	70.6	27.3	0.0	0.0	0.0	0.0	66.5	33.5	
S	100	100	100	97.8	27.3	0.0	0.0	0.0	0.0	0.0	66.5	100	
ETR	14.2	16.6	29.5	53.0	95.9	33.4	1.4	1.5	17.6	40.6	30.5	19.1	353.1
WD	0.0	0.0	0.0	0.0	0.0	108.4	165.8	144.9	78.5	17.7	0.0	0.0	515.2
EW	104.2	89.1	54.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	121.4	369.4
RO	52.1	96.6	71.9	27.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.7	308.7
MR	7.3	5.3	1.9	0.0	-0.7	-1.0	-1.0	-1.0	-0.9	-0.3	2.1	6.4	

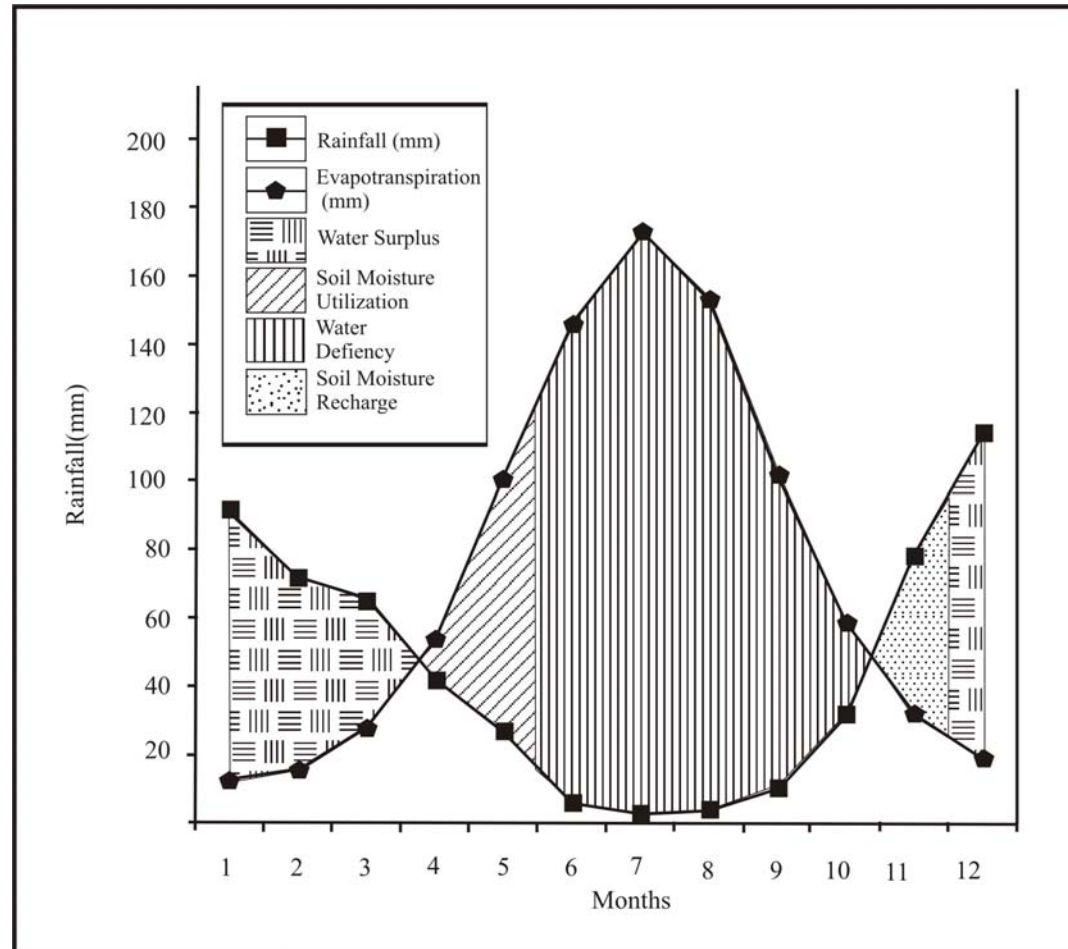


Figure 3.2. Thorntwaite evapotranspiration-rainfall diagram.

3.4 Geophysical Studies in Selçuk Plain

A prospecting was done in 1990 by DSİ (DSİ, 1990b) due to the finding new fresh water areas for Selçuk Municipality by Resistivity Method (RM).

The electrical resistivity method is a good tool for the detection of geological layers that have respective hydrogeological identities (Apostolopoulos et al, 1999). The electrical resistivity method is one of the most useful techniques in groundwater hydrology exploration because the resistivity of a rock is very sensitive to its water content. In turn, the resistivity of water is very sensitive to its ionic content. In general, it is able to map different stratigraphic units in a geologic section as long as the units have a resistivity contrast. Often this is connected to rock porosity and fraction of water saturation of the pore spaces. The application areas are: water table depth; groundwater quality; brine plumes; seawater intrusion; well siting; aquifer exploration; general stratigraphic mapping. Advantages of these methods are both less costly than drilling and non-disturbing. Disadvantages are: (i) cultural problems cause interference, e.g., power lines, pipelines, buried casings, fences ; (ii) resolution; (iii) data acquisition can be slow compared to other geophysical methods, although that difference is disappearing with the very latest techniques (from www.epsc.wustl.edu/classwork/454/pdfs/lecture_phillips_resistivity.pdf).

On the other hand, natural electric fields may be the consequence of diffuse-absorption and filtration processes. As a result of these processes, alterations in the values of the potential take place at the contact of porous media. The sign (+ or –) and intensity of filtration potential depend on numerous factors. These factors are: the character and type of porosity, rate of water movement, electrical resistivity of rocks and water, etc. (Astier, 1971; Semenov, 1980). At water percolation points, some negative anomalies occur, due to the negative ionic charge, whereas the issuing points are characterized by positive values (excess of positive ions). The values of the electrofiltration field rise with the increase in pressure drop. They also rise with a greater difference between electrical resistivities of water and adjoining rocks, or with the reduction in actual thickness of deposits in the roof of the karst aquifer and

smaller depth of circulation of karst streams (Ogilvi, 1957; Arandjelovic, 1969 and 1976). Geologic field tests of structural and tectonic texture, in combination with the methods of simultaneous fluviometric measurements on successive profiles along the streams, may produce positive results for determining a broader zone of subsurface inflow. The SP method alone may identify the subsurface inflows, though in combination with other geophysical methods (Stevanovic and Dragisic, 1998).

In the DSİ 1990b report, Selçuk plain was divided four sub-group as İzmir Gorge (Line I), Sakizli Gorge (Line II), Barutcukoy (Line III) and Andon Gorge (Line IV) (Appendix IV). The alluvium thickness is about 70 m at the İzmir Gorge and the marbles gives 290-7000 ohm-m resistivity value. The distribution of the schist is widely at the Sakizli Gorge and the marbles and schist units have 200-2700 and 260-460 ohm-m resistivity values, respectively. Paleozoic marble and schist units with alluvium can be observed in the Çakalboğazı district. According to Line III, marble levels are very thin. In the Andon Gorge, alluvium is overlaid the marbles. Marbles have 950-3000 ohm-m resistivity value. Due to the distance from the sea and the wide distribution of the marbles, this location may be the optimum point for new fresh water supply according to DSİ 1990b.

3.5 Results

Sample locations are shown in Figure 3.3, and the major ion ratios; minor ions and ratios are given in Table 3.2 and Table 3.3, respectively. Two hydrogeochemical zones are defined in the study area and the processes that control the chemical compositions of waters are different in each zone. First one is occurred by seawater intrusion that the dominant ions are Na and Cl in the coastal zone; and the second one is weathering of Ca-Mg silicates in the hilly area that forms the recharge basin of coastal zone (Figure 3.4). In the coastal area, pH values are range between 6.69 and 8.62 in both seasons. In the hilly area these values (pH) are 7.28 approximately. Remarkable differences are seen in the EC values of these two zones. In the rainy season from inland to coastal zone the EC values are range from 786 to 4480 $\mu\text{S}/\text{cm}$; in dry season these values are increased (e.g. 10250 $\mu\text{S}/\text{cm}$ in karstic spring). In contrast, in the hilly area maximum EC value is determined in sample 56 with 997 $\mu\text{S}/\text{cm}$ value. The mean value is 814 $\mu\text{S}/\text{cm}$. According to Somay and Filiz, 2006; the average pH value is 7.52, and the EC values were range between from 776 to 5350 (from inland to coastal area of plain, approximately) in 2001. Fresh water of the basin that was observed in eastern (Şirince) and southern (Acarlar) has Ca-HCO₃ facies according to IAH (1979), evolving towards the coastal strip to become more mineralized with Na-Cl facies. The Ca-HCO₃ water type is indicating the first evolutionary stage of the process in the Selçuk Basin. Fresh water is commonly dominated by HCO₃ ions because the addition of the large amounts of CO₂ from root zone and calcite, if present, is dissolved (Back et al., 1979). In the study area this fresh water is supplied from both Paleozoic schist and metaolistostrome that are including calcareous layers in it and the vegetation is very dense on the soil in and around hilly area. And also, HCO₃, Ca, Mg ions probably derived from the weathering of Ca-Mg silicates, chiefly from calcite, plagioclase and feldspar in the schist. Water types are generally distinct zones that cation and anion concentrations are described within the defined composition categories, and the dominant anion species of water changes systematically from HCO₃ to Cl along groundwater flow direction from the recharge area (Şirince, Acarlar, Belevi) to the discharge area (Selçuk plain).

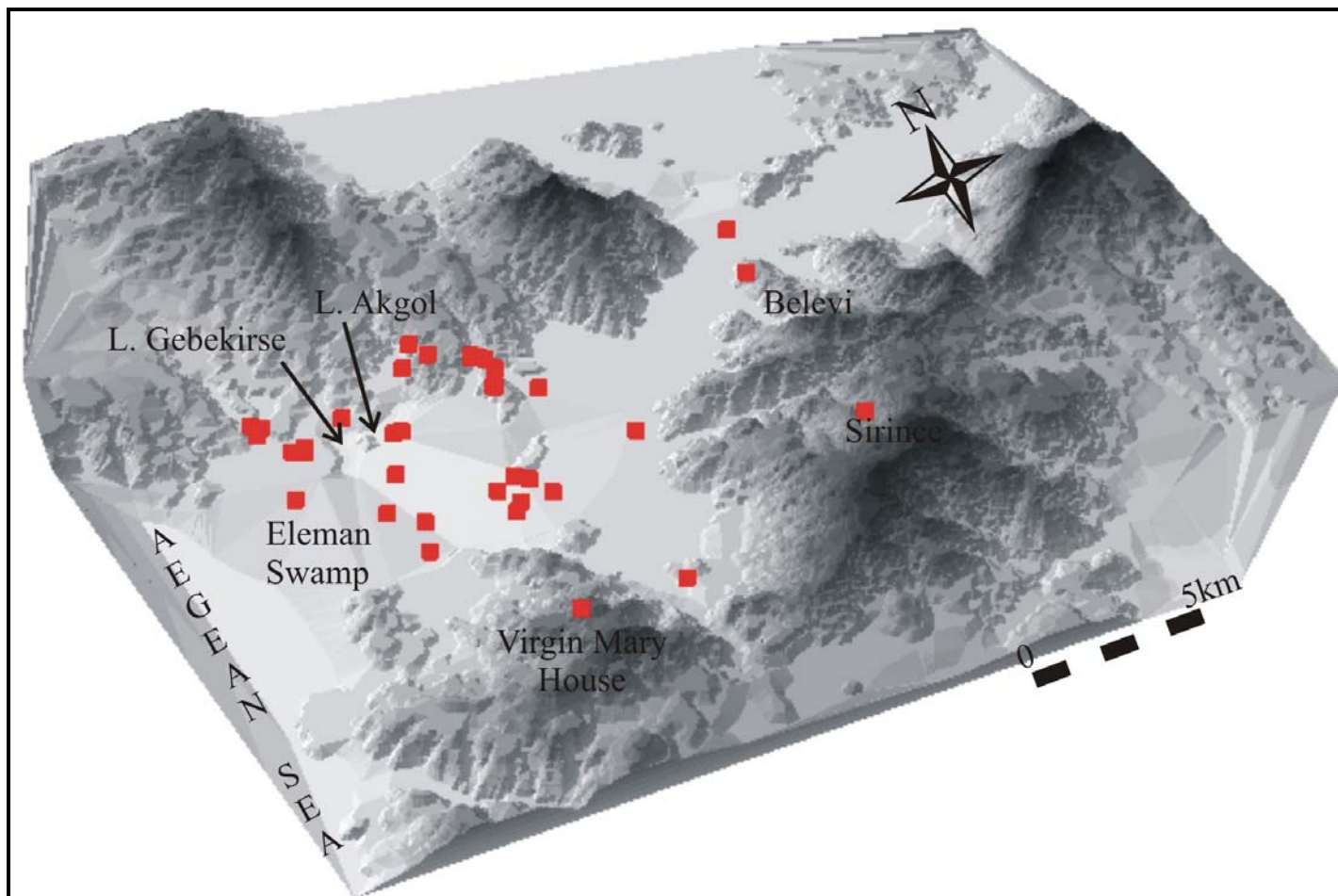


Figure 3.3. Sample points map of these study.

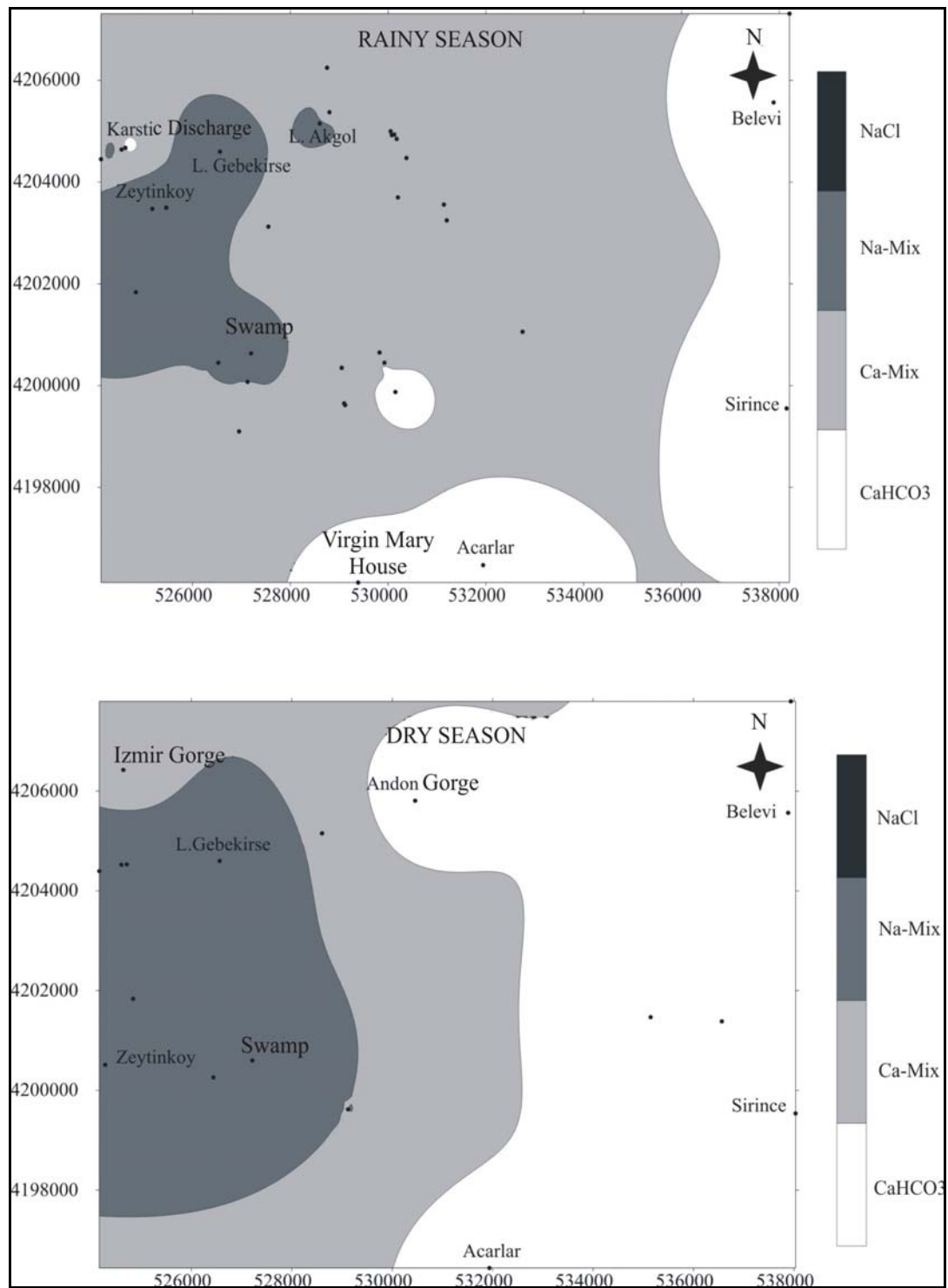


Figure 3.4. Water type maps of the study area (according to IAH, 1979).

The sodium-adsorption-ratio (SAR) has been used for determined the salinity for soil by most of the scientist since 1970s. When the concentration of sodium becomes excessive in proportion to calcium plus magnesium, the soil is said to be sodic. Excessive sodium causes soil mineral particles to disperse and water penetration to decrease. High sodium concentrations become a problem when infiltration rate is reduced to the extent the crop is not adequately supplied with water or when the hydraulic conductivity of the soil profile is too low to provide adequate drainage (Şahinci, 1991). The sodium-adsorption-ratio of irrigation water is generally a good indicator of the sodium status that will occur in the soil. SAR is defined as:

$$SAR = \frac{rNa^{+}}{\sqrt{\frac{rCa^{+2} + rMg^{+2}}{2}}}$$

where rNa^{+} , rCa^{+2} and rMg^{+2} are defined as the concentrations of sodium, calcium and magnesium ions in water, respectively in meq/l (Ayers & Westcot, 1985). In the study area just swamp, Lake Gebekirse and Kazangöl karstic spring are exceeded the tolerance limits with more than 15 (EPA, 1986) SAR values.

3.5.1 Major Ionic Ratios, Classification of Waters and Mixing Ratio

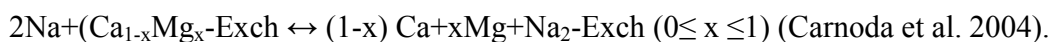
Chloride has been selected by some researchers as a one of fingerprint because it is chemically conservative, that is, once in solution it is not easily removed by most processes other than precipitation at very late stage of salinization, in general (Hem, 1985; Richter and Kreitler, 1993). Chloride has a conservative behavior; deviations from conservative mixing that result from solubility or redox controls are not feasible (Carnoda et al, 2004).

The major ionic species in solution, chloride and sodium, hence closely positive correlation ($r^2=0.99$) and most of the waters lie on the mixing line between two end members. The other major anion, sulfate, has a good correlation with Cl as a result of fresh and salt water (seawater intrusion) mixture.

The local seawater has distinct ionic ratios such as $\text{Na/Cl}=0.905$, $\text{SO}_4/\text{Cl}=0.081$, $\text{Br/Cl}=0.0028$, $\text{Na/Ca}=26.89$, $\text{Mg/Ca}=5.5$, $\text{Sr/Ca}=0.0069$ in the study area (Table 3.2).

According to the M&E (2000), in the coastal aquifer Mg/Ca molar ratio greater than 5 is a direct indicator of seawater intrusion. The local seawater has 5.5 Mg/Ca ratio. In the coastal zone, all of the groundwater has greater than 1 molar ratio that is indicating the seawater intrusion.

Direct cation-exchange reaction takes place during refreshing when fresh water flushes seawater in a coastal aquifer, displacing the freshwater/seawater interface towards to sea. This reaction can be represented as



According to this reaction, it can be clearly seen from Table 3.2., Na/Ca values of coastal zone are more than freshwater. In rainy and dry season, this ratio can be reached 76.55 and 24, respectively; whereas the Na/Ca value of sea water is calculated as 23.23.

Table 3.2. Ionic ratios and minor ions of the waters in the study area (* represents rainy season; DW: Drilling well).

#	Coordinate X Y		EC μS/cm	pH	TDS (mg/l)	Na/Cl	SO ₄ /Cl	Mg/Ca	Na/Ca	SO ₄ /Cl	SAR	Mixing Ratio (%)	Locations
1*	0525175	4203475	1903	7.7	1404.9	1.099	0.188	1.101	4.292	0.188	7.47	2.362	Zeytinköy DW
2*	0525463	4203500	1416	7.6	1063.3	0.830	0.153	0.699	1.352	0.153	3.31	1.541	Zeytinköy DW
3*	0525463	4203500	1388	7.8	1068.2	1.098	0.146	1.012	2.567	0.146	4.69	1.451	Zeytinköy DW
4*	0531200	4203250	2210	7.7	1444.3	0.915	0.107	0.845	2.881	0.107	6.60	2.925	Korudag
5*	0530200	4203700	1470	7.4	1089.5	0.825	0.201	0.280	0.959	0.201	3.07	1.401	Kargi Hill
6*	0530175	4204850	1124	7.0	940.6	0.865	0.308	0.267	0.636	0.308	2.07	0.872	Kargi Hill
7*	0530050	4205000	944	7.5	790.5	0.616	0.299	0.336	0.270	0.299	0.86	0.472	Kargi Hill
8*	0530075	4204925	963	7.1	799.1	0.681	0.252	0.314	0.284	0.252	0.93	0.472	Kargi Hill
9*	0530375	4204475	1004	7.1	811.5	0.811	0.182	0.329	0.542	0.182	1.63	0.681	Kargi Hill
10*	0528800	4205375	776	7.6	683.0	0.696	0.190	0.290	0.218	0.190	0.68	0.270	E of Akgöl
11*	0528750	4206250	786	7.2	581.0	0.706	0.179	0.105	0.232	0.179	0.75	0.264	N of Akgöl
12*	0524625	4204675	4470	7.3	2988.9	0.798	0.087	1.178	5.286	0.087	12.79	8.319	Camurluk
13*	0530150	4199875	952	7.4	794.4	0.920	0.408	0.716	0.359	0.408	0.90	0.298	Ancient cty
14*	0529100	4199650	2070	7.5	1764.2	0.935	0.369	0.265	0.818	0.369	3.52	1.924	7 Uyuyanlar
15*	0529050	4200350	1546	7.7	1162.2	0.782	0.211	0.796	1.165	0.211	2.91	1.547	Pump
16*	0529925	4200450	1451	7.7	1211.3	1.029	0.367	0.714	0.932	0.367	2.66	1.147	Karahallı Farm
17*	0529825	4200650	2940	7.7	1940.8	0.777	0.106	0.898	2.443	0.106	6.61	4.241	Efes airport
18*	0527197	4200633	5417	7.8	3485.4	1.320	0.057	1.800	76.551	0.057	54.90	8.218	Swamp
19*	0526525	4200450	1288	8.3	869.9	0.617	0.083	0.623	1.254	0.083	3.17	1.991	Swamp
20*	0526950	4199100	1390	7.5	1095.2	0.617	0.089	0.556	0.696	0.089	2.16	1.569	Dog Farm
21*	0527125	4200075	2760	7.6	1974.1	0.617	0.105	0.479	1.265	0.105	4.88	4.382	Ex-K.Adasi road

Table 3.2. Ionic ratios and minor ions of the waters in the study area (* represents rainy season; DW: Drilling well).

#	Coordinate X Y		EC μS/cm	pH	TDS (mg/l)	Na/Cl	SO ₄ /Cl	Mg/Ca	Na/Ca	SO ₄ /Cl	SAR	Mixing Ratio (%)	Locations
22*	0532751	4201059	1667	7.3	1211.9	0.330	0.354	1.290	0.289	0.354	0.73	1.153	Selçuk DW
23*	0530126	4204934	1067	7.4	816.2	0.748	0.410	0.496	0.311	0.410	0.92	0.427	Andon farm
24*	0524126	4204452	5800	7.1	3900.2	1.046	0.089	1.505	6.949	0.089	16.07	8.769	Kazangöl karstic
25*	0524547	4204641	4020	7.1	2517.7	0.890	0.112	1.013	4.059	0.112	10.58	6.108	Zeytinköy karstic
26*	0528600	4205153	1586	8.0	2643.0	1.015	0.164	0.914	4.767	0.164	12.66	6.210	Lake Akgöl
27*	0526560	4204600	2255	7.7	3623.3	0.994	0.125	1.342	7.385	0.125	17.42	9.556	Lake Gebekirse
28*	0529121	4199618	1608	7.4	1146.5	0.853	0.284	0.778	1.601	0.284	3.76	1.716	Lake Kocagöz
29*	0527550	4203125	2100	7.7	1658.0	0.961	0.151	0.768	2.600	0.151	6.25	2.638	River
30*	0531141	4203559	659	7.6	515.9	1.164	0.826	0.702	0.818	0.826	1.51	0.287	River
31*	0538210	4207313	1600	7.9	1067.5	1.380	2.557	0.099	0.417	2.557	1.74	0.461	River (Belevi)
32*	0524839	4201836	2850	8.0	1804.7	1.054	0.128	0.857	3.610	0.128	8.54	3.437	River (Pamucak)
33*	0538151	4199552	934	7.1	876.9	0.485	0.449	0.389	0.142	0.449	0.51	0.202	Şirince
34*	0529387	4196129	645	7.3	539.6	0.526	1.155	0.731	0.103	1.155	0.21	0.028	Virgin Mary
35*	0531944	4196472	624	7.4	507.2	0.589	2.143	0.113	0.076	1.380	0.24	0.000	Acarlar
36*	0537885	4205566	922	7.0	717.2	0.688	1.013	0.724	0.176	1.013	0.43	0.141	Belevi
37*	0528409	4200943	4480	8.6	2919.7	0.839	0.196	1.369	4.788	0.196	11.10	7.138	Disposal site
38*	0530240	4203222	565	7.8	657.6	0.565	0.148	0.607	0.707	0.148	1.30	0.557	Treatment site
39	0524282	4200512	1717	7.4	1001.6	0.708	0.087	0.449	1.364	0.087	3.78	2.050	Zeytinköy DW
40	0524712	4204530	1684	7.3	1174.0	0.882	0.116	0.480	1.570	0.116	4.36	1.932	Zeytinköy DW
41	0527214	4200599	5790	7.9	3603.0	1.160	0.086	2.267	24.622	0.086	27.18	8.342	Swamp
42	0526440	4200259	5490	7.4	3114.6	0.521	0.090	0.726	1.372	0.090	6.07	8.792	Swamp

Table 3.2. Ionic ratios and minor ions of the waters in the study area (* represents rainy season; DW: Drilling well).

#	Coordinate X Y		EC μS/cm	pH	TDS (mg/l)	Na/Cl	SO ₄ /Cl	Mg/Ca	Na/Ca	SO ₄ /Cl	SAR	Mixing Ratio (%)	Locations
43	0524165	4204396	10250	7.3	5611.3	0.771	0.107	1.758	7.048	0.107	18.19	7.161	Kazangöl karstic
44	0524605	4204525	4150	6.8	2760.5	0.804	0.097	0.985	3.805	0.097	10.58	2.106	Zeytinköy karstic
45	0528600	4205153	2020	7.4	1297.6	0.799	0.142	0.389	1.235	0.142	3.96	18.689	Lake Akgöl
46	0526560	4204600	11510	8.1	6433.2	0.866	0.104	1.530	7.493	0.104	21.96	1.066	Lake Gebekirse
47	0529121	4199618	1488	6.7	1075.1	1.185	0.376	0.886	1.524	0.376	3.33	1.229	Lake Kocagöz
48	0537938	4207800	2460	7.7	1971.0	0.798	1.567	0.408	0.329	1.567	1.57	4.096	River (Belevi)
49	0524839	4201836	2900	7.9	2170.0	1.050	0.174	0.680	3.037	0.174	8.93	3.478	River (Pamucak)
50	0524715	4204535	2530	7.8	1616.5	0.907	0.105	0.758	3.067	0.105	7.52	6.824	Irrigation channel
51	0528409	4200943	4550	8.5	2743.3	0.825	0.051	1.455	4.316	0.051	10.03	0.756	Disposal site
52	0524643	4206425	977	6.8	741.1	0.824	0.142	0.418	0.718	0.142	1.88	0.228	İzmir Gorge
53	0530456	4205808	780	6.9	664.5	0.699	0.274	0.239	0.185	0.274	0.58	0.087	Andon Gorge
54	0531935	4196438	652	7.8	534.7	0.507	1.109	0.646	0.119	1.109	0.26	0.000	Acarlar
55	0537885	4205566	997	7.4	483.0	0.536	1.268	0.089	0.020	1.268	0.06	0.127	Belevi
56	0536564	4201383	773	7.2	676.8	0.845	1.160	1.003	0.241	1.160	0.47	0.000	Degirmen Spring
57	0538033	4199538	305	8.0	249.9	0.601	0.740	0.364	0.117	0.740	0.21	0.267	Şirince
58	0535145	4201467	813	7.4	675.1	0.634	0.693	0.583	0.242	0.693	0.59	1.336	DW on Şirince road
59			430	6.8	339.8	0.597	0.924	0.150	0.060	0.924	0.14	0.000	Tire
SW	0524140	4199607	58800	8.3	34519.8	1.103	0.121	5.518	23.237	0.081	67.56	100.00	Seawater

The TDS vs. inter-ionic ratios (Na/Ca and HCO_3/Cl) diagrams were examined to evaluate the effect of seawater mixing qualitatively (Figure 3.5 and Figure 3.6). There is a specific trend in a TDS vs. Na/Ca diagram (Figure 3.5), suggesting that Na/Ca ratios are controlled by seawater mixing process.

In the TDS vs. HCO_3/Cl diagram (Figure 3.6), good correlation between in the two variables is seen ($r^2=0.8$ in both season) suggesting that high TDS groundwaters are typically enriched in chloride ion, mainly due to seawater mixing.

If seawater intrudes into a freshwater aquifer, the Na/Cl ratio of the invaded groundwater is progressively change along the mixing line (Custodio, 1987). According to Nordstrom et al, 1989, Na/Cl ratios above 0.5 are common in surface waters and low salinity groundwater, whereas those below that value correspond to natural waters with cations, such as Ca, which occurs in significant amounts. The relation of Cl vs. Na/Cl, shown in Fig. 3.7, suggests that mixing coastal zone groundwaters with a Cl concentration >280 mg/l. In the Na/Cl mixed model it has been seen that most of the saline groundwater samples that were taken from coastal area plot very close or slightly below the conservation line indicating some depletion of Na through ion exchange reactions during mixing process. The high Na concentrations in coastal zone show Na deficiency with respect to the conservative mixing line due to reverse cation-exchange reactions. The Na/Cl molar ratio (Figure 3.7) for coastal zone shows consistently high values above the corresponding seawater dilution line, whereas samples from hilly area lie below this line.

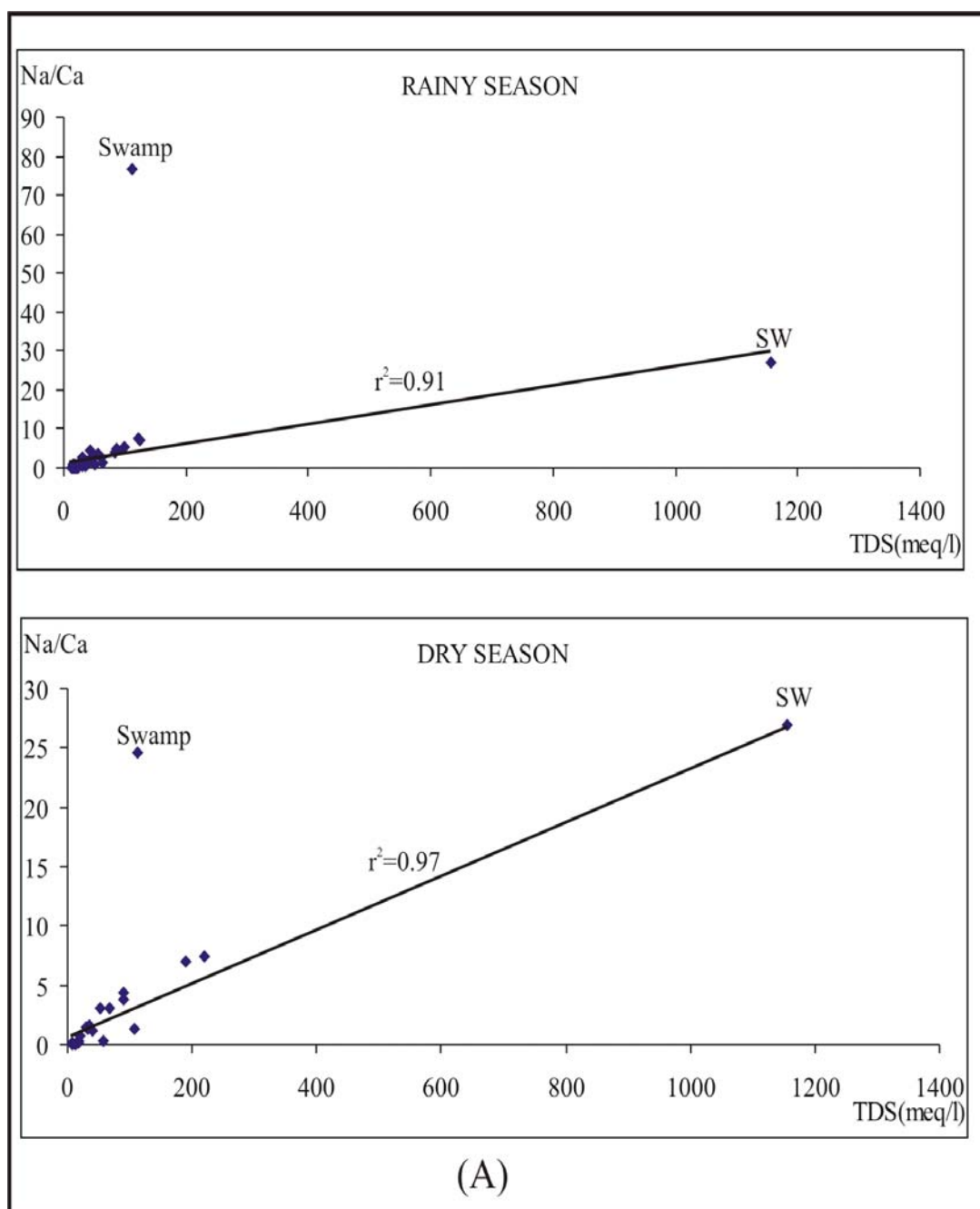


Figure 3.5. Na/Ca vs Cl diagram in both dry and rainy seasons.

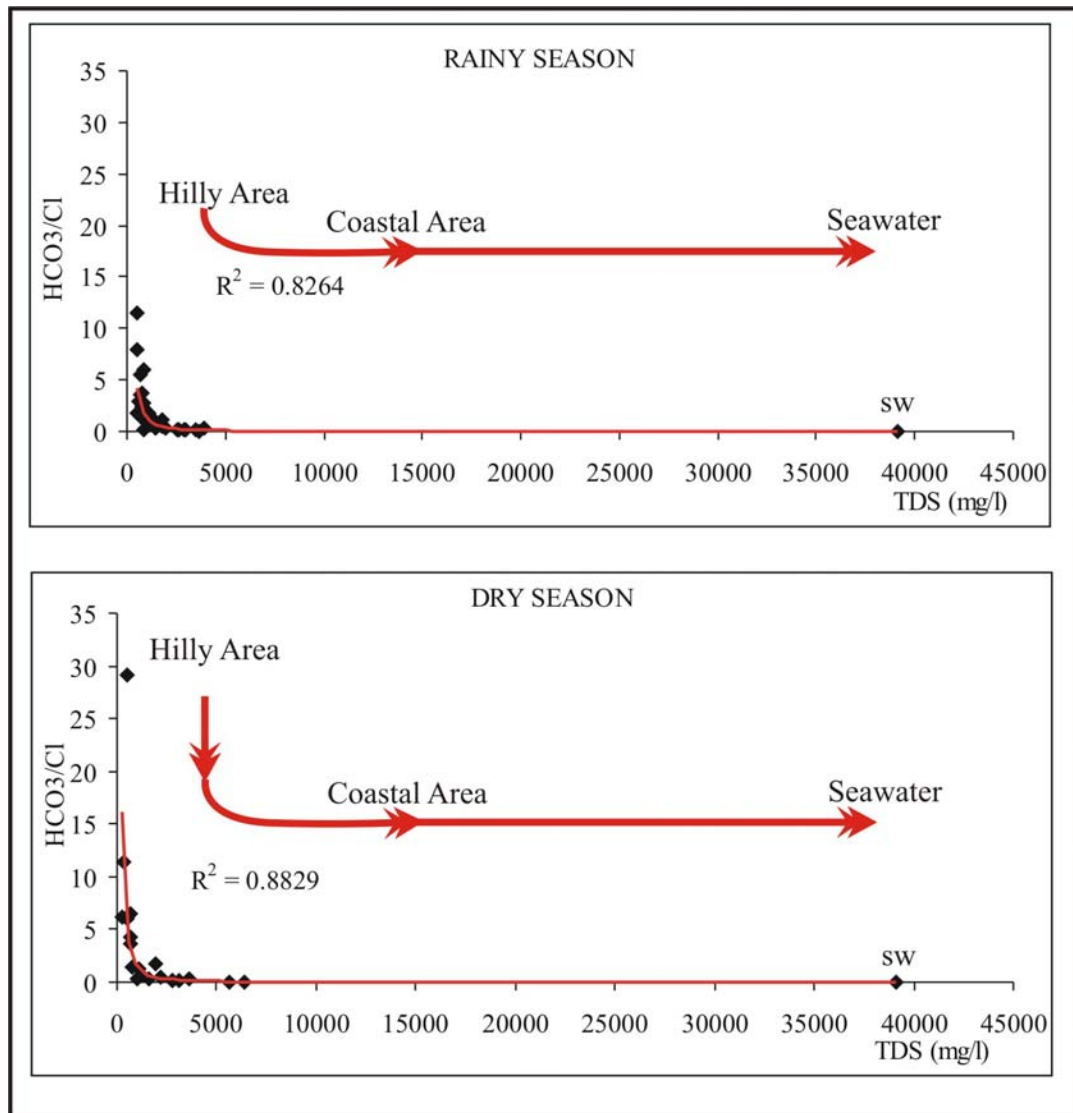


Figure 3.6. $\text{HCO}_3^-/\text{Cl}^-$ vs Cl diagram in both dry and rainy seasons.

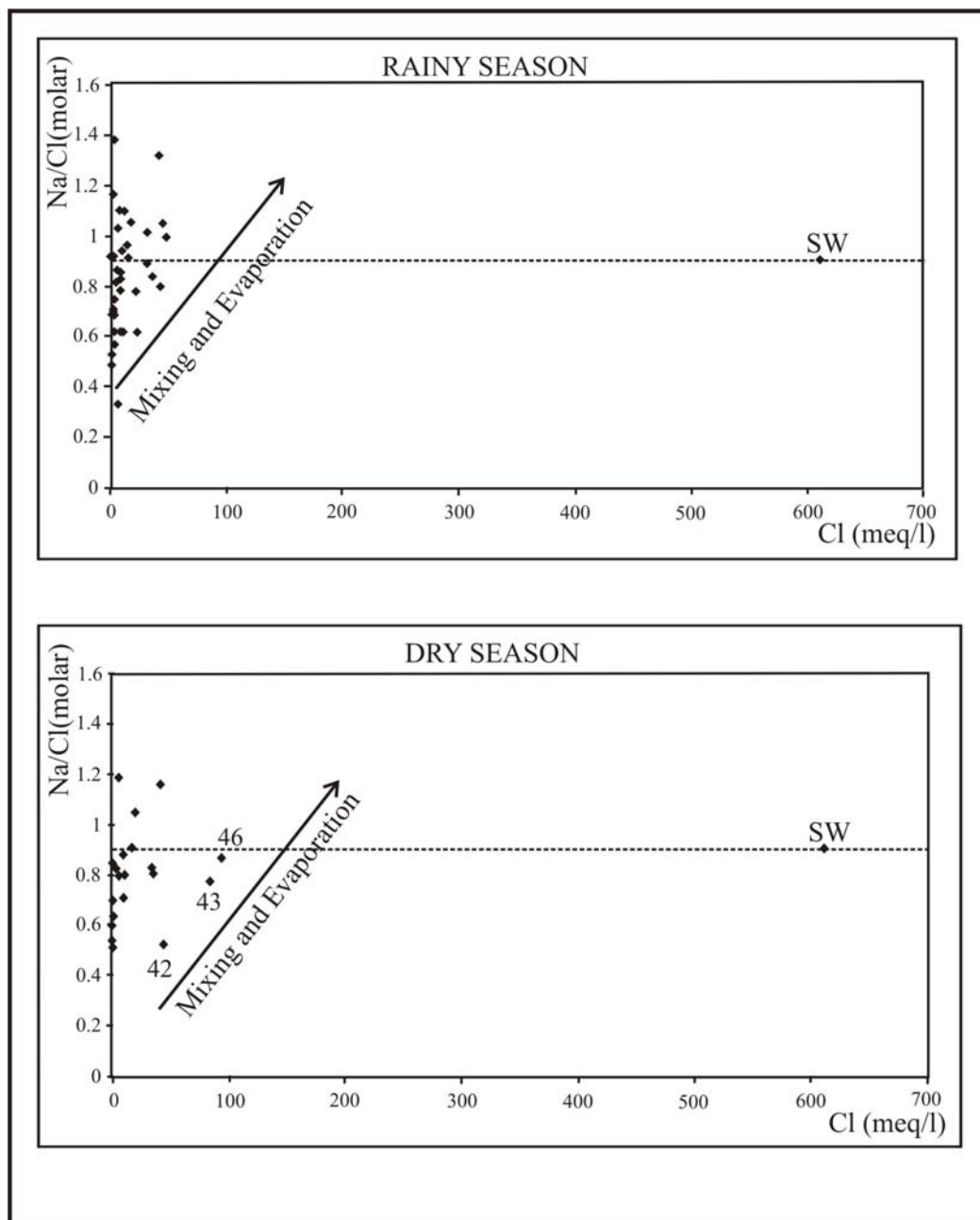


Figure 3.7. Na/Cl vs Cl diagram in both dry and rainy seasons.

The SO_4 mixing represents either the oxidation of rock sulfur by a marine derived groundwater or the mixing of two different water masses, a deep marine derived groundwater and an oxidizing recharge (Beaucaire et al. 1999). In the SO_4/Cl versus Cl diagram (Figure 3.8); coastal zone takes places on the “Seawater Influence” line in both seasons that was proved the coastal zone is under seawater effect. On the other hand, a high SO_4/Cl ratio attributed to the application of gypsum fertilizers (Vengosh et al, 2002). At the study area SO_4/Cl ratio of the river gives 1.5-2.5 values (samples 31 and 48) that is higher than other samples and can be explained by gypsum fertilizers.

A preliminary characterization, carried out using the Piper diagram (1944), shown in Figure 3.9, shows the different geochemistry of sampled water. According to this diagram, the mineralization is increased towards to the sea. The hilly area takes place in “Ca-Mg- HCO_3 ” water type area whereas the coastal zone is plotted near the sea water area (Na-Cl). These geochemical changing is observed from high altitude to sea level in both season.

Schoeller semi-logarithmic diagram is used for compare the all basin waters that is shown in Figure 3.10. The coastal zone waters are indicating sea water character but in contrast hilly waters are different from sea water that are represented with dash line in Figure 3.10 in both season. On the other hand, the increasing mineralization is observed in the dry season because of high evaporation in the area.

The diagram of Gibbs (1970) shows the evolution of global salinity (TDS) versus $(\text{Na}+\text{K})/(\text{Na}+\text{K}+\text{Ca})$ for waters of the Selçuk Plain. Such diagram allows the distinction between waters controlled by evaporation and those influenced by water-rock interaction process. It indicates that all of the samples that located in Selçuk plain are grouped in “Evaporation/Crystallization Dominant” area in both dry and rainy seasons (Figure 3.11).

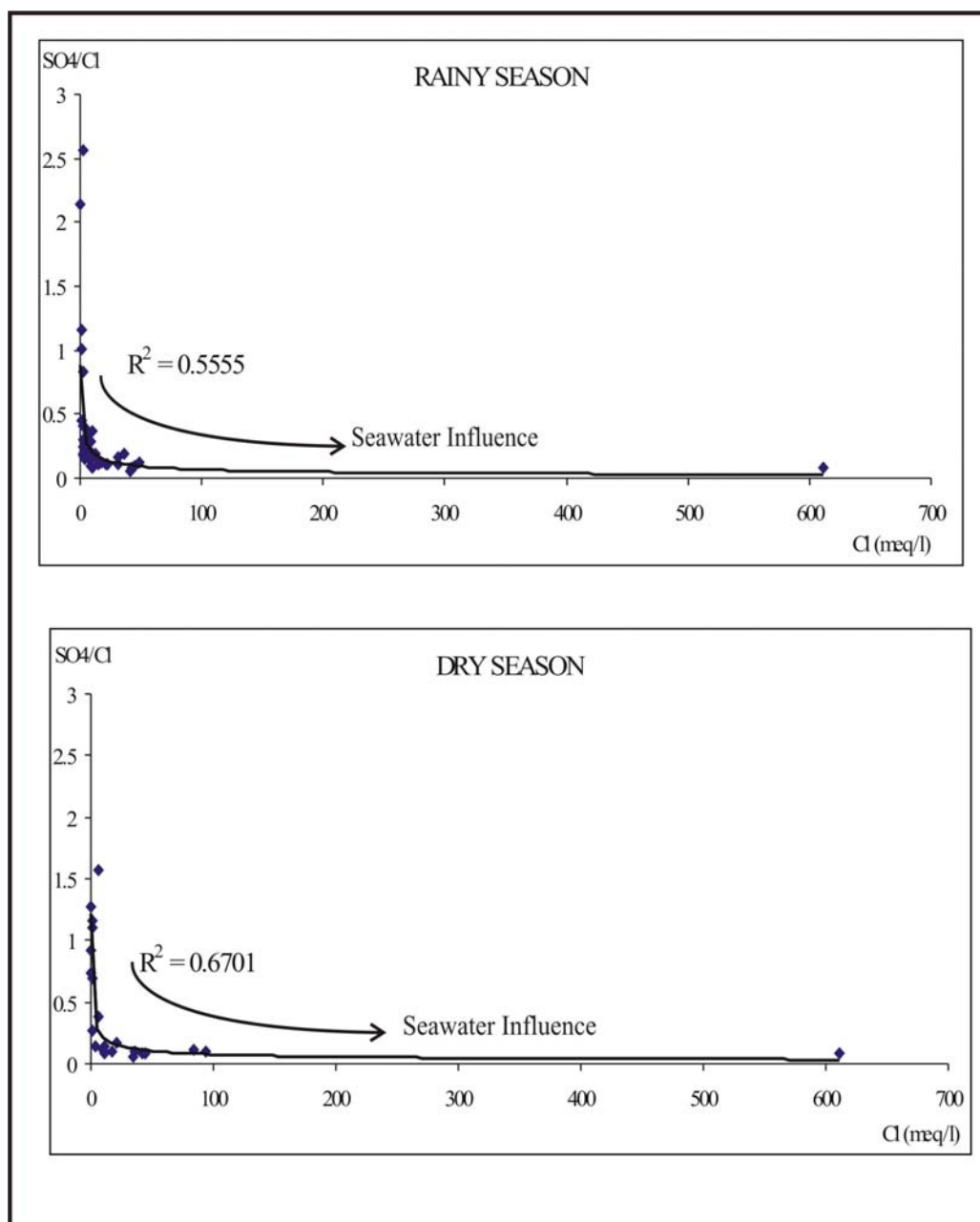


Figure 3.8. SO₄/Cl vs Cl diagram in both dry and rainy seasons.

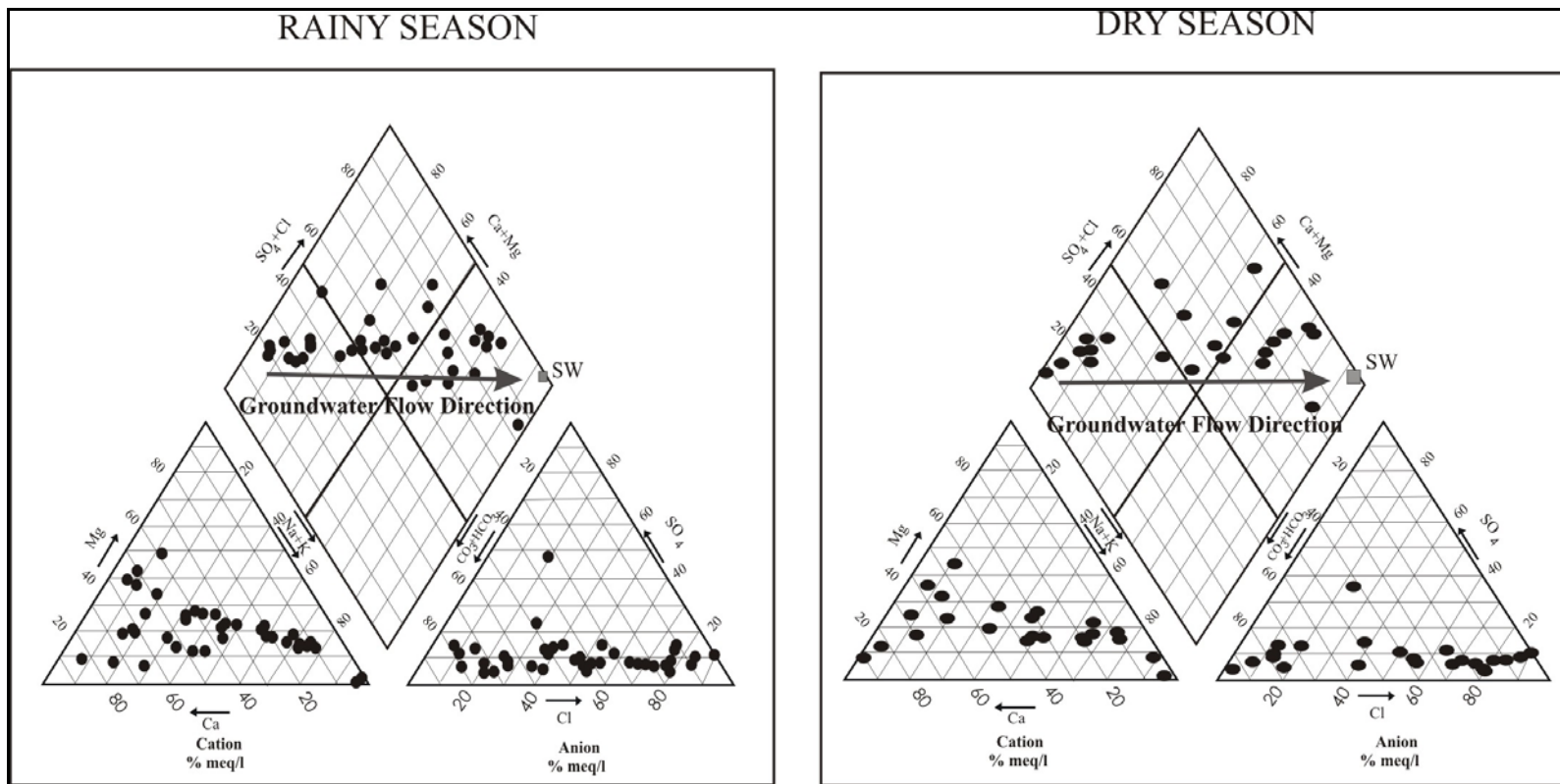


Figure 3.9. Distribution of the waters in the Piper diagram.

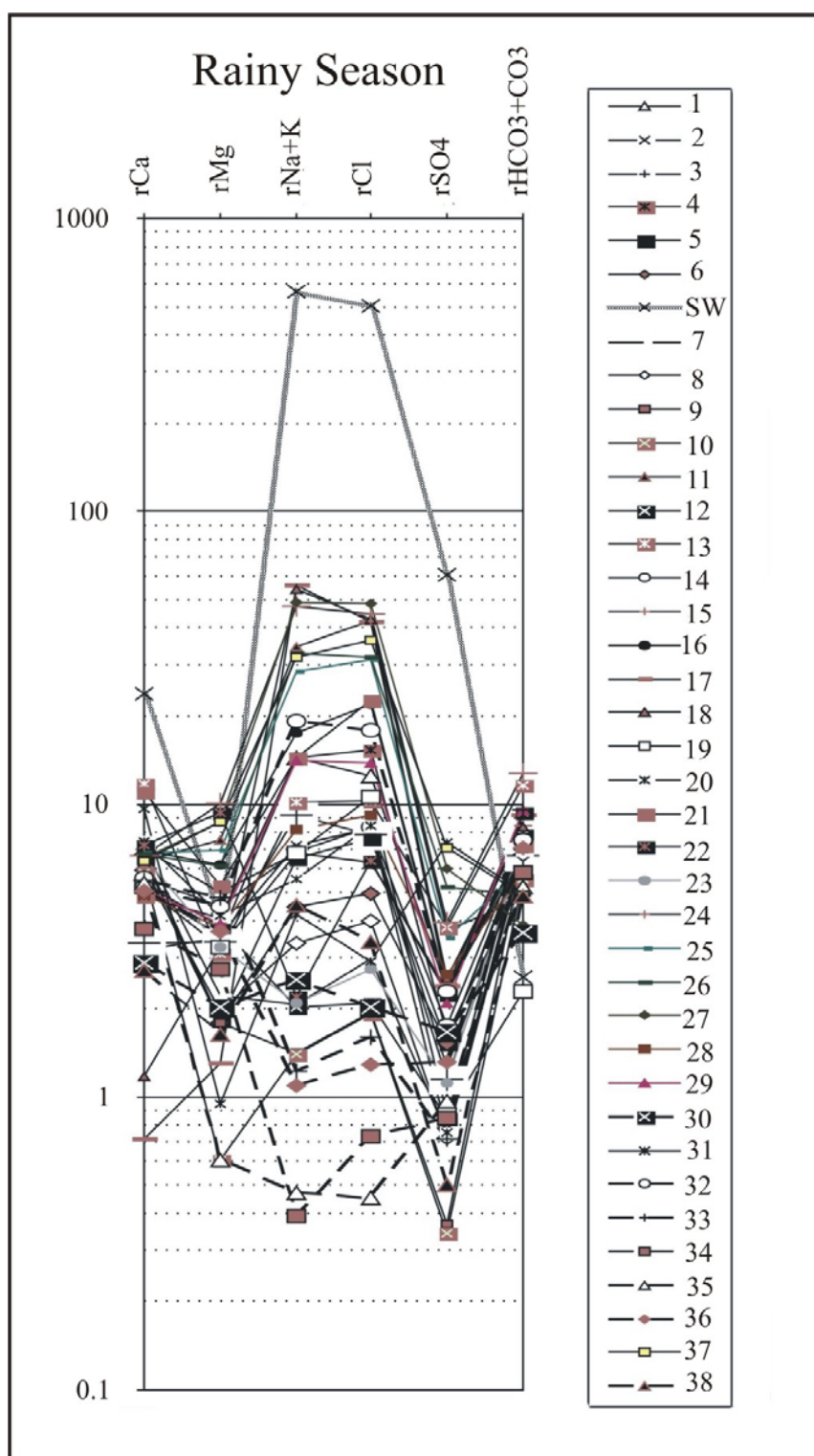


Figure 3.10. Distribution of waters in the Schoeller semi-logarithmic diagram.
(A) rainy season.

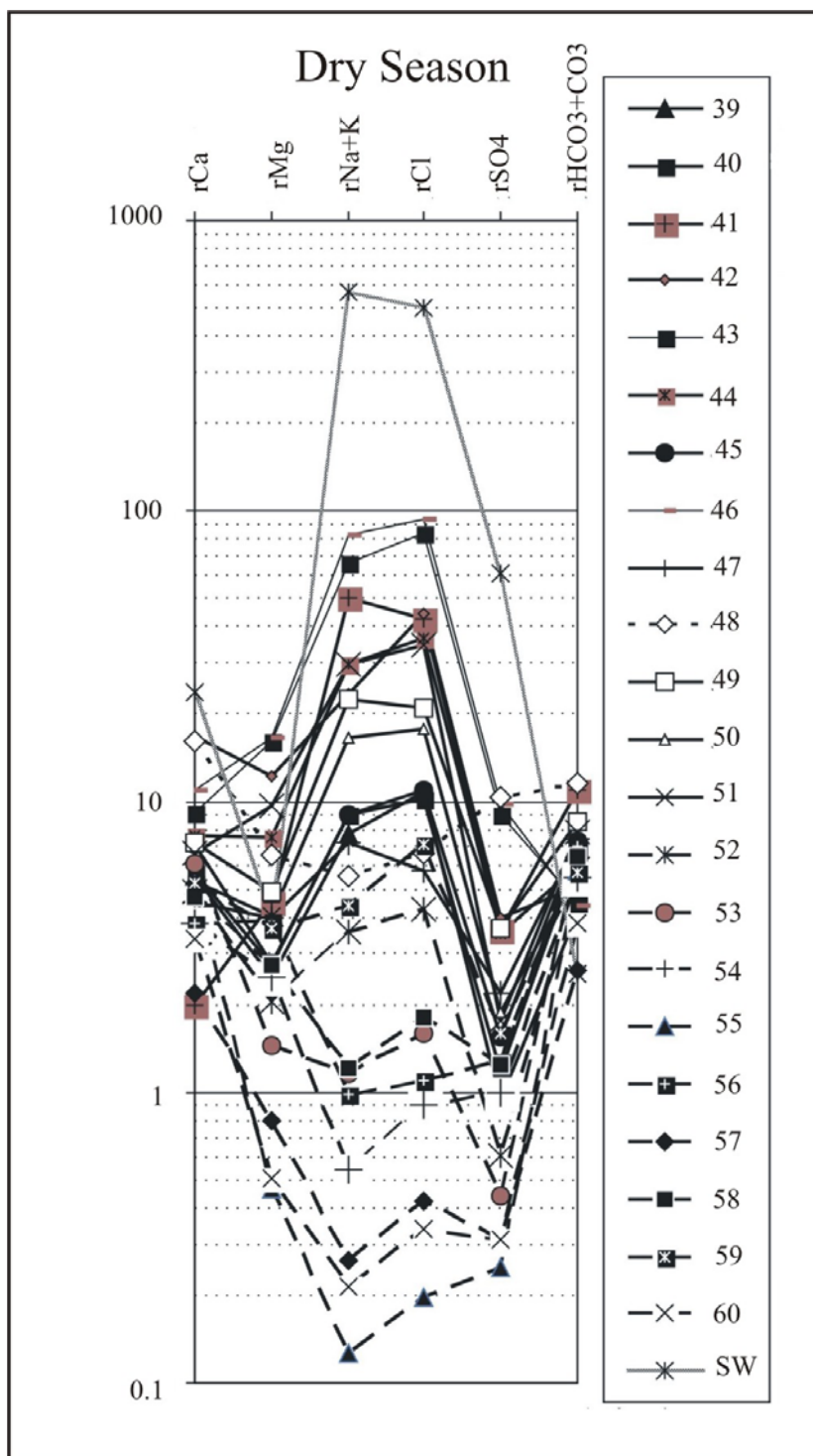


Figure 3.10. Distribution of waters in the Schoeller semi-logarithmic diagram.
(B) dry season.

Evaporation of surface water is the main process in the evolvement of groundwater chemical composition in the unsaturated zone. Evaporation concentrates the remaining water and leached to precipitation and deposition of evaporates that are eventually leached into the saturated zone. This is expected, as evaporation greatly increases the concentration of ions formed by chemical weathering, leading to high salinity TDS. From this diagram, the second process is “Rock Dominant” process that is determined at the hilly area (Şirince, Belevi, Acarlar, İzmir and Andon gorges).

Mixing ratios determined by using physically or chemically non-reactive component in hydrogeological studies (Kurttaş, 2002). For this aim, the chloride was selected due to its non-reactive characterize. In addition, for these ratios two of end member must be chosen in the study area. The fresh member in our study area is chosen from Virgin Mary drilling well and Acarlar village (mean value of sample 34 and 35). The second end member is the sea water chlorine value in meq/l (Table 3.2.). Mixing ratio is calculated as shown in below (Kurttaş, 2002):

$$\text{Mixing ratio (\%100)} = (Cl_{\text{sample}} - Cl_{\text{fresh}}) / (Cl_{\text{sea}} - Cl_{\text{fresh}})$$

From the point view of the Table 3.2., in the rainy season maximum sea water mixing areas are swamp, karstic discharge points and the nearest lake, Gebekirse (sample 12, 18, 24, 25, 26, 27) with 9.55 % value. In the dry season same places have maximum values than hilly area especially in sample 43 and 46 with 17.68 % mixing value. In the dry season, in addition to high evaporation irrigation is done every year for crops in Selçuk Plain. So, the pumping rate of groundwater reached the maximum value giving raise the seawater intrusion.

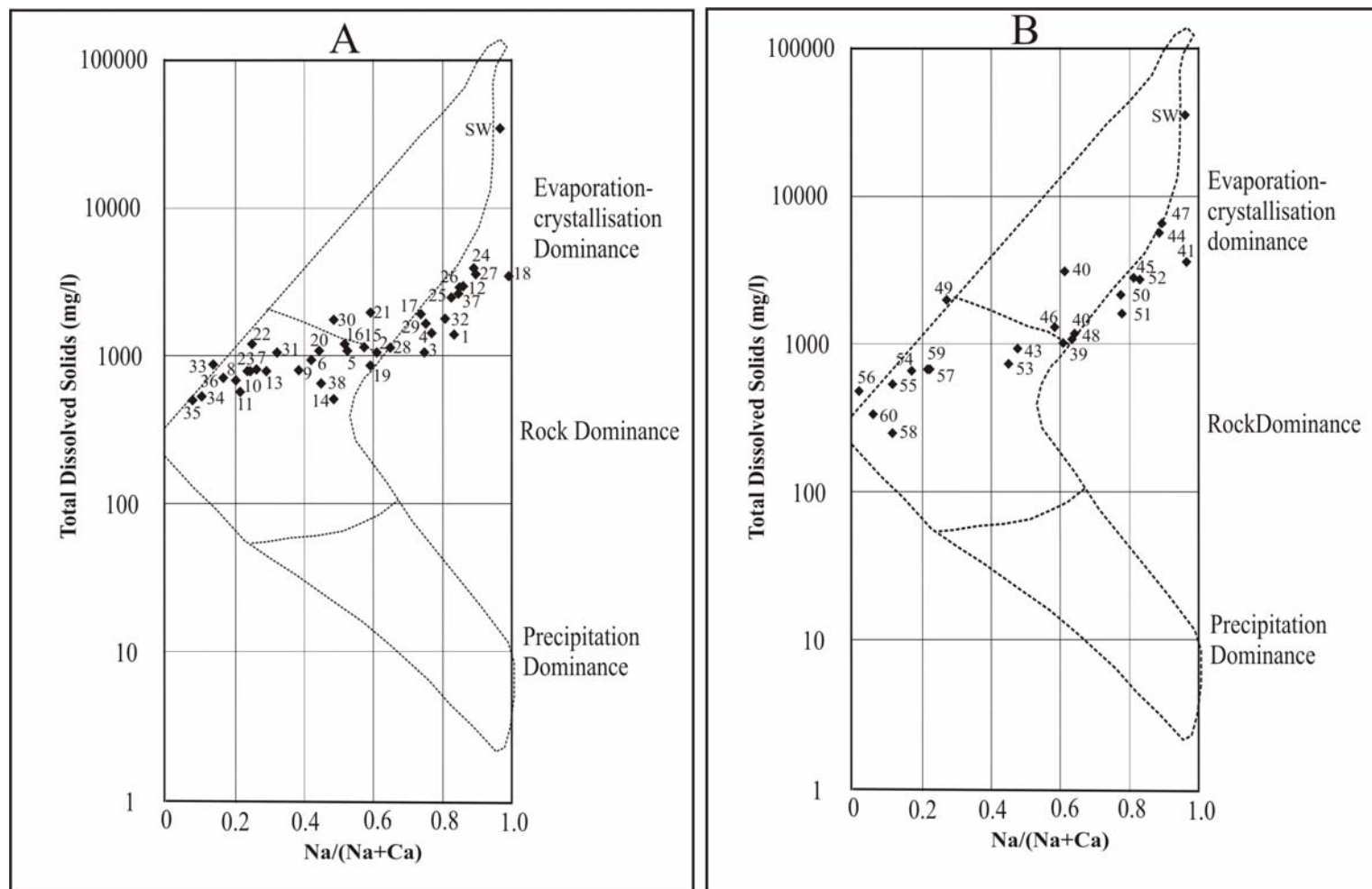


Figure 3.11. Gibbs diagram for the waters (A) Rainy season, (B) Dry season.

3.5.2 Minor Ions Ratios

The hydrogeochemistry of some minor elements, such as Br, B, Li and Sr are good indicators of seawater intrusion. The relationship between these minor elements with Cl shows a close positive correlation. Additionally to the major ion chemistry, the recent investigations focused on the minor elements (bromide, strontium and boron) to constrain origin(s), mixing rates and salinization processes. Concentrations of Sr, Li, B in relation to the salinity of groundwater suggest that the extreme saline member involved in the blend has a different composition to that of modern seawater (Carnoda et al. 2004).

The bromide ion is considered as a good indicator of seawater intrusion in coastal aquifers. Because of their similar geochemical behavior and low chemical activity, bromide and chloride are often associated to study the origin of chloride and the anomalies of salinity affecting groundwater (Tadolini and Tulipano 1975; Marjoua et al., 1997; Hsissou et al., 1999). The hydrogeochemical interest of bromine is basically in the study of saline waters and brines, since its concentration allows the degree of evaporation of seawater to be known, as bromine accumulates in the residual brine (Sanders, 1991; Richter and Kreitler, 1993). The ratio Cl/Br has been used to identify different saline flows and their relative contribution (Dror et al., 1999), to distinguish between natural and anthropogenic causes of salinization (Arad et al., 1986; Gerritse and George, 1988; Richter and Kreitler, 1993; Tijani et al., 1996; Andreasen and Fleck, 1997; Hsissou et al., 1999; Cruz and Silva, 2000; Fakir et al., 2002). However, Br can be accumulated by marine organisms which as a consequence of diagenetic processes can be released, increasing therefore its concentration in the water (Fabrika Martin et al., 1991). Also, Fontes and Matray (1993) reported that Cl/Br ratio values vary in the cases of precipitation or dissolution of solid chlorides and during convective or diffusive mixing of saline solutions. Ratios of bromide to chloride (Br/Cl) have been extensively used in the determination of sources of salinity. Only a few halogen series elements such as chloride and

Table 3.3. Minor Ions and ratios of some waters in the study area.

Number	Br/Cl	B/Cl	Sr/Ca	Br ppb	B ppb	Li ppb	Sr ppb
18	0.00296	0.00105	11.776	4394	1553	19.8	371.44
24	0.00263	0.00018	1.864	4161	283	16	547.11
25	0.00377	0.00020	1.771	4168	223	13	530.14
26	0.00345	0.00018	1.865	3884	205	15.2	551.66
27	0.00368	0.00021	2.729	6324	365	27.1	779.63
30	0.00452	0.00046	1.211	466	47	4	509.35
31	0.00215	0.00045	1.507	1356	285	9.9	343.23
32	0.00065	0.00026	0.960	37	15	3.4	230.56
33	0.00169	0.00058	1.005	44	15	2.3	164.59
34	0.00344	0.00094	0.604	55	15	2.8	142.85
35	0.00372	0.00080	2.071	171	37	11.6	460.57
36	0.00148	0.00103	1.653	177	124	5.2	195.49
39	0.00364	0.00013	0.936	1388	51	4.1	228.22
40	0.00309	0.00016	0.871	1112	56	4.3	217.4
41	0.00417	0.00089	5.538	6261	1332	18.5	482.79
42	0.00401	0.00017	2.289	6338	268	15	1693.71
43	0.00416	0.00019	2.989	12390	570	30.7	1202.71
44	0.00286	0.00017	1.629	3689	219	13.8	548.09
45	0.00423	0.00023	0.848	1655	89	7.3	264.81
46	0.00438	0.00021	2.863	14627	695	40.3	1363.22
47	0.00458	0.00062	1.711	943	128	8.8	338.49
48	0.00517	0.00022	1.143	1216	52	5.8	804.42
49	0.00271	0.00040	1.578	2018	296	15.2	501.57
50	0.00311	0.00019	1.345	1977	119	7.9	311.65
51	0.00389	0.00048	2.612	4788	589	11.1	758.42
52	0.00305	0.00019	0.634	461	29	2.1	135.65
53	0.00253	0.00051	0.345	144	29	2.1	91.95
54	0.00313	0.00047	1.120	100	15	3.4	187.92
55	0.00314	0.00214	0.243	22	15	1.4	55.44
56	0.00318	0.00054	1.825	124	21	5.7	307.36
57	0.00240	0.00100	0.501	36	15	0.5	47.79
58	0.00325	0.00048	1.494	208	31	6.1	308.67
59	0.00217	0.00125	1.079	26	15	0.3	159.94
SW	0.00343	0.00022	6.890	60984	3923	169.3	7184.15

bromide are known to be chemically unreactive, that is, once in solution, they are not easily removed by processes other than precipitation at very late evaporation stages (Gat, 1981; Richter and Kreitler, 1993). The Br/Cl ratios have been used to distinguish salinity of marine and non-marine origins (Andreasen and Fleck, 1997). Because Br and Cl are relatively conservative in hydrological systems, the Br/Cl ratios of fresh waters are primarily controlled by the initial ratio in precipitation (Kim et al., 2003). Most of the chloride-enriched samples exhibit Cl/Br ratios close to seawater values (Figure 3.12).

They correspond, in fact, to groundwaters located generally more than 1 km from the coastline and which are affected by seawater intrusion. The Br/Cl molar ratio of local seawater is equal to 0.028 and the same ratios can be determined in Zeytinköy village, Lake Gebekirse, Lake Akgöl, Zeytinköy karstic discharge, Küçük Menderes River (Pamucak Bridge) and İzmir Gorge (Table 3.2.). The average Br/Cl molar ratio in the saline groundwaters of the study area is approximately 0.0031, 0.0038 in rainy and dry season, respectively that is slightly greater than the average ratio in seawater of the study area (0.0028). Thus, the mixing of intruded seawater with fresh water caused only a slight change in the Br/Cl ratio.

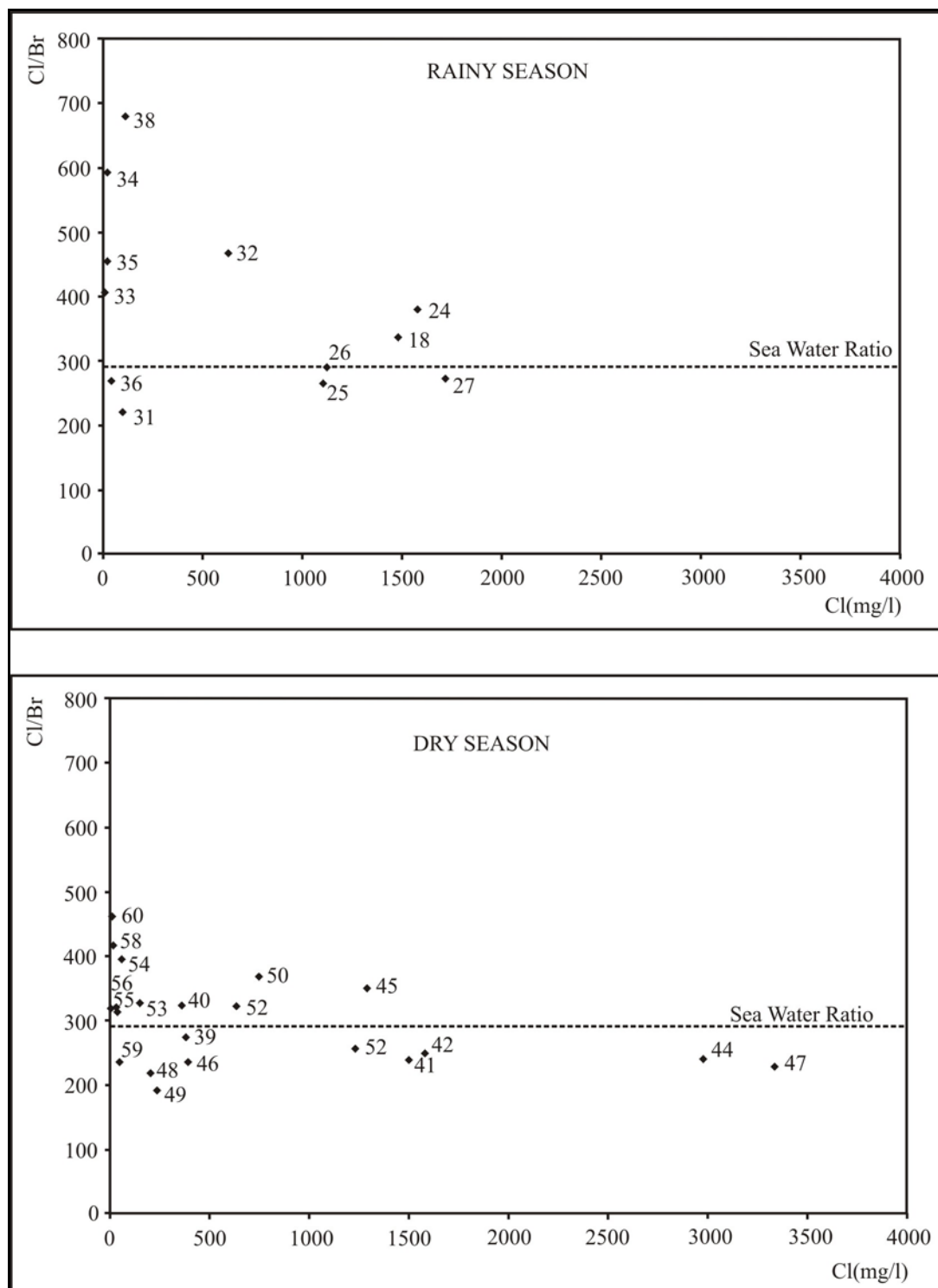


Figure 3.12. Cl/Br vs Cl diagram for rainy and dry season.

The variable occurrence of boron in the groundwaters suggests that it is controlled by a whole series of different factors (Sanches-Martos and Pulido-Bosch, 1999). Boron tends to be concentrated in environments with limited water circulation such as evaporates or brines of marine or continental origin (Uhlman, 1991). This is highlighted by the correlation between the salinity of the environment and that of the sediments (Adams et al., 1965). The boron and various relationships with other ions have been used to distinguish the origin of salinity (Arad et al., 1986). The high boron concentration in sea-water leads one to consider it is an indicator of marine intrusion processes (Gimelez, 1994). Based on these considerations it could be deduced that a direct relationship exists between the conductivity of the groundwaters and their boron content (Sanches-Martos and Pulido-Bosch, 1999). Boron values versus EC diagram is shown in Figure 3.13. At this diagram, surface waters: lakes, river and swamp are demonstrated distortion line from groundwater-seawater line due to the high evaporation rate in the area. The ratio B/Cl was used to distinguish the marine influence on boron. In the study area, the seawater has $18 \cdot 10^{-4}$ B/Cl ratios. Lake Gebekirse and Akgöl, karstic spring shows the same ratios in both season. In addition, in dry season the river, swamp, Zeytinköy village groundwater and İzmir Gorge show the similar ratios with seawater.

In some cases, the elevated boron content, is related to the influence of other types of salinization, to contamination from anthropogenic origin associated with urban wastewaters (Vengosh and Rosenthal, 1994) can be explained the why the irrigation channel and river is the similar with seawater.

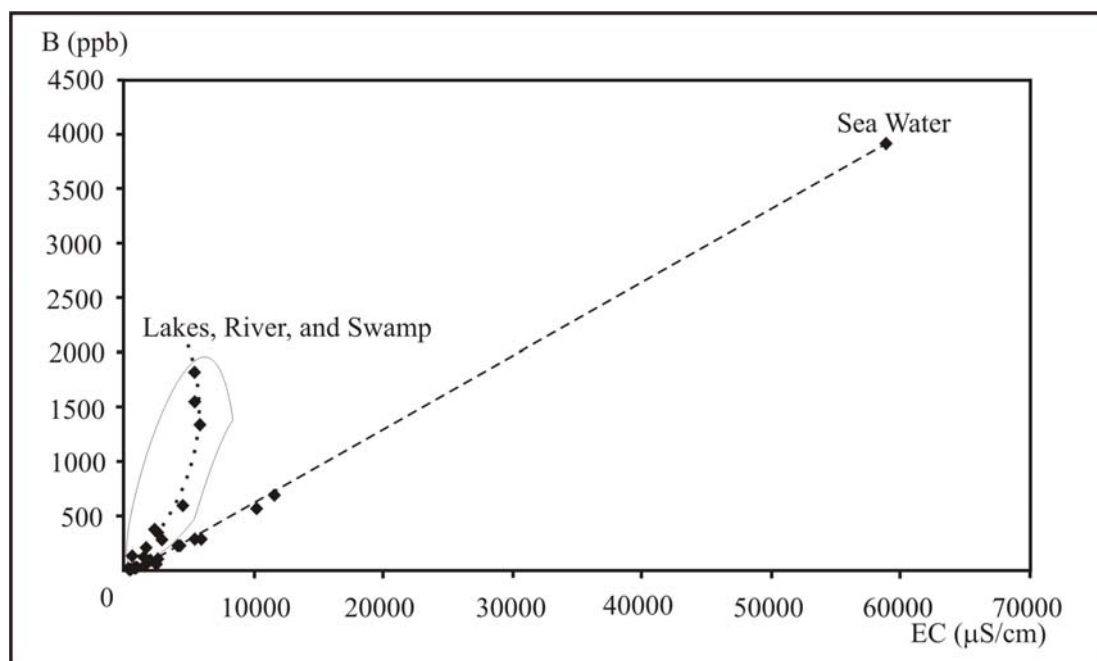


Figure 3.13. Boron vs EC diagram in the Selçuk Plain.

Lithium has even been used as a tracer in the mixing of brines produced by evaporation of seawater (Fontes and Matray, 1993). In coastal aquifers suffering from marine intrusion there is a linear relationship between the Li and Cl content, assuming that there are no other inputs of water (Brondi et al., 1983; Gimenez and Morell, 1991). In the study area, Cl vs Li shows a perfect correlation in both dry and rainy season; $r^2 = 0.9$ and $r^2 = 0.8$, respectively (Figure 3.14).

Clayey minerals play an important role for lithium, due to its capacity for replacing to Mg and Fe in the lattice (Gimenez and Morell, 1997). Lithium can be used as indicator of residence time of water in aquifer, related to the rock-water contact time or the residence time of sea-water in the aquifer (Brondi et al., 1973; Tulipano and Fidellibus, 1984). Lithium is directly related to water temperature whilst B content increases in more saline areas, since it is associated with the presence of evaporitic and or marine influences (Sanchez-Martos et al., 2001).

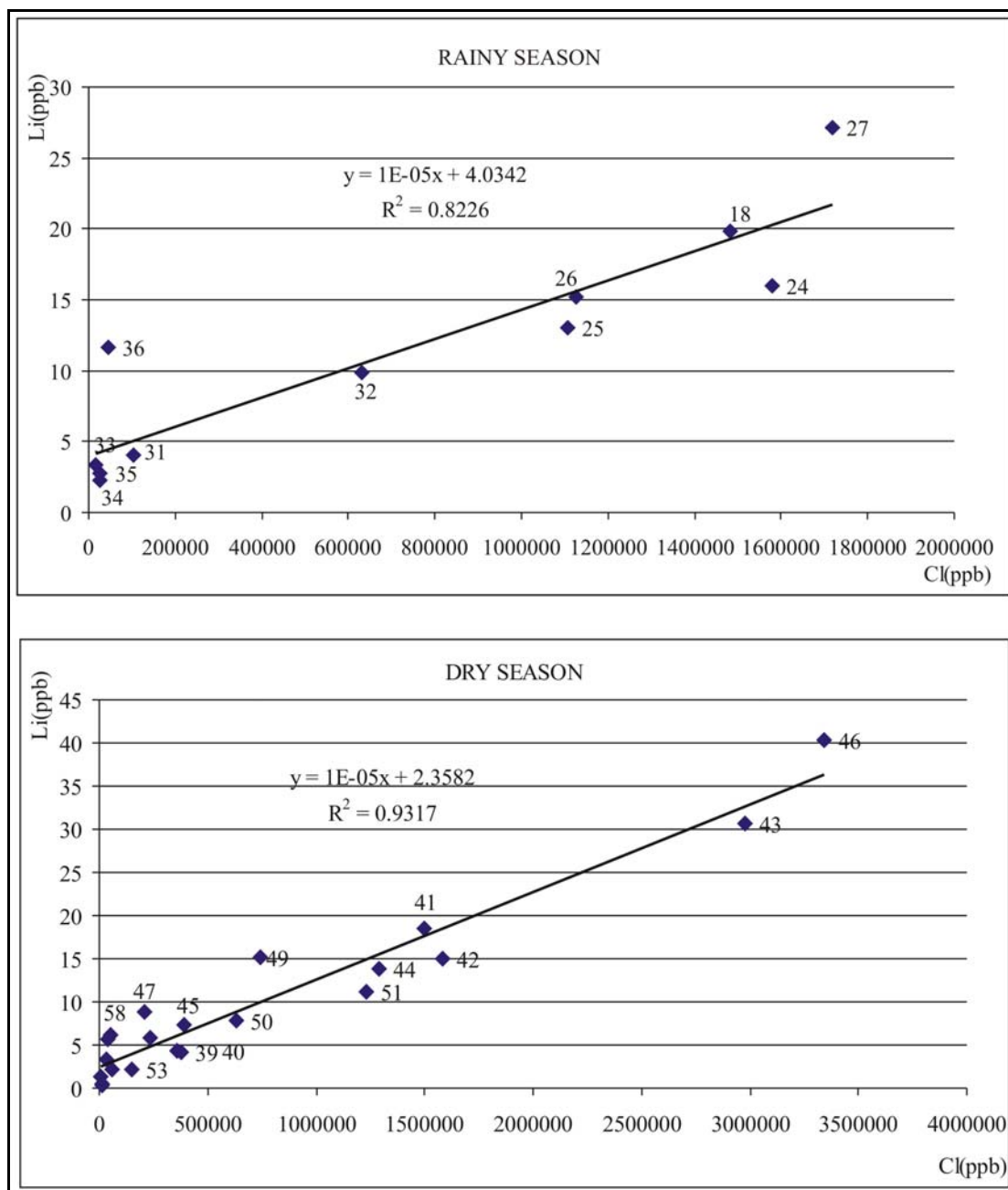


Figure 3.14. Relationship between Cl and Li in the study area.

The lithium concentration of swamp, karstic discharges, lakes and river are greater than other parts of the study area. Except swamp water, all other waters show perfect correlation with boron and lithium that suggests a common origin. The existence of lithium as an exchangeable ion in organic matter must also to be considered, because of the high exchange capacity of these materials (Heier and Billings, 1970). So in the swamp, the relationship between B and Li can be shown an irregularity.

Strontium, probably because of multiple sources of dissolved strontium in these aquifers as well as in the brackish water of the lagoons. Although classified as a trace element, Sr occurs in easily measurable quantities in most rock types and behaves geochemically like Ca (Gosselin et al., 2004). Enrichment of Sr in some waters could be related with the time of residence of water in the aquifer, so that the ion is a good environmental tracer (Brondi et al., 1983). According to Meybeck (1984), a ratio of Sr/Ca superior to 1‰ characterizes water of evaporitic origin. In the coastal zone samples 18, 24, 25, 26 and 27 in rainy season; samples 41, 42, 43 and 44 in dry season are exceeded 1‰ Sr/Ca molar ratio due to the sea-water effect. On the other hand, the seawater where the strontium concentration is of the order of 9–14 mg/l Morell et al., 1986 can bring this cation to coastal aquifers affected by seawater intrusion. In our study area, the sea-water has 7.184 mg/l Sr value. Above the 0.5 mg/l Sr concentration that can be seen at the coastal zone is pointed out the sea-water intrusion. On the other hand, high ratio values of Sr/Ca indicate an additional input of strontium that can be derived from carbonate precipitation/dissolution reactions in the hilly area.

3.6 Conclusion

To identify the salinization process in Selçuk Plain, the major ion ratios (Na/Cl, Na/Ca, Mg/Ca, SO_4/Cl , HCO_3/Cl), minor ions (B, Br, Li, Sr) and minor ion ratios (Br/Cl, B/Cl, Sr/Ca) were used.

According to major ion ratios, coastal zone that included wetland shows seawater character as Na/Cl, Na/Ca. In the plain, especially alluvium, the Na-Ca direct exchange reaction can be seen clearly due to the seawater intrusion. HCO_3/Cl diagram is suggesting that high TDS coastal zone groundwaters are typically enriched in chloride ion, mainly due to seawater mixing. According to SO_4/Cl ratios, coastal zone takes places on the “Seawater Influence” line in both seasons that was proved the coastal zone is under seawater effect.

Minor ions have good correlation with Cl ion that can be a result the seawater influence. As major ion ratios, the minor ions are identified the salinization process is a result of seawater intrusion. Cl/Br, B/Cl, Sr/Ca give the similarity with local seawater characteristics.

On the other hand, Piper Diagram, Schoeller semi logarithmic diagram, Gibbs Diagram and mixing ratios are proved the salinization problem comes from seawater.

CHAPTER FOUR

GEOGRAPHICAL INFORMATION SYSTEM (GIS)

4.1 Introduction

“Geographical Information System (GIS) is a collection of computer hardware, software, and geographic data for capturing, managing, analyzing, and displaying all forms of geographically referenced information” (ESRI, 2006).

According to Constantin Gogu et al, 2001 that they were studied about “GIS-based hydrogeological databases and groundwater modelling”, a GIS is defined as a system for input, storage, manipulation, and output of geographically referenced data (Goodchild, 1996). GIS provides a means of representing the real world through integrated layers of constituent spatial information (Corwin, 1996). Geographic information can be represented in GIS as *objects* or *fields*. The object approach represents the real world through simple objects such as points, lines, and areas. The objects, representing entities, are characterised by geometry, topology, and non-spatial attribute values (Heuvelink, 1998). In hydrogeology, some examples of spatial objects are wells, piezometers, boreholes, galleries, and zones of protection. Attribute values of objects could be the number of a well, the ownership, and the diameter of a gallery or drain. The field approach represents the real world as fields of attribute data without defining objects; some examples are strata elevation, hydraulic head, and vulnerability zones. This approach provides attribute values in any location. In GIS, this distinction between *objects* and *fields* is often associated with *vector* data models and *raster* data models. The *vector model* represents spatial phenomena through differences in the distribution of properties of points, lines, and areas. In this system, each layer is an adapted combination of one or more classes of geometrical features. A *raster model* consists of a rectangular array of cells with values being assigned to each cell. In the raster model, each cell is usually restricted to a single value. Thus, representing the spatial distribution of a number of parameters or variables requires multiple layers. In their work, environmental

specialists need to have available clear representations of the spatial variation of the data. In GIS, two ways exist to solve this problem: (1) field variables (a variable can be given a single, welldefined value at every location), and (2) kernel functions (spatially continuous functions). For digital representation of the spatial variation characterised by fields, six methods are distinguished: the raster model, grid model (rectangular array of sample points), point model (areally irregularly distributed sample points), contour model (isolines), polygon model (polygons holding average attribute values), and triangular irregular network (TIN). Storing and manipulating data through spatial relationships can be achieved with the GIS packages using the “georelational” model or the “geodatabase” model. The first consists of linking a relational database to geometrical features. The modelled entities are organised into categories sharing common characteristics (points representing wells, piezometers, or gallery wells). A table represents each category. The different attributes occur as columns of the table, and the rows assure the data registration. Relationships “one to one” or “one to many” can be established between tables (Levene and Loizou 1999).

4.2 Materials and Methods

To investigate the salinization zone in Selçuk Plain (Figure 4.1), Idrisi Kilimanjaro (Eastman, 1999) and ArcGIS (Booth and Mitchell, 1999) Geographical Information System (GIS) and remote sensing packages manipulated all the calculated data. IDRISI is a grid-based geographic information and image processing system developed by the Graduate School of Geography at Clark University and supported by the United Nations Institute for Training and Research (UNITAR) and the United Nations Environment Programme Global Resource Information Database (UNEP/GRID) (Ross and Beljin, 1994). IDRISI provides an extensive set of tools for image processing, geographic and statistical analysis, spatial decision support, time series analysis, data display, and import/export and conversion. In addition, as a set of independent program modules linked to a broad set of simple data structures.

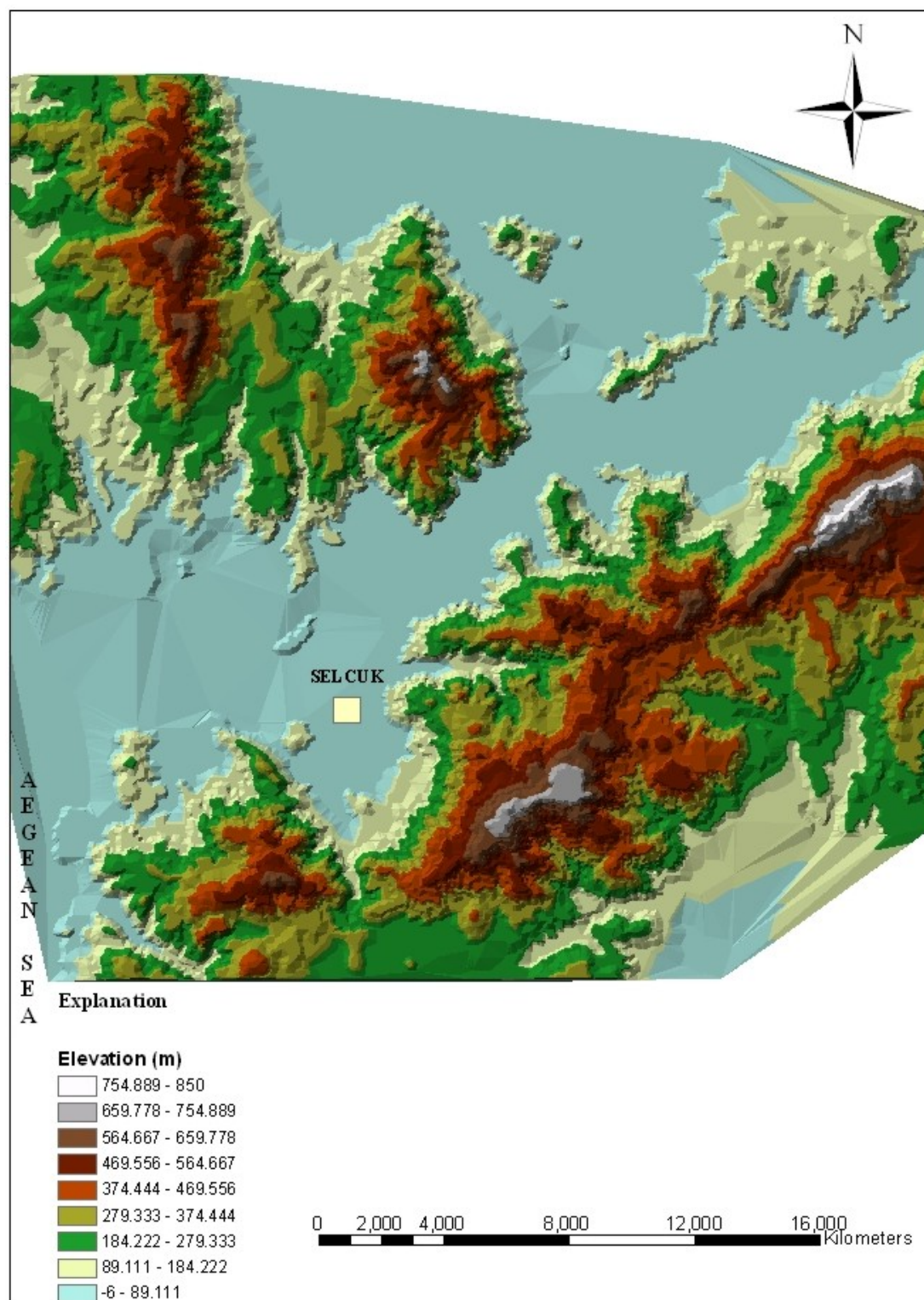


Figure 4.1. Location map of the study area.

GIS is used as a tool to determine the salinization zone with the Na/Cl, Na/Ca, Mg/Ca ratios and, EC and mixing ratios. The flow chart is explained as follows (Figure 4.2):

- a. The location of water samples were digitized in Idrisi as point data.
- b. The database for the data obtained from the sample locations was constructed in Idrisi Kilimanjaro package.
- c. Digital point data and constructed database were linked.
- d. Point data that have database were converted to shape file and these data were exported to ArcGIS package.
- e. The distribution map of each ratio was constituted in ArcGIS package by using point data. For these processes, applied ArcGIS spatial analyst extension was used. The “Inverse Distance” interpolation method was applied to obtain the distribution values.
- f. The distribution values maps were queried using the “raster calculator” tool in ArcGIS package.
- g. The logical relationships were constructed between the each distribution value maps that represent saline and fresh water areas.
- h. The zones showing the saline and fresh areas obtained from the each distribution values maps were gained.
- i. These results maps are in Boolean format (1, 0) that represents saline and fresh water zones, respectively.

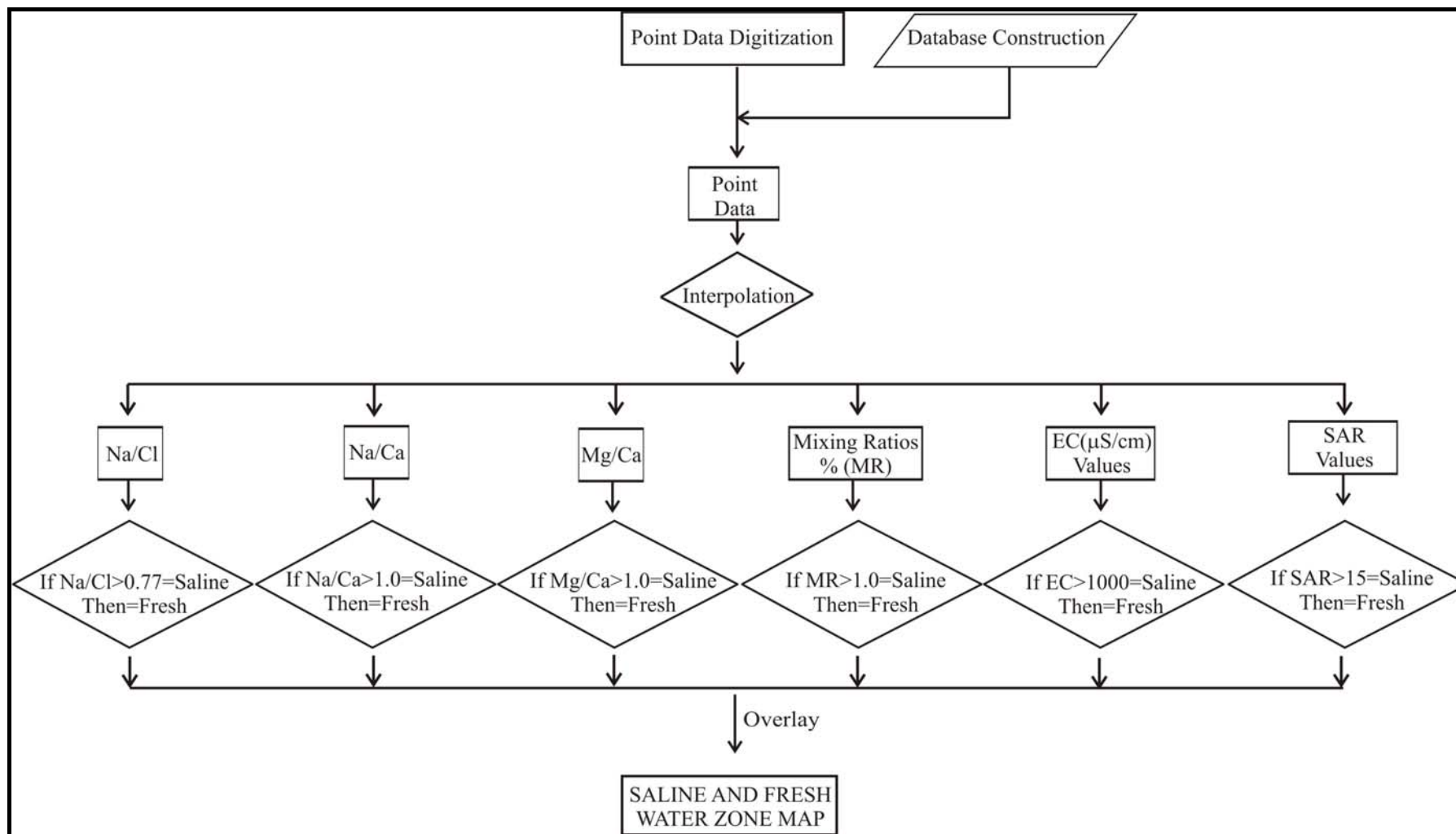


Figure 4.2. Flow chart of GIS processes for this study.

4.3 Evaluation and Interpretation the Thematic Maps of the GIS System

“GIS systems provide an integrated tool for the illustration of the physical characteristics within a certain area, as well as the presentation of relative statistical or elaborated data onto properly designed thematic maps. Therefore they may be used by authorities for the management of natural resources within a certain extent” (Kallioras et al, 2006).

A GIS-based method is developed in this study related with major ion ratios (Na/Cl, Na/Ca, Mg/Ca), mixing ratios (MR), measured EC values and calculated SAR to determine the “Saline” and “Fresh” water zones at the Selçuk Plain in both dry and rainy seasons. Finally, a composite salinization zone map is obtained (Figure 4.8).

The reasons why these parameters were chosen is explained as follows:

Cl is chemically conservative and is not easily removed by most processes then precipitation (Hem, 1985; Richter and Kreitler, 1993) as cited in Chapter Three. So the Na/Cl ratio is used as one of the salinization parameters.

Na/Ca ratio is used for direct cation-exchange reaction that occurs freshwater/seawater interface (Chapter Three).

Mg/Ca ratio can be a direct indicator if greater than 5 in the coastal area. In Selçuk Plain only seawater has 5.5 values (Table 3.2) and the influenced waters in the coastal zone have greater than 1 Mg/Ca ratio value.

Since conductance is a strong function of the total dissolved ionic solids, either EC measurement or a total dissolved solids (TDS) analysis could be used in measuring the salinity of water (Simsek and Gunduz, 2006). So EC values are chosen to indicate the salinity of waters. According to Petalas 1997, an EC values greater than 1000 $\mu\text{S}/\text{cm}$ was considered to be indicative of saline-water intrusion and was used for mapping contaminated areas.

The two most common water quality factors that influence the normal rate of infiltration of water are the salinity of water and the relative concentrations of sodium, magnesium and calcium ions in water that is also known as the sodium adsorption ratio (SAR) (Simsek and Gunduz, 2006). SAR values have been used for salinization since 1970s.

A salinization map method is developed by all of these chemical data. The range values were determined according to both early studies (eg. Mg/Ca, EC, SAR) and these study's data (eg. Na/Cl, Na/Ca, MR) (Table 4.1).

Table 4.1. Parametres to determine the salinization zone .

Parameters	Range	Suitability	Boolean format	Referances
Na/Cl	> 0.777	Saline	1	
	< 0.777	Fresh	0	
Mg/Ca	> 1	Saline	1	M&E, 2000
	< 1	Fresh	0	
Na/Ca	> 1	Saline	1	
	< 1	Fresh	0	
MR	$> 1 (\%)$	Saline	1	
	$< 1(\%)$	Fresh	0	
EC	$> 1000 \mu\text{S/cm}$	Saline	1	Petalas, 1997
	$< 1000 \mu\text{S/cm}$	Fresh	0	
SAR	>15	Saline	1	EPA,1986
	<15	Fresh	0	

Distribution map of the Na/Cl ratio is given Figure 4.3 (A: Dry Season - B: Rainy Season). The Na/Cl ratio is about 1 in and around Eleman Swamp. In the dry season this ratio was reached seawater value in and around Lake Kocagöz that takes place southern of the study area because of more evaporation, no precipitation. But in rainy season, due to the precipitation and so dilution, the high values recede to the coastal zone such as Eleman Swamp.

High values of Na/Ca ratio represents direct cation-exchange reaction in fresh/seawater interface. The calculated value of Na/Ca of the seawater is 23.23 (Chapter Three, Table 3.2). As seen from Figure 4.4 (A: Dry Season - B: Rainy Season), the high values of this ratio can be seen in and around swamp due to the clay minerals in the alluvium and this ratio are reached 76 in the swamp in rainy season.

If Mg/Ca molar ratio is bigger than 1, it indicates the seawater intrusion in the study area. From the point view of Figure 4.5 (A: Dry Season - B: Rainy Season), Mg/Ca ratio of especially Eleman Swamp, Zeytinköy village, all of lakes, and karstic springs are more than 1 in both season whereas the seawater value is 5.5 in Pamucak. The differences between dry and rainy season is the maximum value is gone forward to the northern part of the study area.

Mixing ratio distribution map (Figure 4.6- A: Dry Season - B: Rainy Season) is clearly explain the mixing process between fresh and salt water in the study area. In the coastal zone the MR are more than 1 (%). According to Figure 4.6, it can be clearly seen that, Lake Gebekirse, Kazangöl Karstic spring, Zeytinköy Karstic spring, Eleman Swamp and Lake Akgöl are influence from the seawater directly in both season.

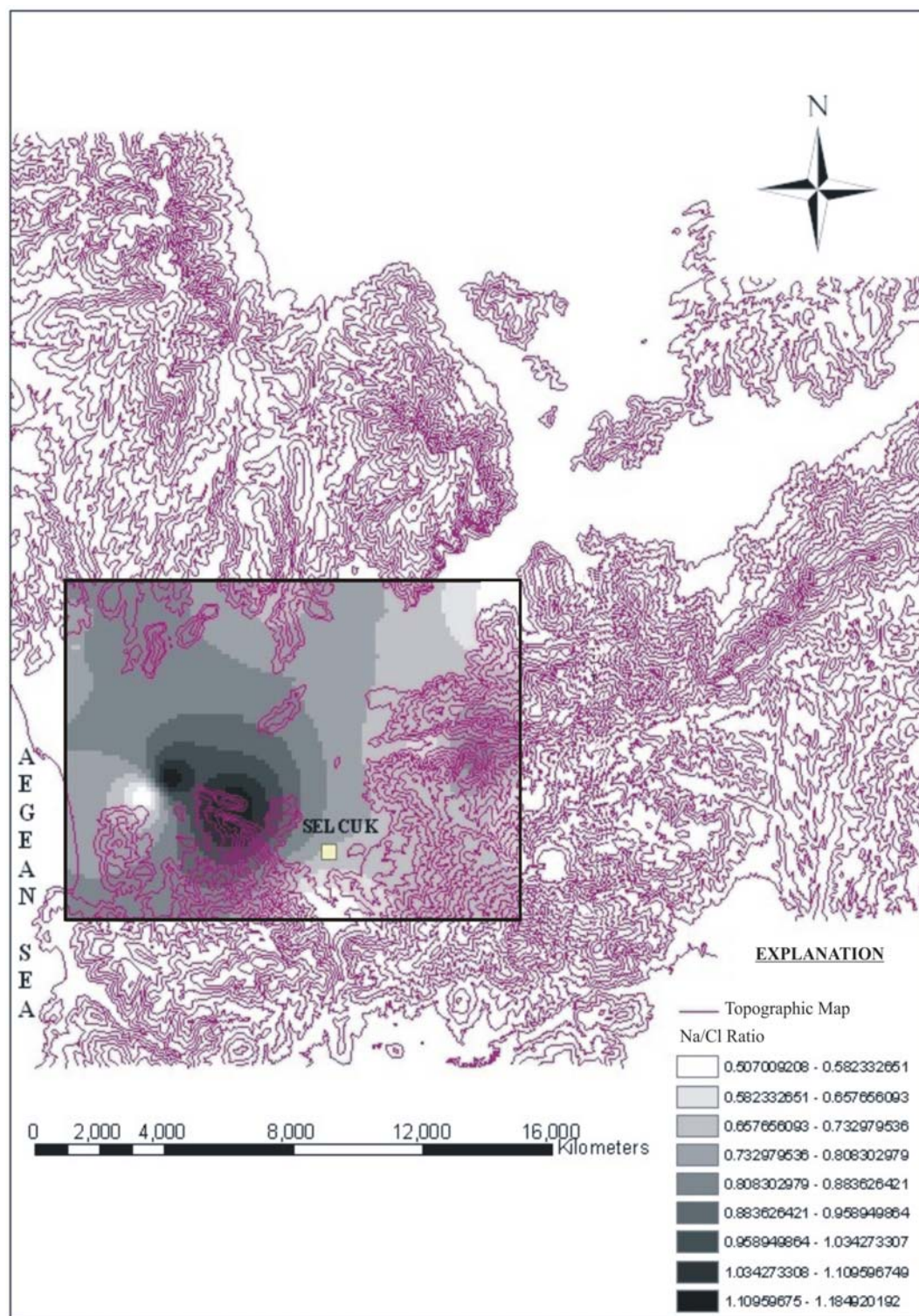


Figure 4.3. (A) Na/Cl ratio distribution map in dry season

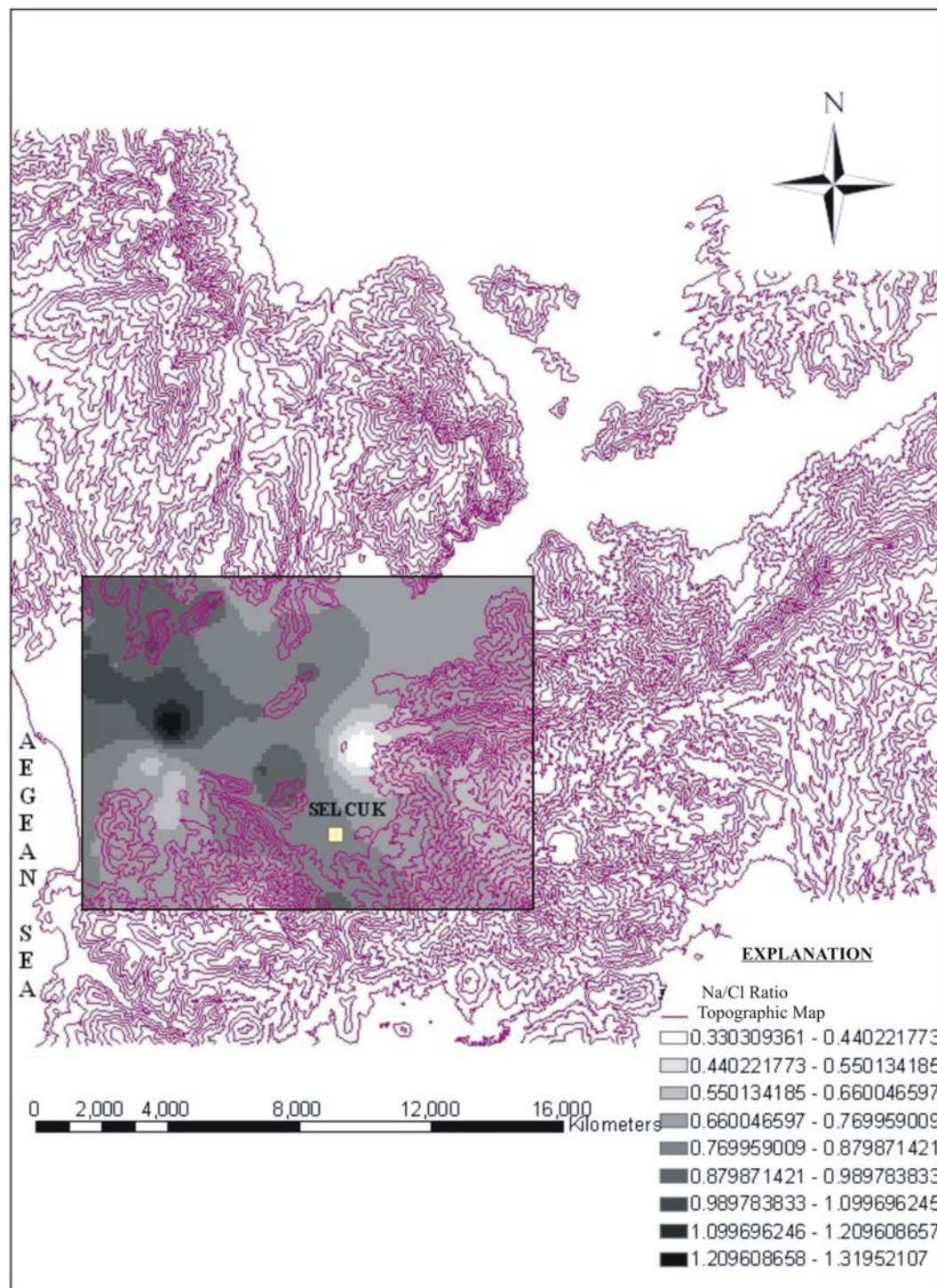


Figure 4.3. (B) Na/Cl ratio distribution map in rainy season.

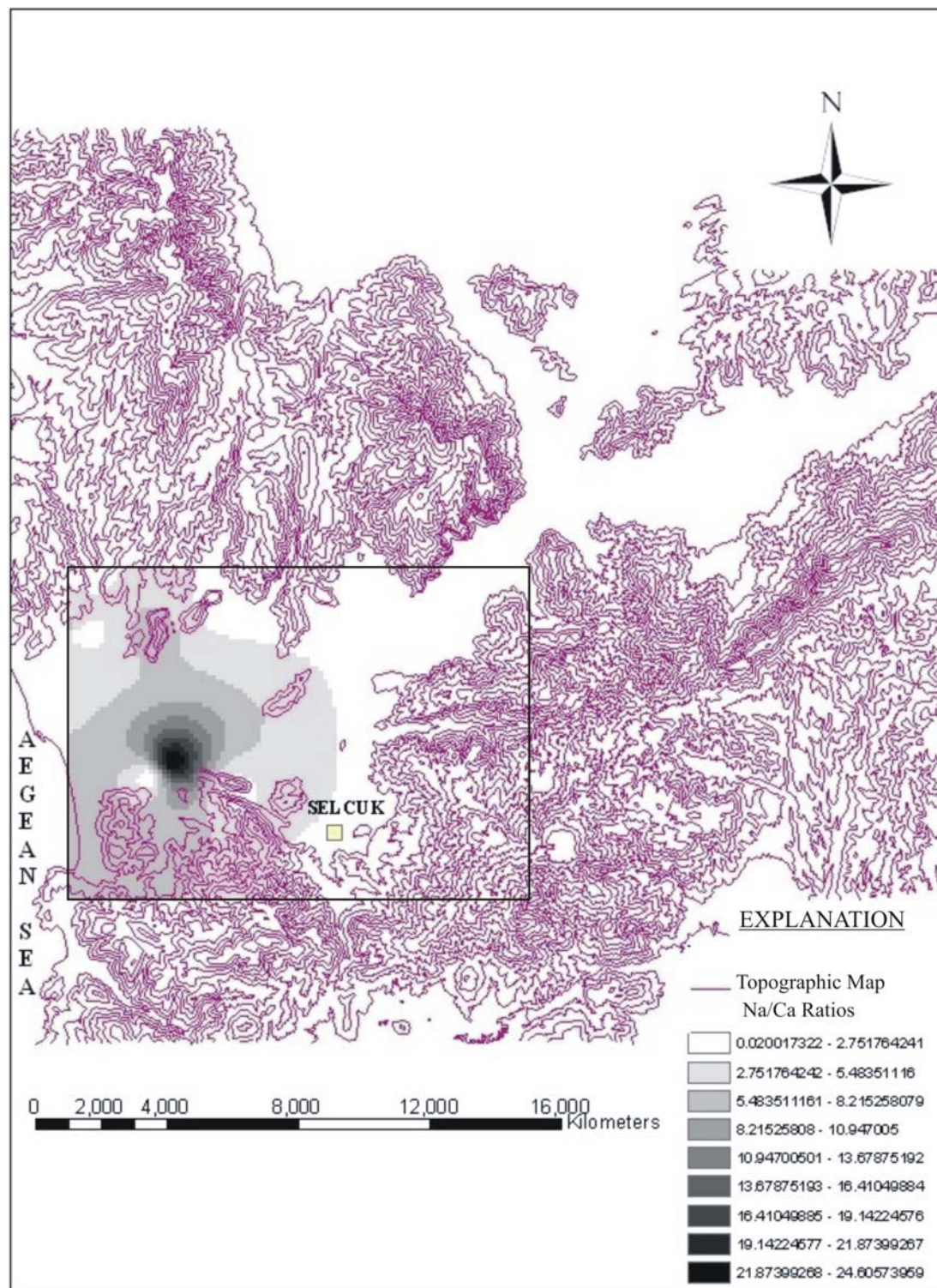


Figure 4.4. (A) Na/Ca ratio distribution map in dry season.

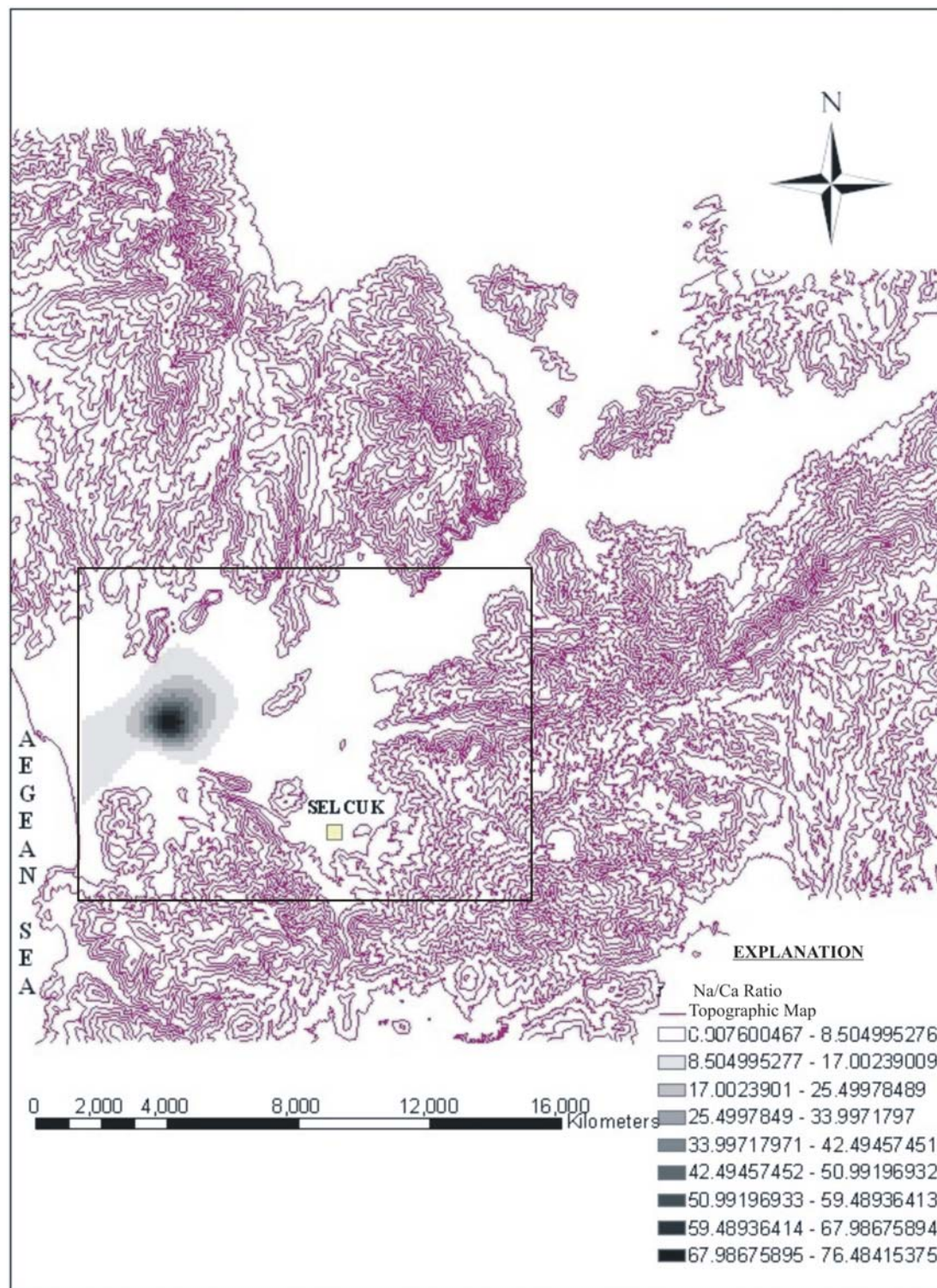


Figure 4.4. (B) Na/Ca ratio distribution map in rainy season.

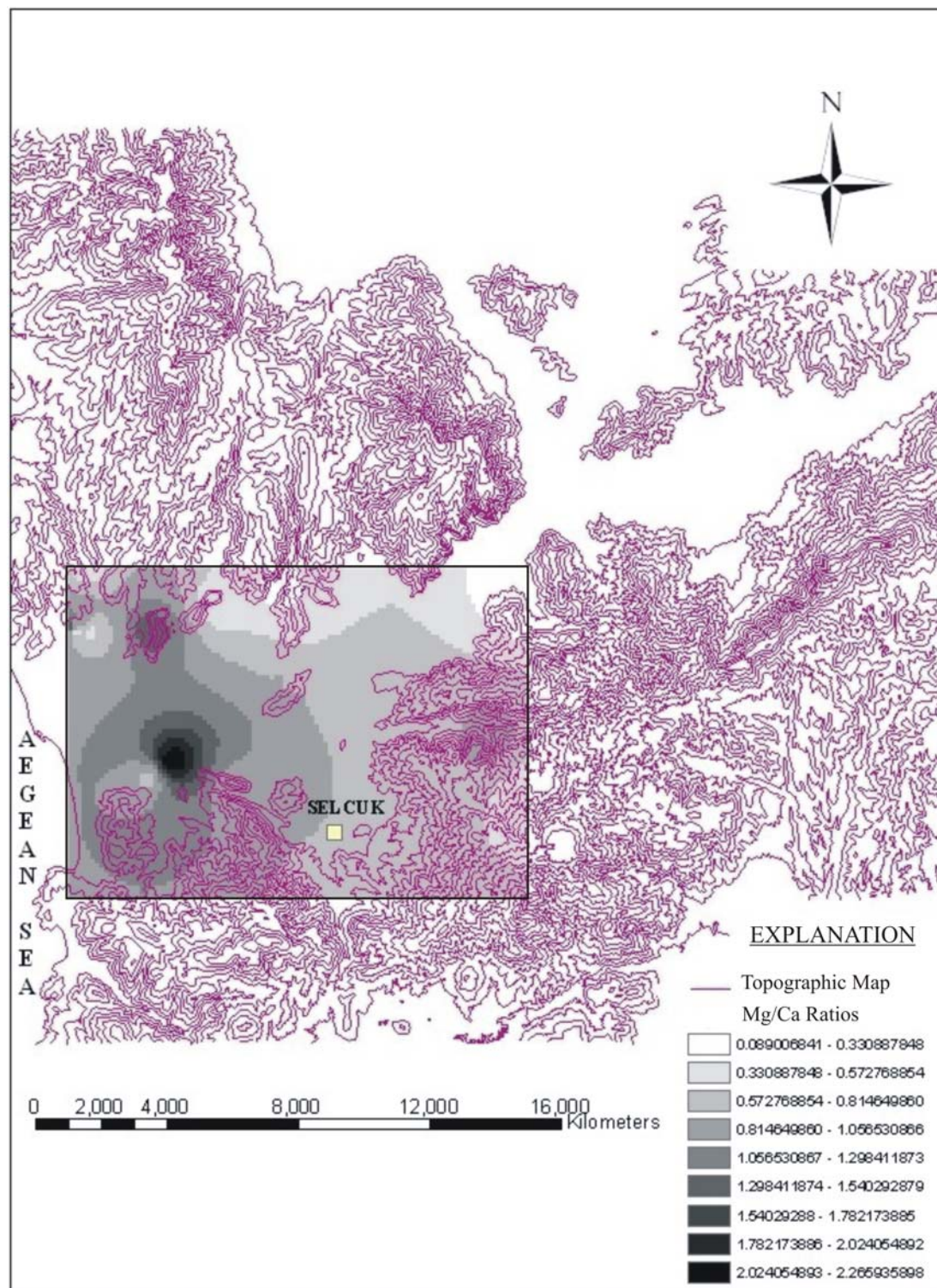


Figure 4.5. (A) Mg/Ca ratio distribution map in dry season.

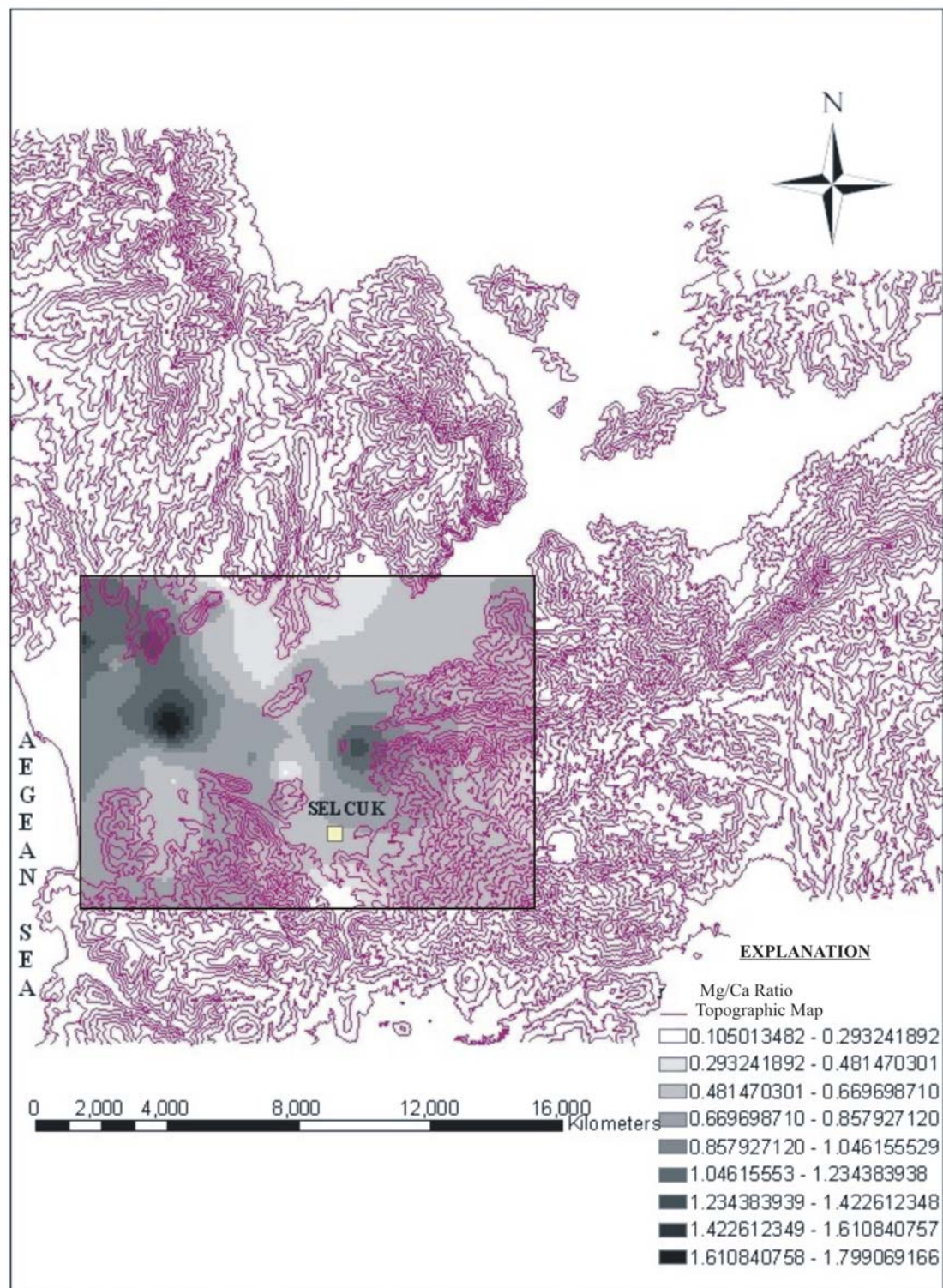


Figure 4.5. (B) Mg/Ca ratio distribution map in rainy season.

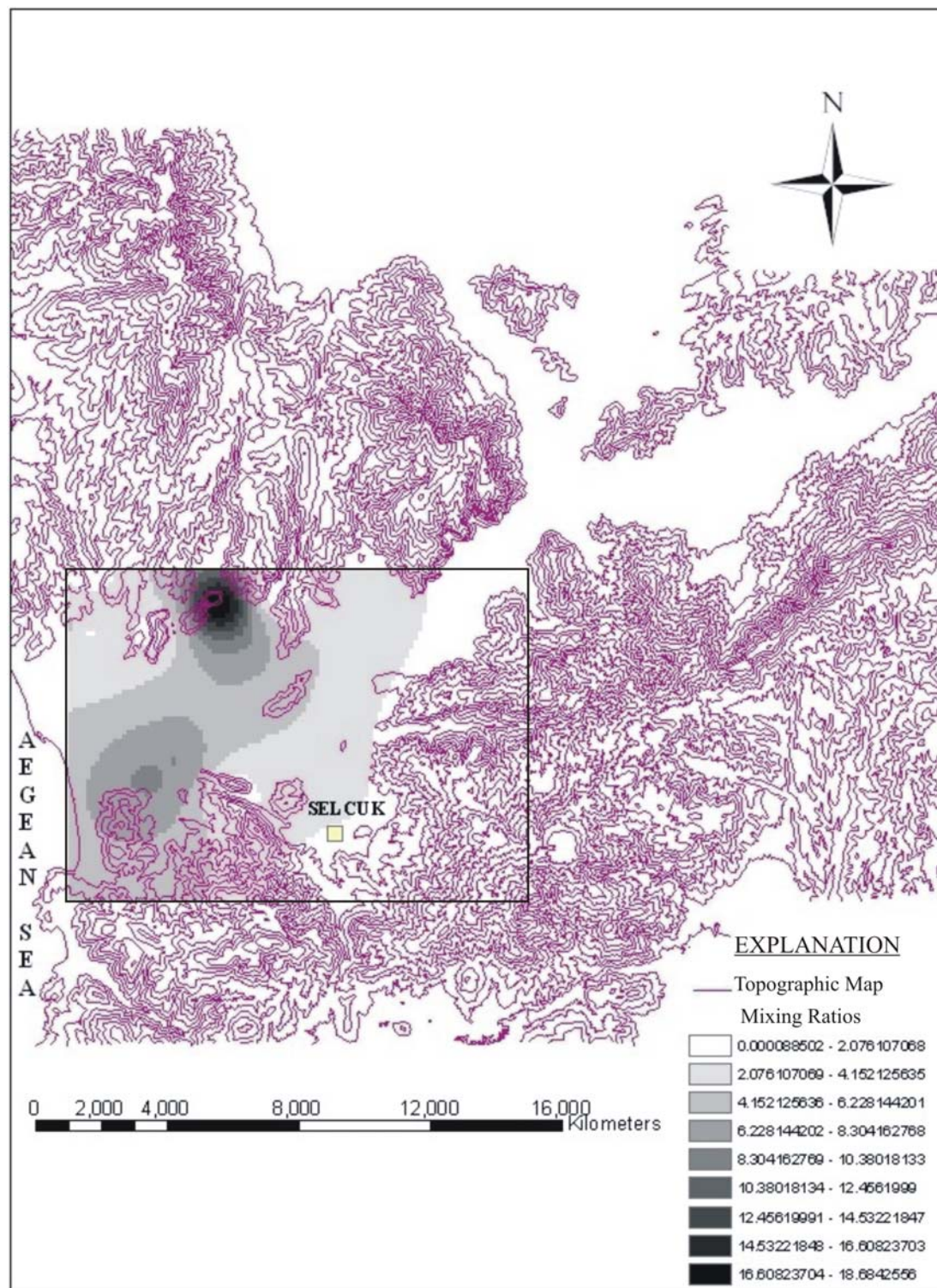


Figure 4.6. (A) Mixing ratio distribution map in dry season.

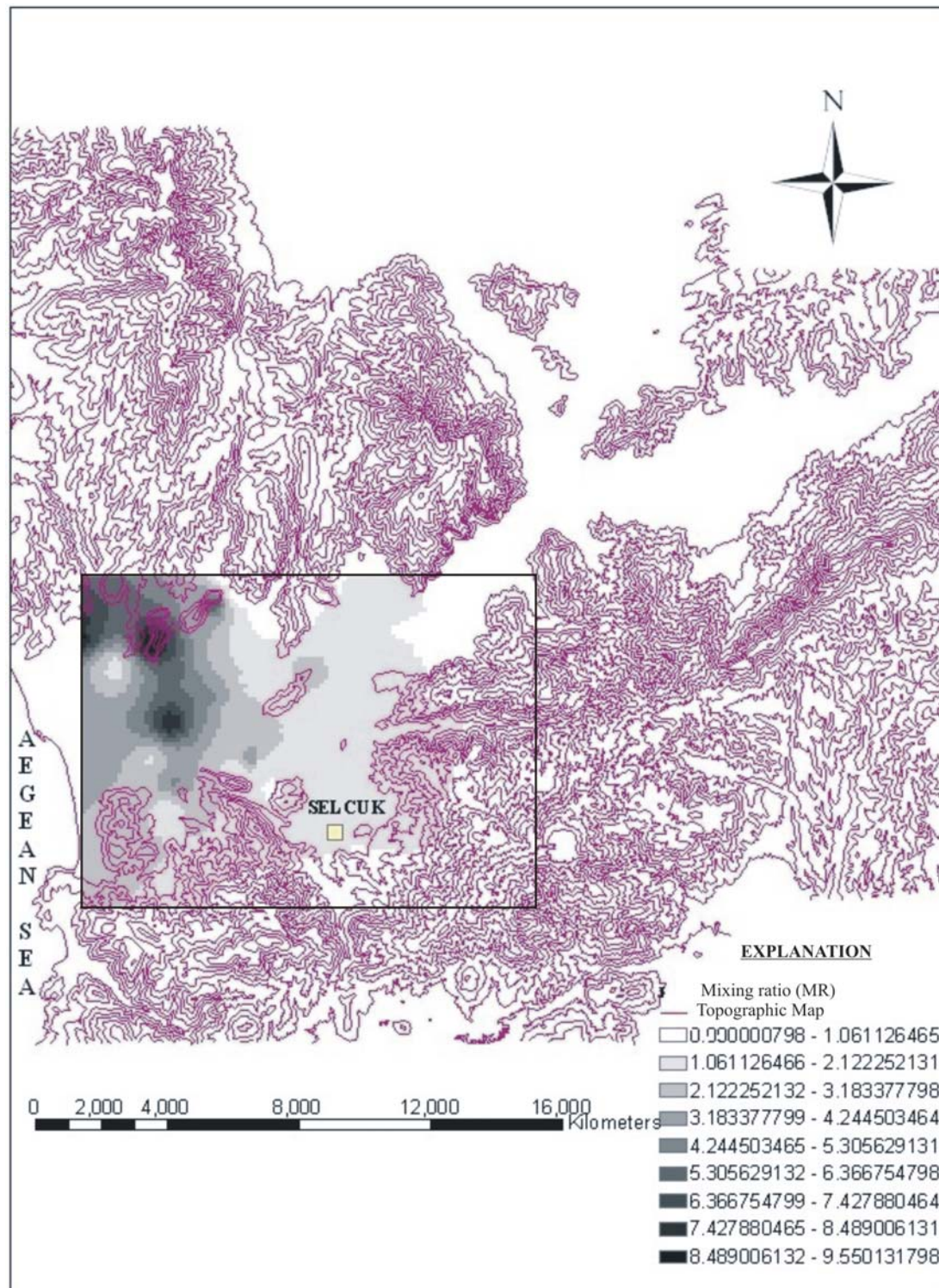


Figure 4.6. (B) Mixing ratio distribution map in rainy season.

According to EC distribution map (Figure 4.7), due to the high evaporation rate, the EC values increase in dry season. In contrast, these values are decreased in rainy season because the rainfall values are increased. EC values distribution show the similarity with MR distribution map due to the relationship between Cl and EC. As MR map, the coastal zone is affected from seawater intrusion.

In the dry season, the SAR values can be exceeded the 15 value in and around swamp and Lake Gebekirse (Figure 4.8-A). SAR is a function of salinity so in the dry season the distribution of SAR is widely then rainy season due to the high evaporation rate in dry season. But in rainy season, due to the dilution from precipitation Na ions are decreases and the SAR values are, too. In Figure 4.8-B this situation can be clearly seen. The distribution of high values of SAR become narrow and can be seen in and around only swamp.

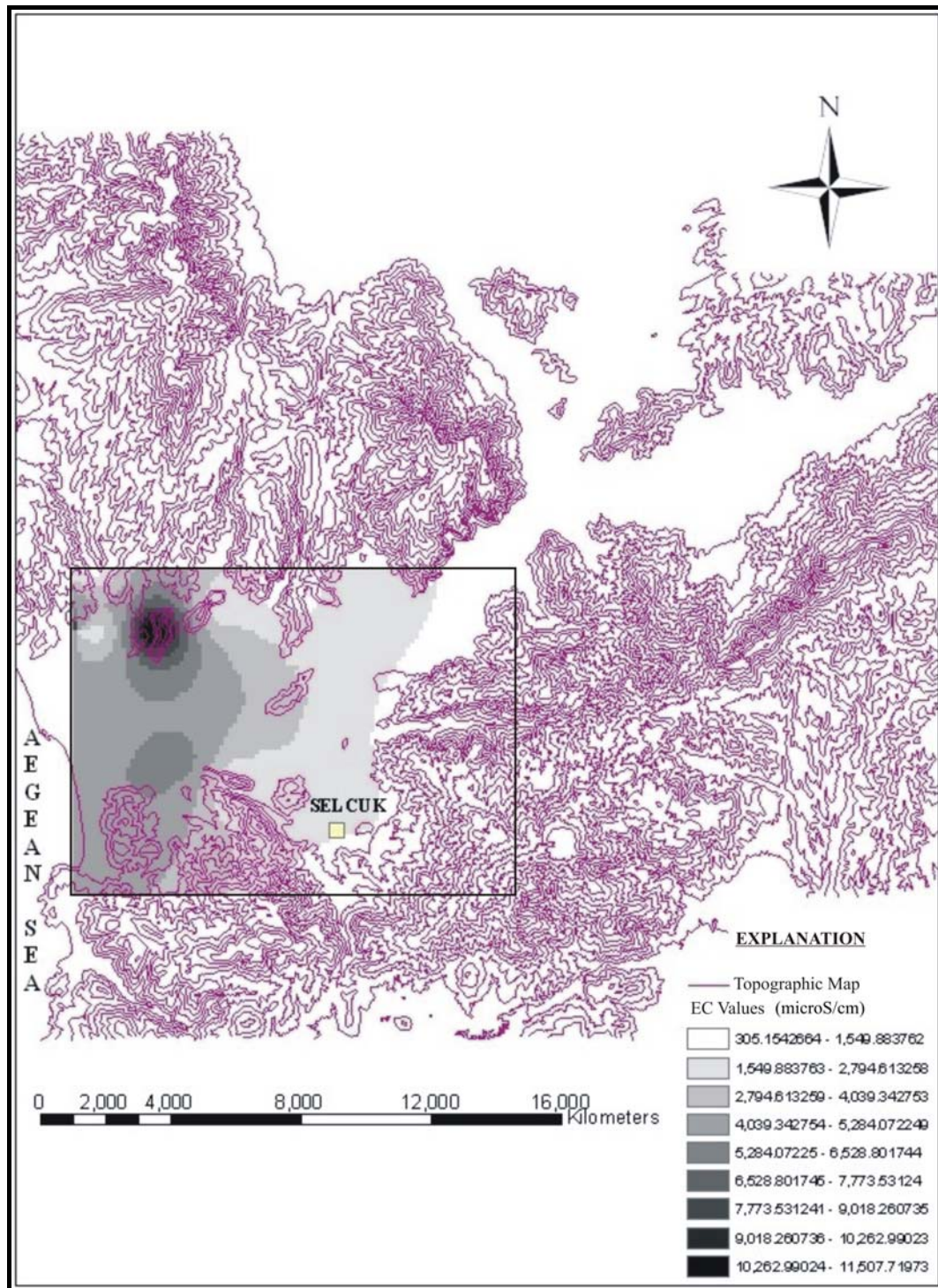


Figure 4.7. (A) EC distribution map in dry season.

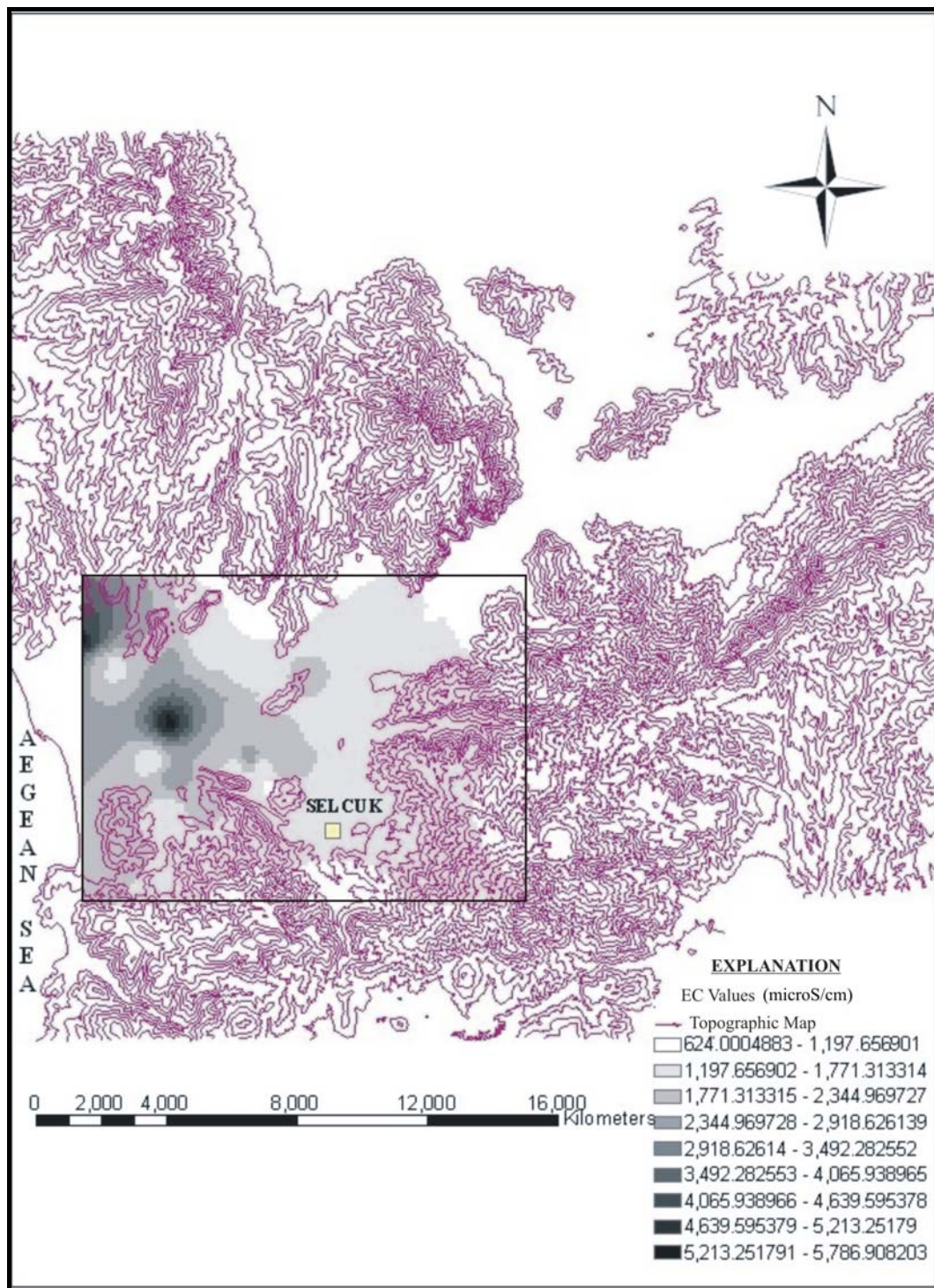


Figure 4.7. (B) EC distribution map in rainy season.

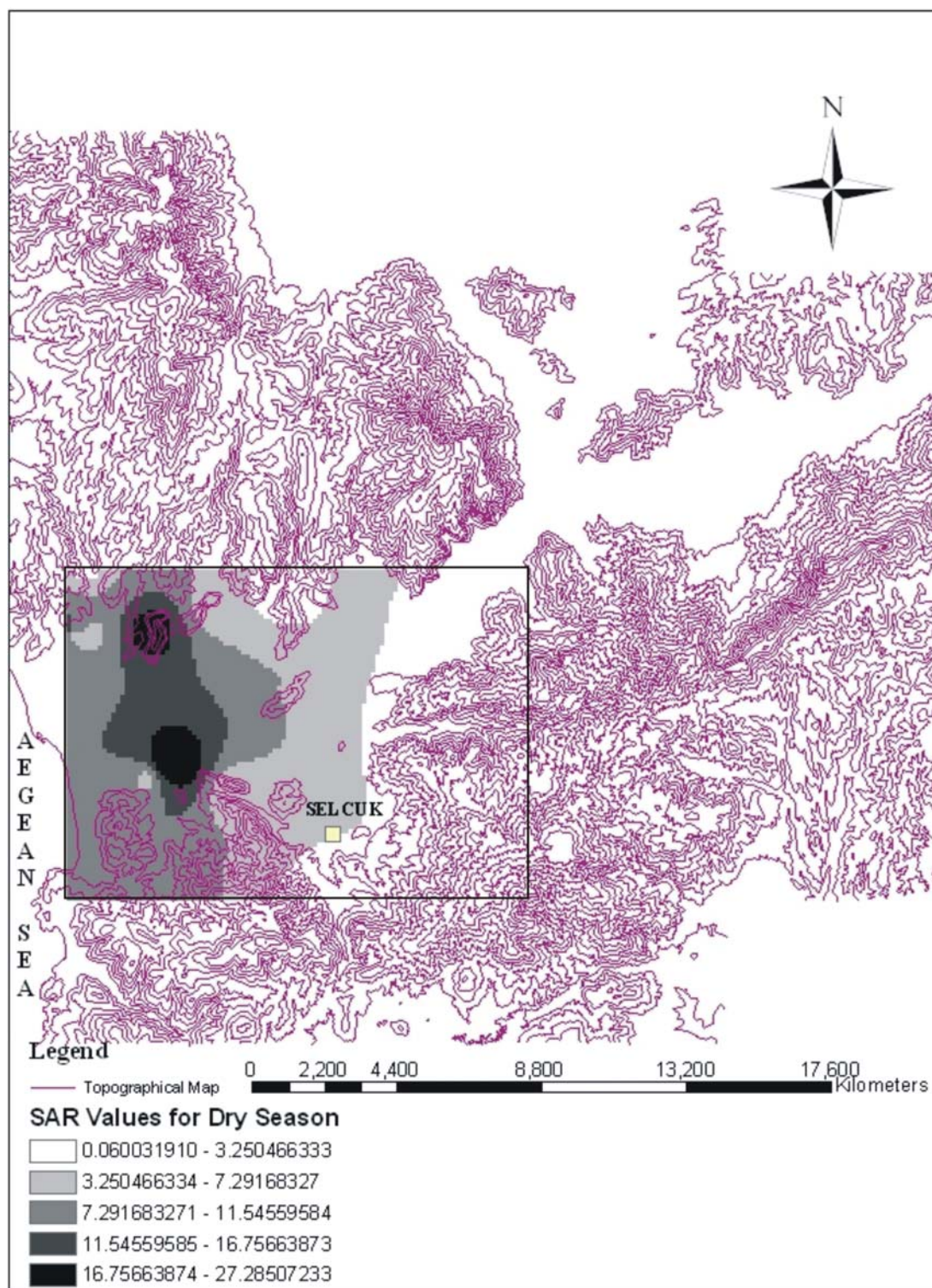


Figure 4.8. (A) SAR distribution map in dry season.

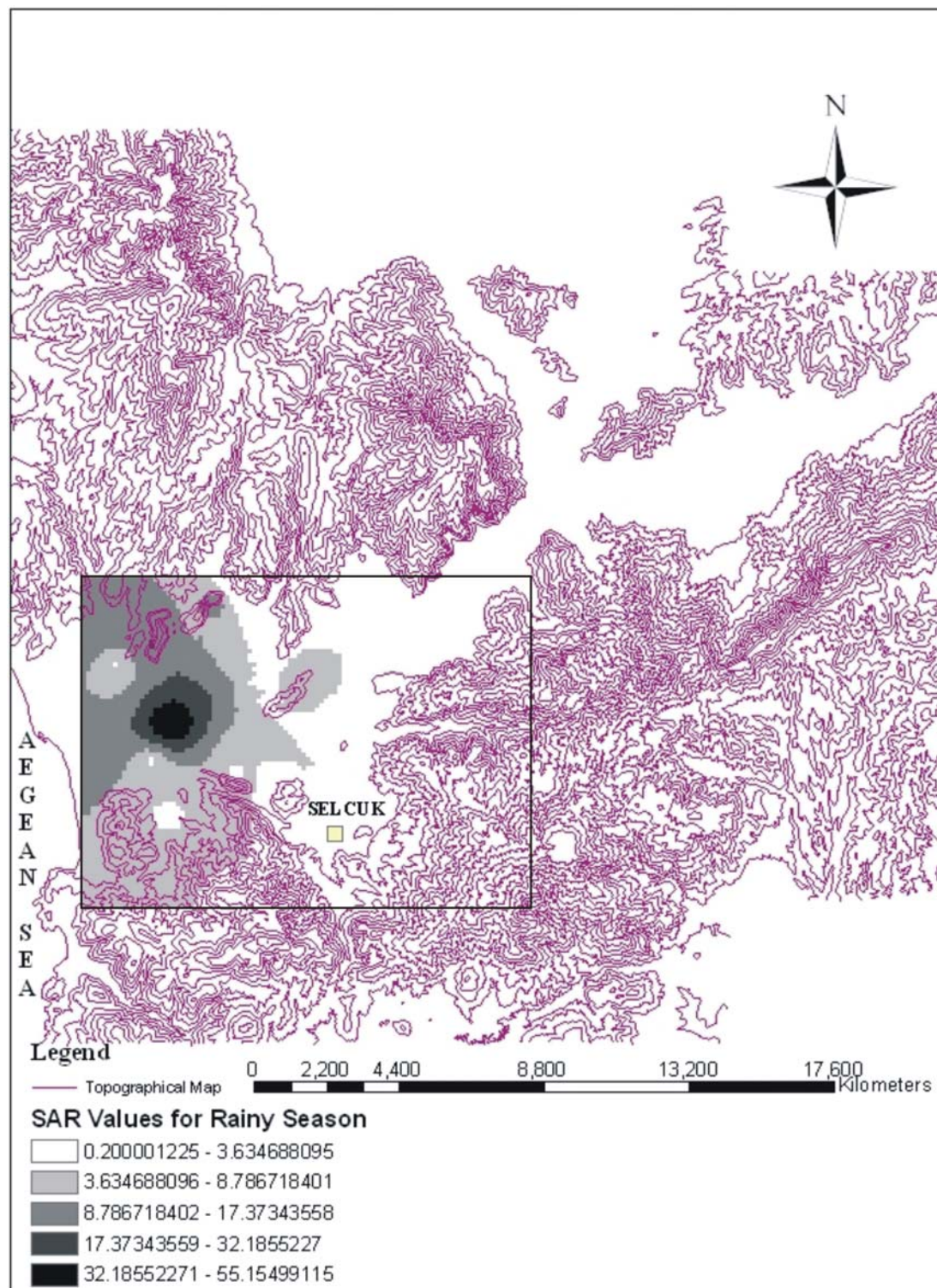


Figure 4.8. (B) SAR distribution map in rainy season

All explained as above, finally a composite map was done that contains both all of the parameters and all of the seasons (Figure 4.9). Na/Cl, Na/Ca, Mg/Ca, EC, mixing ratio (MR) and SAR (sodium adsorption ratio) values are used to form this composite map in both dry and rainy seasons and it identified the “Salinization Zone Map” in the Selçuk Plain.

This “Salinization Zone Map” is explained the saline/fresh zone in Selçuk Plain. The black area is always “saline” zone in both dry and rainy season that covers Lake Gebekirse and Kazangöl and Zeytinköy karstic springs. This is also shown the relationship between karstic springs and Lake Gebekirse. But grey zone can be widen or narrowed based on the chemical reactions, dilution and evaporation in the study area.



Figure 4.9. General thematic map of the Salinization Zone.

CHAPTER FIVE

ENVIRONMENTAL ISOTOPES APPLICATIONS

5.1 Introduction

The isotopic compositions of O and H in water, modified by meteoric processes, are useful tracers for determining groundwater origin and movement. Stable isotopes of O and H are particularly useful as tracers because the isotopic composition of O and H in groundwater does not change as a result of rock–water interactions at low temperatures (Marfia et al, 2004).

“Both chemical and stable isotope data provide important supplemental information to more traditional hydraulic data and unravel the processes that underpin the large variations in chemical and stable isotopic composition within a coastal wetland system” (Marimthu et al, 2005).

Meteoric processes, for instance, modify the stable isotopic composition of water, and so the recharge waters in a particular environment will have a characteristic isotopic signature. This signature then serves as a natural tracer for the provenance of groundwater. On the other hand, radioisotopes decay, providing us with a measure of circulation time, and thus groundwater renewability. Environmental isotopes provide, however, much more than indications of groundwater provenance and age. Environmental isotopes provide, much more than indications of groundwater provenance and age and also used for recharge processes, subsurface processes, geochemical reactions and reaction rates (Clark and Fritz, 1997). The stable environmental isotopes and radioisotopes are given in Table 5.1, Table 5.2, respectively.

The isotope $\delta^{18}\text{O}$ and δD compositions are sensitive tracers and widely applied to studying the natural water circulation and groundwater movement (Krabbenhof et al, 1990; Herczeg et al, 1992; Turner et al, 1992; Chambers et al, 1996).

Table 5.1. The stable environmental isotopes (Clark and Fritz, 1997); (The bold rows represent the isotopes that were used in this chapter).

Isotope	Ratio	% natural abundance	Reference (abundance ratio)	Commonly measured phases
^2H	$^2\text{H}/^1\text{H}$	0.015	VSMOW ($1.5575 \cdot 10^{-4}$)	H_2O, CH_2O, CH_4, H_2, OH^- minerals
^3He	$^3\text{He}/^4\text{He}$	0.000138	Atmospheric He ($1.3 \cdot 10^{-6}$)	He in water or gas, crustal fluids, basalt
^6Li	$^6\text{Li}/^7\text{Li}$	7.5	L-SVEC ($8.32 \cdot 10^{-2}$)	Saline waters, rocks
^{11}B	$^{11}\text{B}/^{10}\text{B}$	80.1	NBS 951 (4.04362)	Saline waters, clays, borate, rocks
^{13}C	$^{13}\text{C}/^{12}\text{C}$	1.11	VPDB ($1.1237 \cdot 10^{-2}$)	CO_2 , carbonate, DIC, CH_4 , organics
^{15}N	$^{15}\text{N}/^{14}\text{N}$	0.366	AIR N_2 ($3.677 \cdot 10^{-3}$)	N_2 , NH_4^+ , NO_3^- , N-organics
^{18}O	$^{18}\text{O}/^{16}\text{O}$	0.204	VSMOW ($2.0052 \cdot 10^{-3}$) VPDB ($2.0672 \cdot 10^{-3}$)	H_2O, CH_2O, CO_2, sulphates, NO_3^-, carbonates, silicates, OH^- minerals
^{34}S	$^{34}\text{S}/^{32}\text{S}$	4.21	CDT ($4.5005 \cdot 10^{-2}$)	Sulphates, sulphides, H_2S , S-organics
^{37}Cl	$^{37}\text{Cl}/^{35}\text{Cl}$	24.23	SMOC (0.324)	Saline waters, rocks, evaporites, solvents
^{81}Br	$^{81}\text{Br}/^{79}\text{Br}$	49.31	SMOB	Developmental for saline waters
^{87}Sr	$^{87}\text{Sr}/^{86}\text{Sr}$	$^{87}\text{Sr} = 7.0$ $^{86}\text{Sr} = 9.86$	Absolute ratio measured	Water, carbonates, sulphates, feldspar

Table 5.2. The environmental radioisotopes (Clark and Fritz, 1997). * The bold row represents the isotopes that were used in this chapter.

Isotope	Half-life (years)	Decay mode	Principal Sources	Commonly measured phases
^3H	12.43	β^-	Cosmogenic, weapons testing	H_2O, CH_2O
^{14}C	5730	β^-	Cosmogenic, weapons testing, nuclear reactors	DIC, DOC, CO_2 , CaCO_3 , CH_2O
^{36}Cl	301,000	β^-	Cosmogenic and subsurface	Cl^- , surface Cl-salts
^{39}Ar	269	β^-	Cosmogenic and subsurface	Ar
^{85}Kr	10.72	β^-	Nuclear fuel processing	Kr
^{81}Kr	210,000	ec	Cosmogenic and subsurface	Kr
^{129}I	$1.6 \cdot 10^7$ yr	β^-	Cosmogenic, subsurface, nuclear reactors	I^- and I in organics
^{222}Rn	3.8 days	α	Daughter of ^{226}Ra in ^{238}U decay series	Rn gas
^{226}Ra	1600	α	Daughter of ^{230}Th in ^{238}U decay series	Ra^{2+} , carbonate, clays
^{230}Th	75,400	α	Daughter of ^{234}U in ^{238}U decay series	Carbonate, organics
^{234}U	246,000	α	Daughter of ^{234}Pa in ^{238}U decay series	UO_2^{2+} , carbonate, organics
^{238}U	$4.47 \cdot 10^9$	α	Primordial	UO_2^{2+} , carbonate, organics

β^- - beta emission.

α - alpha emission.

ec - electron capture.

5.2 General Overview of Environmental Isotopes (Oxygen-18, Deuterium and Tritium)

5.2.1 General Showing of Stable Isotopes (δ and ‰)

The isotopic compositions of ^{18}O and ^2H are reported as parts per thousand (‰) with respect to SMOW (Standard Mean Ocean Water) using the (δ) notation;

$$\delta = (R_{\text{sample}}/R_{\text{standard}} - 1)1000,$$

(where R_{sample} and R_{standard} represent the ratio of heavy to light isotopes of the sample and standard, respectively). The reasons are (Mook, 2001):

- i) the type of mass spectrometers, suitable for measuring isotope abundances with high sensitivity in order to detect very small natural variations, are basically not suitable for obtaining reliable absolute ratios,
- ii) the necessity of international comparison requires the use of references to which the samples have to be related,
- ii) the use of isotope ratios would lead to reporting results as numbers consisting of a large number (5 or 6) of digits,
- iv) absolute ratios are in principle less relevant than the changes in ratios occurring during transitions between phases or molecules.

According to Clark and Fritz 1997, rather than measuring a true ratio, an apparent ratio can easily be measured by gas source mass spectrometry. Isotopic concentrations are then expressed as the difference between the measured ratios of the sample and reference over the measured ratio of the reference. Mathematically, the error (m) between the apparent and true ratios is cancelled.

This is expressed using the delta (δ) notation:

$$\delta^{18}\text{O}_{\text{sample}} = \frac{m(^{18}\text{O}/^{16}\text{O})_{\text{sample}} - m(^{18}\text{O}/^{16}\text{O})_{\text{reference}}}{m(^{18}\text{O}/^{16}\text{O})_{\text{reference}}}$$

As fractionation processes do not impart huge variations in isotope concentrations, δ -values are expressed as the parts per thousand or permil (‰) difference from the reference. This equation then becomes the more familiar:

$$\delta^{18}\text{O}_{\text{sample}} = \left(\frac{(^{18}\text{O}/^{16}\text{O})_{\text{sample}}}{(^{18}\text{O}/^{16}\text{O})_{\text{reference}}} - 1 \right) \cdot 1000 \quad \text{‰ VSMOW}$$

5.2.2 Stable Isotopes (Oxygen 18 and Deuterium)

The chemical element oxygen has three stable isotopes, ^{16}O , ^{17}O and ^{18}O , with abundances of 99.76, 0.035 and 0.2%, respectively (Nier, 1950) (Table 5.1.).

The chemical element hydrogen consists of two stable isotopes, ^1H and ^2H (D or Deuterium), with an abundance of about 99.985 and 0.015% and an isotope ratio $^2\text{H}/^1\text{H} \approx 0.00015$ (Urey, 1947). This isotope ratio has a natural variation of about 250‰, higher than the $^{13}\delta$ and $^{18}\delta$ variations, because of the relatively larger mass differences between the isotopes (Mook, 2001).

^{18}O is often enriched in (saline) lakes subjected to a high degree of evaporation, while high-altitude and cold-climate precipitation, especially in the Antarctic, is low in ^{18}O . Generally in the hydrological cycle in temperate climates we are confronted with a range of $^{18}\delta$ not exceeding 30‰ (Mook, 2001). The oceans form the largest global water reservoir. The ^{18}O content in the surface layer is rather uniform, varying between +0.5 and -0.5‰ (Epstein & Mayeda, 1953). In tropical regions more positive values are caused by strong evaporation: $^{18}\delta$ of water in the Mediterranean amounts to +2‰ ($^2\delta = +10\text{‰}$). In polar regions more negative values originate from water melting from isotopically light snow and ice. (Mook, 2001).

According to Mook 2001, the transformation of atmospheric water vapour to precipitation depends on so many climatological and local factors, that the $^{18}\delta$ variations in precipitation over the globe are very large. As a general rule $^{18}\delta$ becomes more negative the further the rain is removed from the main source of the vapour in the equatorial regions (Figure 5.1):

- 1) latitudinal effect** with lower $^{18}\delta$ values at increasing latitude.
- 2) continental effect** with more negative $^{18}\delta$ values for precipitation the more inland.
- 3) altitude effect** with decreasing $^{18}\delta$ in precipitation at higher altitude.
- 4) seasonal effect** (in regions with temperate climate) with more negative $^{18}\delta$ values during winter.
- 5) amount effect** with more negative $^{18}\delta$ values in rain during heavy storms. Dansgaard (1964) observed a relation between the amount of precipitation and $^{18}\delta$. On the other hand, small amounts of rain are, as a rule, enriched in the heavy isotopes along typical evaporation lines, especially in the more arid regions.

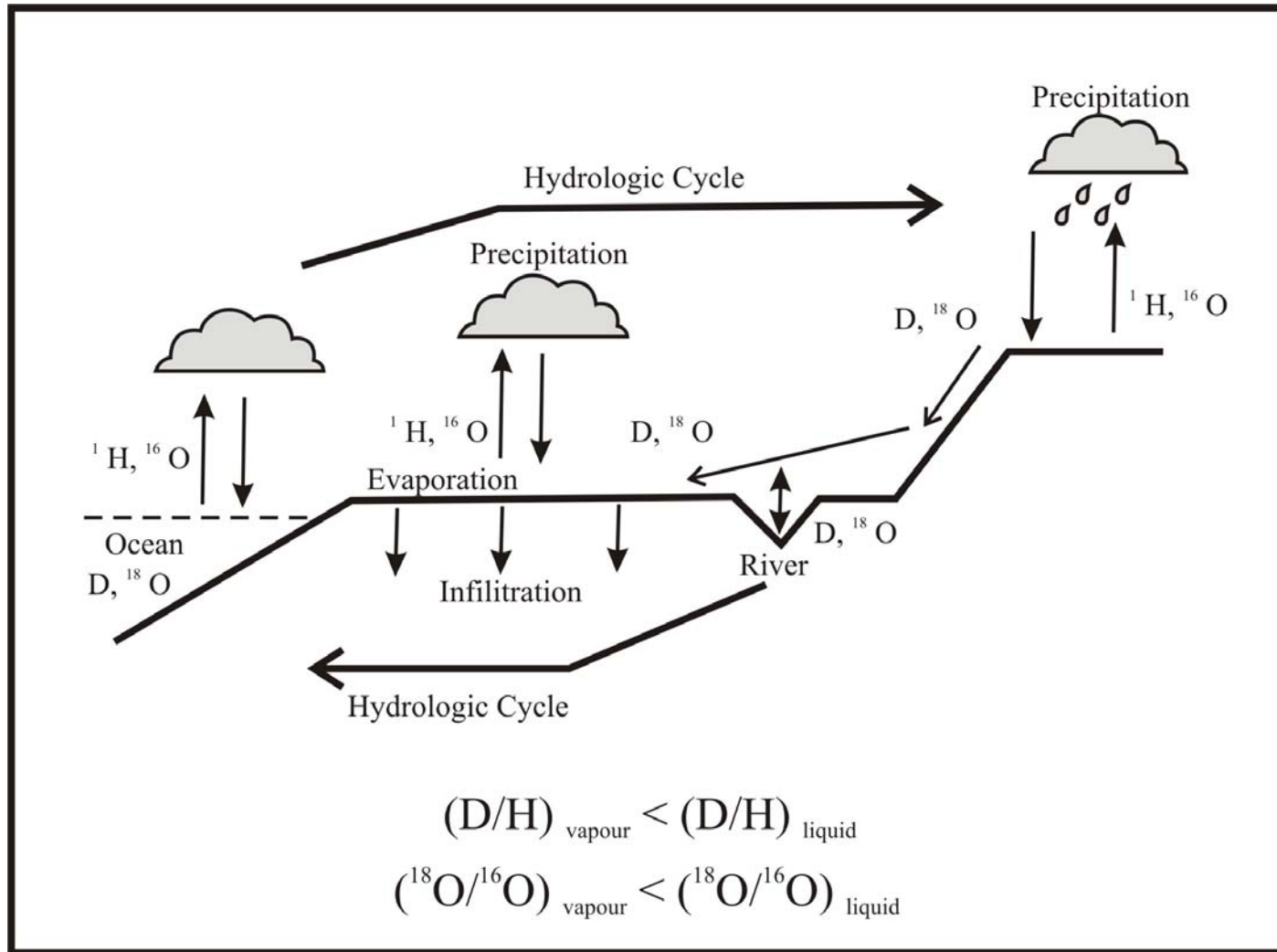


Figure 5.1. Schematic expression of oxygen and hydrogen isotopes in hydrological cycle (Mook, 2001).

5.2.3.. Relationship Between $\delta^{18}\text{O}$ and δD (Mook, 2001)

Craig (1961) and Dansgaard (1964) found a relation between the $^2\delta$ and $^{18}\delta$ values of precipitation from various parts of the world:

$$^2\delta = 8^{18}\delta + 10 (\text{‰})$$

This relation, has become known as the *Global Meteoric Water Line* (GMWL) and is characterised by a *slope* of 8 and a certain *intercept* with the ^2H axis (= the $^2\delta$ value at $^{18}\delta = 0\text{‰}$). The general relation is of the MWL is:

$$^2\delta = s^{18}\delta + d$$

where the slope $s = 8$, as is explained by the ratio between the equilibrium isotope fractionations of hydrogen and oxygen for the rain condensation process; d is referred to as the *deuterium excess* (*d-excess*), the intercept with the $^2\delta$ axis. In several regions of the world as well as during certain periods of the year and even certain storms the $^2\delta$ value is different from 10 ‰, depending on the humidity and temperature conditions in the evaporation region. The isotopic composition of water vapour over seawater with $^2\delta = ^{18}\delta = 0 \text{‰}$ vs VSMOW is somewhat lighter than would follow from isotopic equilibrium with the water: the evaporation is a non-equilibrium (partly kinetic) process.

Apart from this, deviations occur in evaporating surface waters, showing slopes of 4 to 5 rather than 8 (Figure 5.2).

Local meteoric water line (LMWL) is selected from Kos Island-Greece in this study:

$$^2\delta = 8^{18}\delta + 12 (\text{‰}) \text{ (La Ruffa, et al. 1999)}$$

due to the lack of environmental isotope data of İzmir city precipitation.

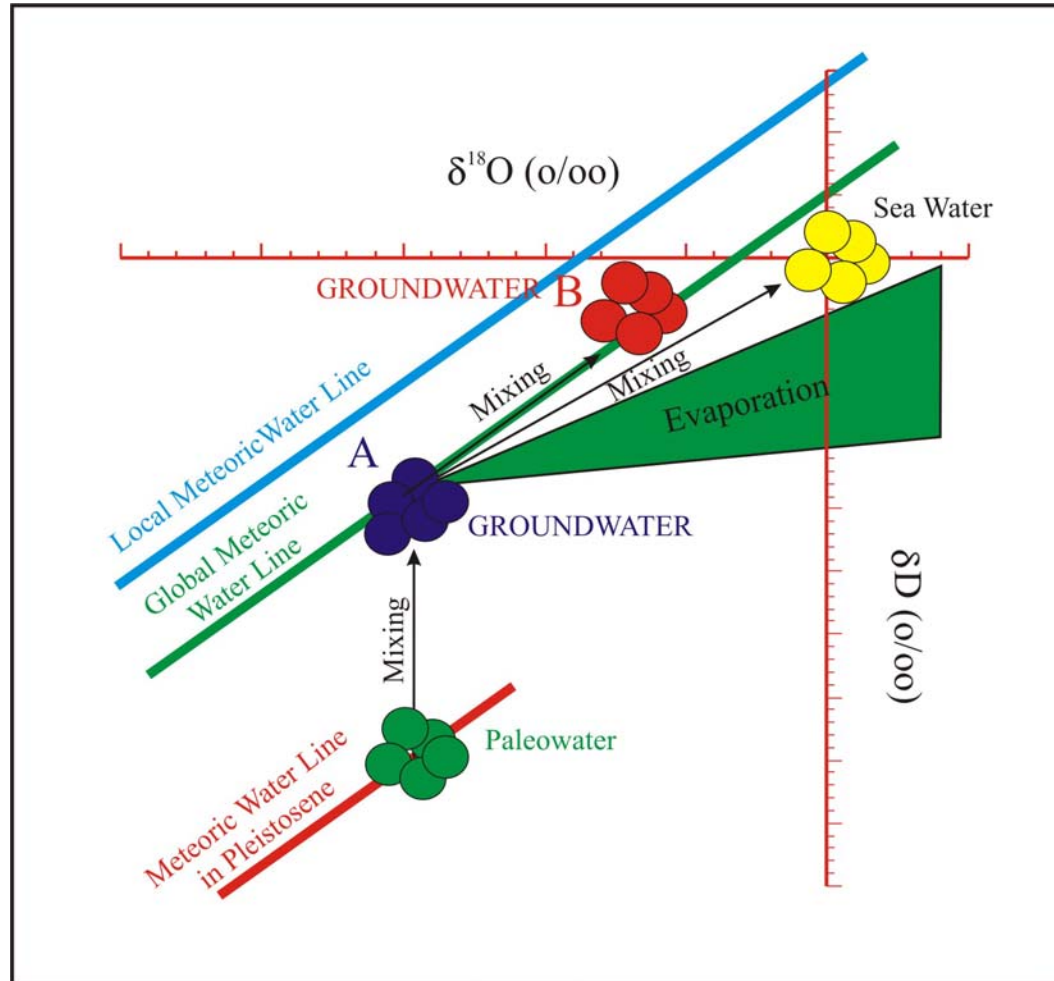


Figure 5.2. Schematic δ^2 and δ^{18} diagram and the end-members of mixing processes (Mook, 2001).

Water rock interactions can be determined by $^2\delta$ and $^{18}\delta$ diagram as shown in Figure 5.3.

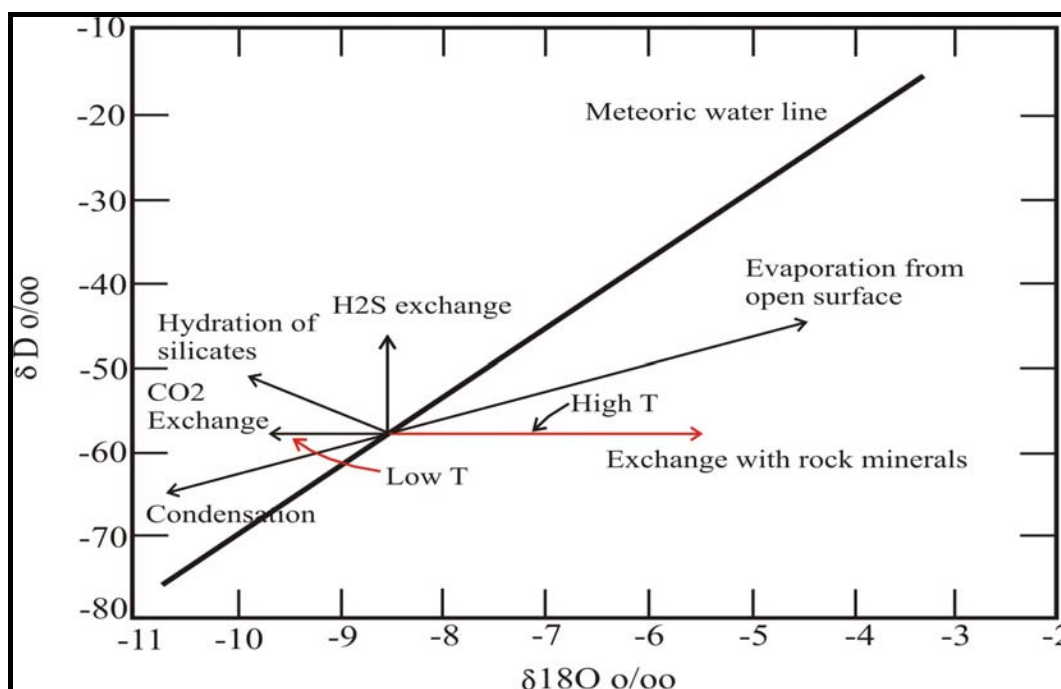


Figure 5.3. Water-rock interaction processes in the schematic $^2\delta$ and $^{18}\delta$ diagram (Mook, 2001).

5.3 Material and Methods

The isotopic composition ($\delta^{18}\text{O}$, δD and tritium) of the some dry season water samples (samples 8, 10, 12, 14, 17, 20) were analyzed at the Department of Technical Research and Quality Control of General Directorate of Hydraulic Work (DSİ). Other of them was done at the University of California, Davis Stable Isotope Laboratory by isotope ratio mass spectrometer with a GVI Optima Stable Isotope Ratio Mass Spectrometer (SIRMS). For both deuterium and O-18 analyses, 50 ml unfiltered waters were sampled in polyethylene bottles.

5.4 Results:

The samples were chosen from wetland components (lakes, swamp, river and karstic discharges) and from recharge (hilly) area, Şirince, Acarlar, Belevi and Virgin Mary house drilling well (Figure 5.4) (Table 5.3).

Land masses have the effect of forcing rainout from vapor masses. As a vapor mass moves from its source region across a continent, its isotopic composition involves more rapidly due to topographic effects and the temperature extremes that characterize continental climates. Coastal precipitations are isotopically enriched, while the colder inner continental regions receive isotopically depleted precipitation with strong seasonal differences (Clark and Fritz, 1997). This continental effect rule is given in Figure 5.5 for the study area.

In any region with even minor relief, orographic precipitation will occur as a vapour mass rises over the landscape. Rainout proceeds as the air mass cools, imparting a depletion on precipitation. Thus, at higher elevation and cools adiabatically (by expansion), thus driving rainout. At higher altitudes where the average temperatures are lower, precipitation will be isotopically depleted. For ^{18}O , the depletion varies between about -0.15 and -0.5‰ per 100-m rise in elevation, altitude, with a corresponding decrease of about -1 to -4‰ for ^2H (Clark and Fritz, 1997). This altitude effect is shown in Figure 5.6 for the study area.

The relation between δD and $\delta^{18}\text{O}$ values of precipitation in various parts of the world is as follows, according to Craig 1961:

$$\delta\text{D} = 8 * \delta^{18}\text{O} + 10 \text{‰} \text{ (Global Meteoric Water Line-GMWL)}$$

At this study not only GMWL but also Mediterranean meteoric water line (MMWL) (Yurtsever, 1983) with +22 deuterium excess and was used (Figure 5.7). Local meteoric water line with +12 deuterium excess (LMWL) (La Ruffa et al. 1999) was selected from Kos Island, due to the lack of İzmir precipitation data.

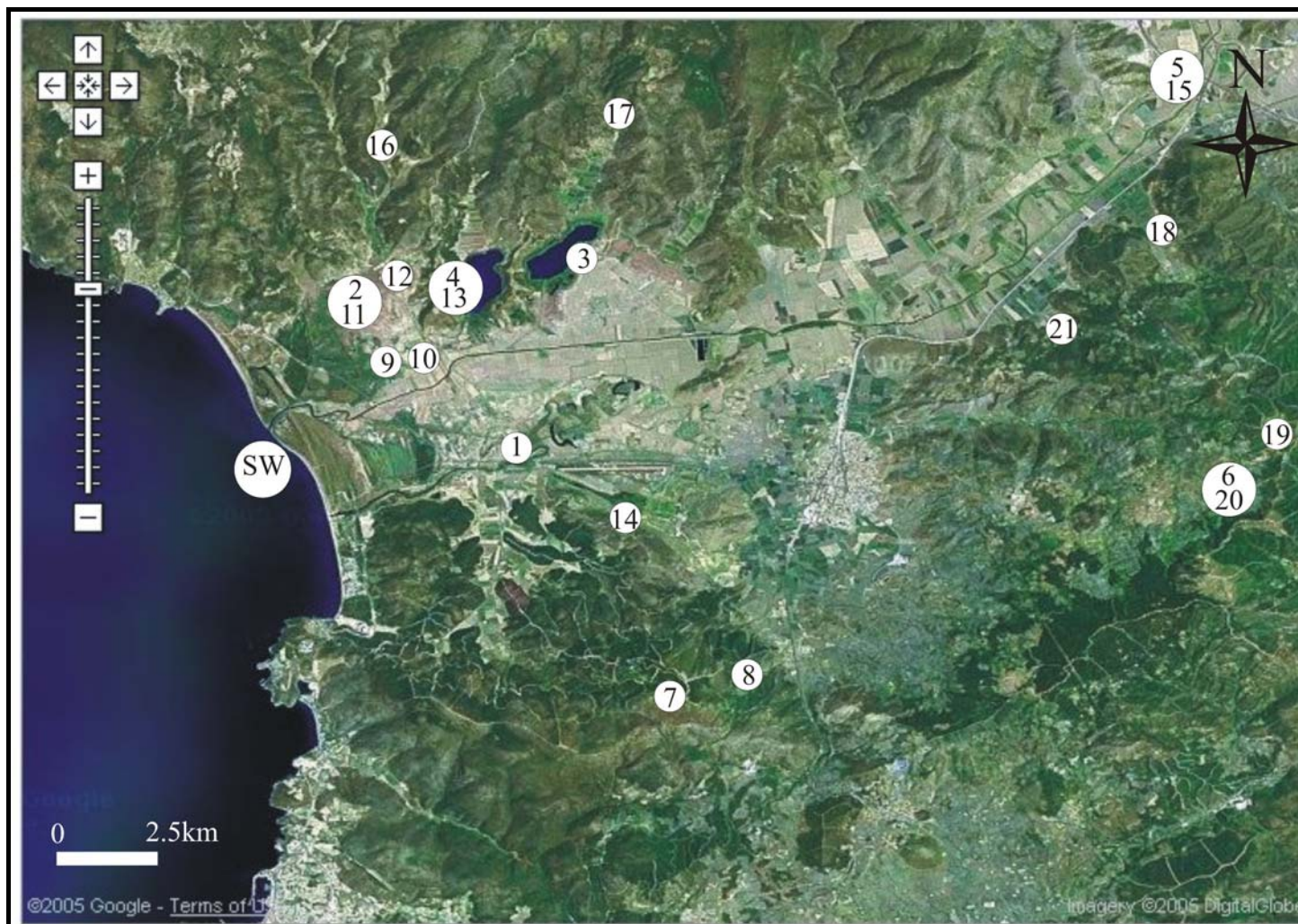


Figure 5.4. Sample location map of the study area.

Table 5.3. Environmental isotope values of waters (n.m. not measured).

Location	Sample Number	$\delta^{18}\text{O}$ (‰)	δD (‰)	Tritium (TU)	Cl (mg/l)	Salinity (‰)	Altitude (m)	Distance from Sea (km)
Swamp	1	-5.21	-32.9	—	1482	2.8	0	3
Kazangöl Karstic Discharge	2	-4.99	-28.5	—	1580	3.1	-1	3
Lake Akgöl	3	-4.56	-29.9	—	1125	n.m.	-1	6
Lake Gebekirse	4	-4.97	-35.1	—	1720	n.m.	-1	4
River (Belevi)	5	-5.25	-33.7	—	103	0.6	0	15
Şirince	6	-6.42	-23.8	—	57	0	400	14
Virgin Mary House	7	-6.38	-36.4	—	26	0.1	400	8
Acarlar	8	-5.87	-33.3	—	16	0	100	10
Zeytinköy Drilling well	9	-5.22	-30.99	5.60±0.70	381	n.m.	0	2
Zeytinköy Drilling well	10	-5.40	-31.8	—	360	0.7	0	1.5
Kazangöl Karstic Discharge	11	-4.57	-27.93	5.35±0.70	2980	n.m.	-1	3
Zeytinköy Karstic Discharge	12	-5.12	-30.0	—	1290	2.1	-1	2
Lake Gebekirse	13	-2.93	-19.55	5.15±0.70	3340	n.m.	-1	4
Lake Kocagöz	14	-4.62	-24.8	—	206	0.6	-0.5	5
River (Belevi)	15	-3.35	-22.35	5.30±0.70	235	n.m.	0	15
İzmir Gorge	16	-5.42	-32.1	—	151	0.3	50	5
Andon Gorge	17	-5.86	-33.1	—	57	0.1	20	8
Belevi	18	-5.95	-35.99	6.45±0.75	7	n.m.	50	14
Degirmen Spring	19	-6.07	-35.2	—	39	0.1	130	13
Şirince	20	-6.53	-37.9	—	15	0	400	14
Şirince Road	21	-6.03	-35.57	5.05±0.70	64	n.m.	80	12
Tire	22	-6.69	-36.6	—		n.m.		
Sea water	23	+1.61	+8.4	—	21702	38.8	0	0

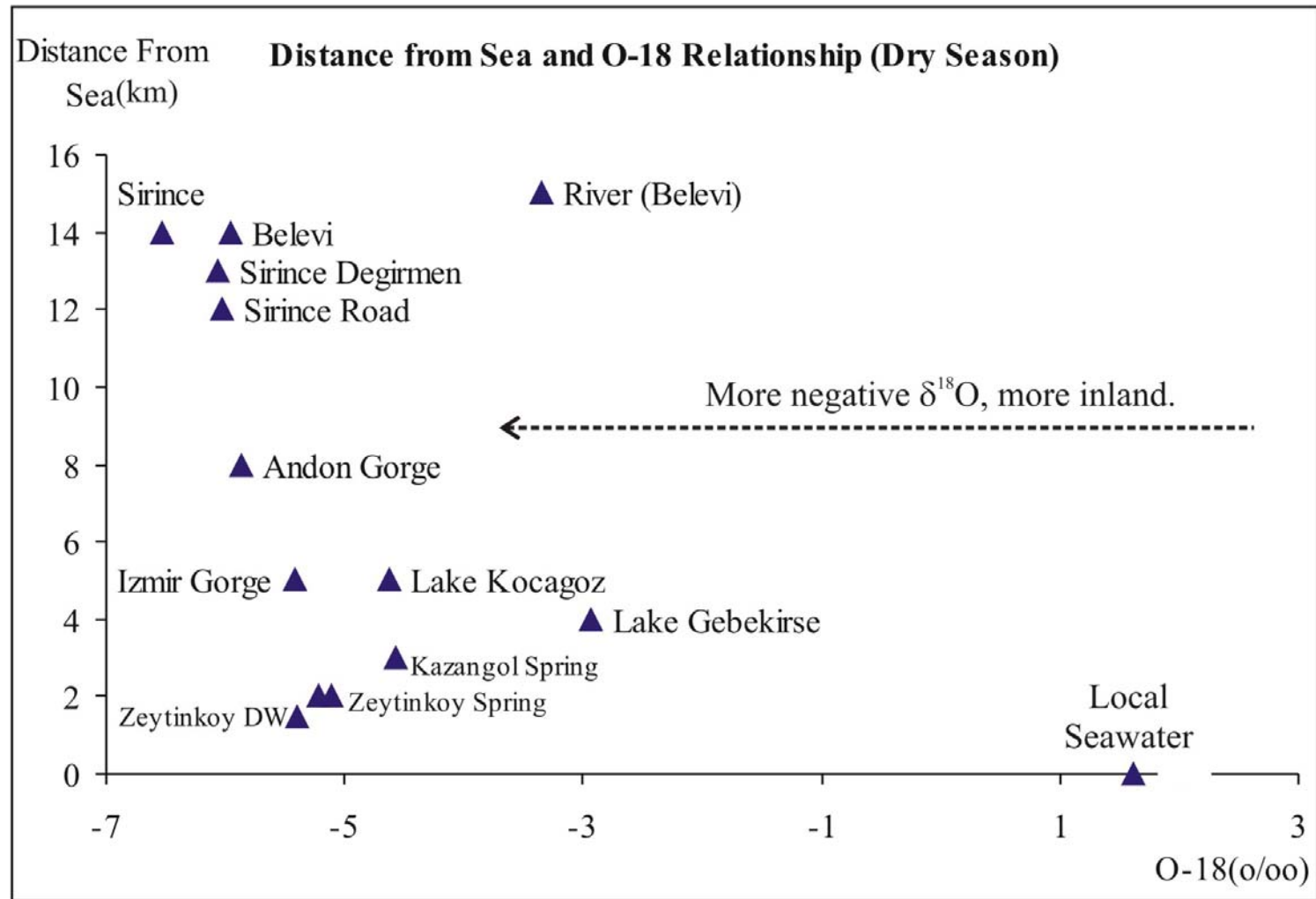


Figure 5.5. Continental effect of $\delta^{18}\text{O}$ in the study area.

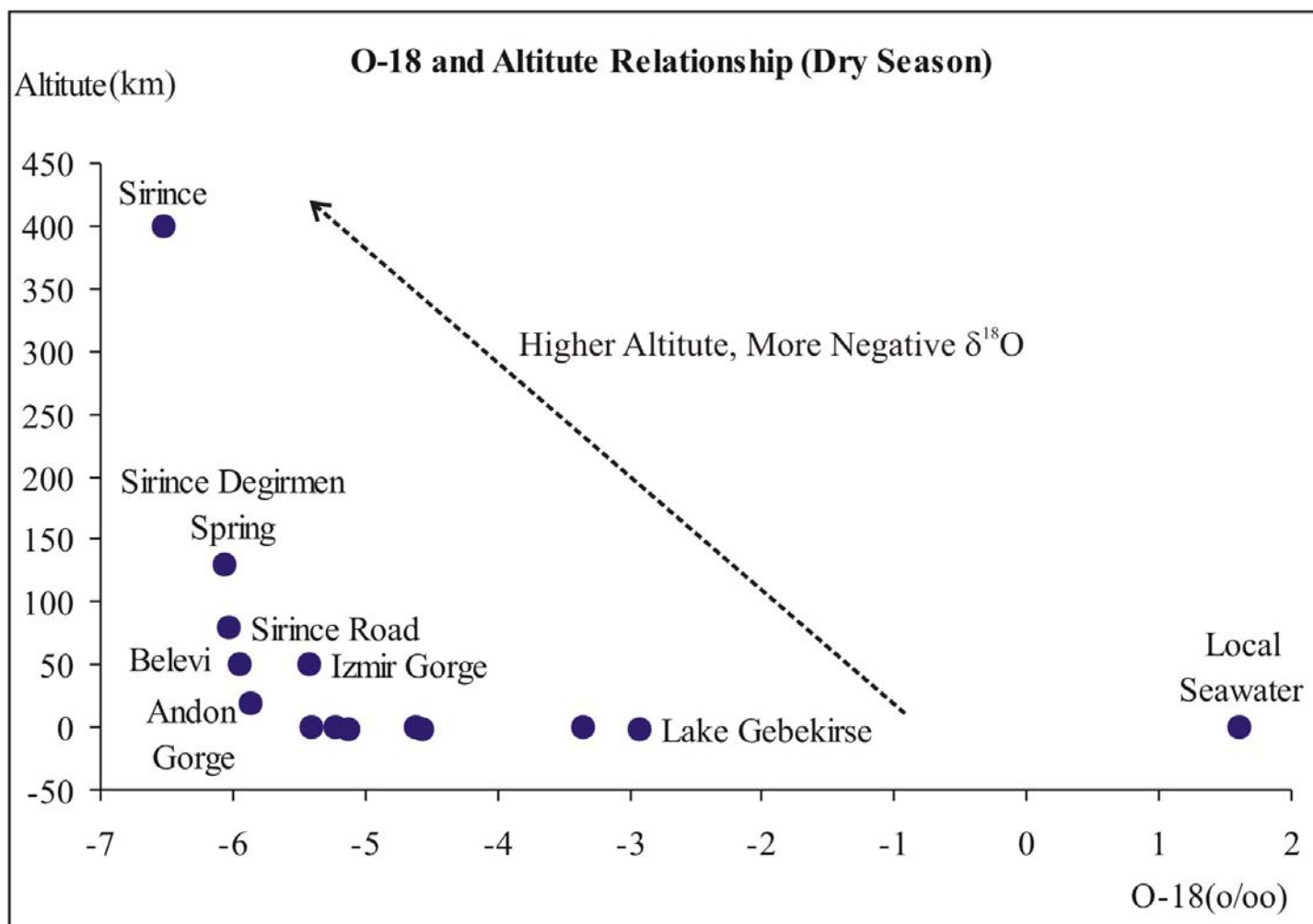


Figure 5.6. Altitude effect of $\delta^{18}\text{O}$ in the study area.

The environmental isotopes ($\delta^{18}\text{O}$, δD and Tritium) were measured in the wetland and hilly area. From the point view of Figure 5.7, the δD and $\delta^{18}\text{O}$ relation is formulated as:

In rainy season: $\delta\text{D}=5.8 * \delta^{18}\text{O} - 1.8$

In dry season: $\delta\text{D}=5.5 * \delta^{18}\text{O} - 1.8$

Samples 1, 3, 4, 5 (in rainy season) and 10, 12, 14 (in dry season) are located around the mixing line by slopes of 5.8 and 5.5, respectively. Fresh water samples are distributed more negative part of the diagram due to their continental properties. The $\delta^{18}\text{O}$ and δD composition of wetland area (samples 1, 3, 4, 5: rainy season; samples 9, 12, 13, 14: dry season) samples are range between -5.40‰ and -2.93‰, and -35.1‰ and -19.55‰, respectively. The hilly area $\delta^{18}\text{O}$ and δD values are more depleted (more negative) due to the high elevation and more terrestrial effects than wetland area (Figure 5.7). It can be clearly seen that the lakes and rivers are plotted on the mixing-evaporation line because they belong to the open system in the hydrologic cycle. On the other hand, the groundwater of the whole basin is plotted between global meteoric line (GMWL) (Craig, 1961) and Mediterranean meteoric line (MMWL) (Yurtsever, 1983). So without much doubt, the groundwaters are originated from meteoric waters. In comparison with coastal area groundwater samples, Şirince and Virgin Mary samples (in rainy season) and 16, 17, 18, 19, 20 (in dry season) are distinctly enriched in their stable isotope compositions and deviate significantly from the LMWL (Fig. 5.7), and are characterized by comparatively low Cl contents (Table 5.3).

On the other hand coastal area waters plot along a line having a slope of 5.80 in rainy season and 5.5 in dry season, that is, a slope considerably lower than that of the LMWL (8). Such a low slope can be produced by evaporation and/or mixing of groundwater and seawater.

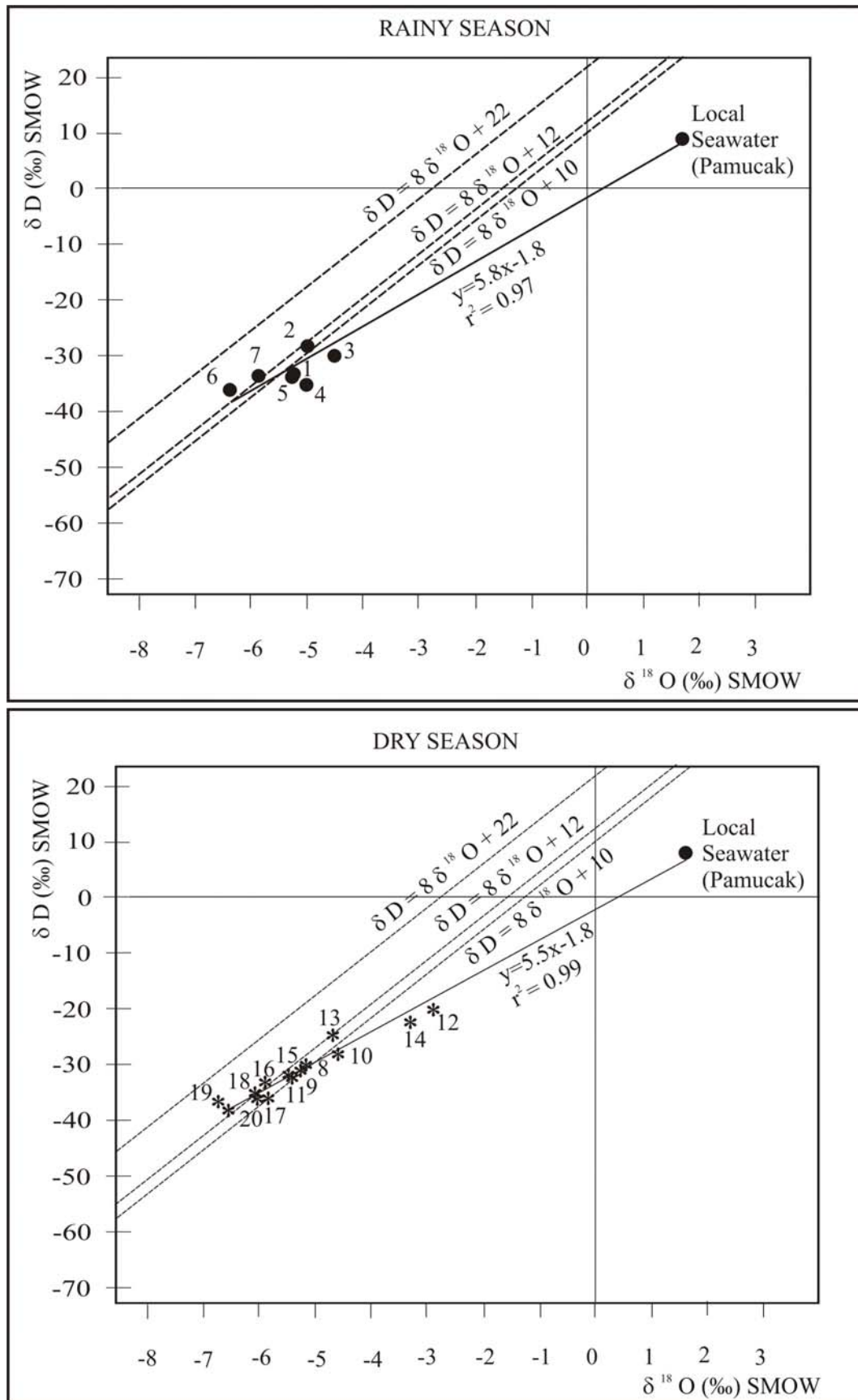


Figure 5.7. $\delta^{18}O$ and δD compositions of the groundwaters in the study area.

In the Figure 5.8 and 5.9, the schematic cross-sections can be seen that are explained the cycle of stable isotopes in Lower Küçük Menderes Basin. From coastal to inland, the stable isotopes are more negative due to altitude and continental effects. On the other hand; stable isotope values of lakes, swamp and river are richer than the other groundwater in the wetland area due to the evaporation rates.

The most pronounced factors which determine the offset of monthly data at any station from a classical meteoric water relationship are:

- *different source characteristics of the moisture, either due to the seasonal change of the meteorological conditions over the ocean, or different location of the source regions. This basically fixes a series of parallel meteoric water lines, for each of the seasons.

- *evaporative enrichment in the falling droplets beneath the cloud base, effective during warm and dry months when rain amounts are small. This partially evaporated rain is characterised by relatively higher $^{18}\delta$ values and small to negative d-excess values.

- * high values of the d-excess parameter associated with snow or hail (Jouzel and Merlivat, 1984). These events are also associated with very depleted isotopic values (Clark and Fritz, 1997).

If we focus on the seasonal changes of the Lake Gebekirse, Küçük Menderes River and Kazangöl Karstic discharge, there are significant changes both in $\delta^{18}\text{O}$ and δD except karstic discharge. In the dry season due to the high rate of evaporation there is enrichment in $\delta^{18}\text{O}$ values (Figure 5.10).

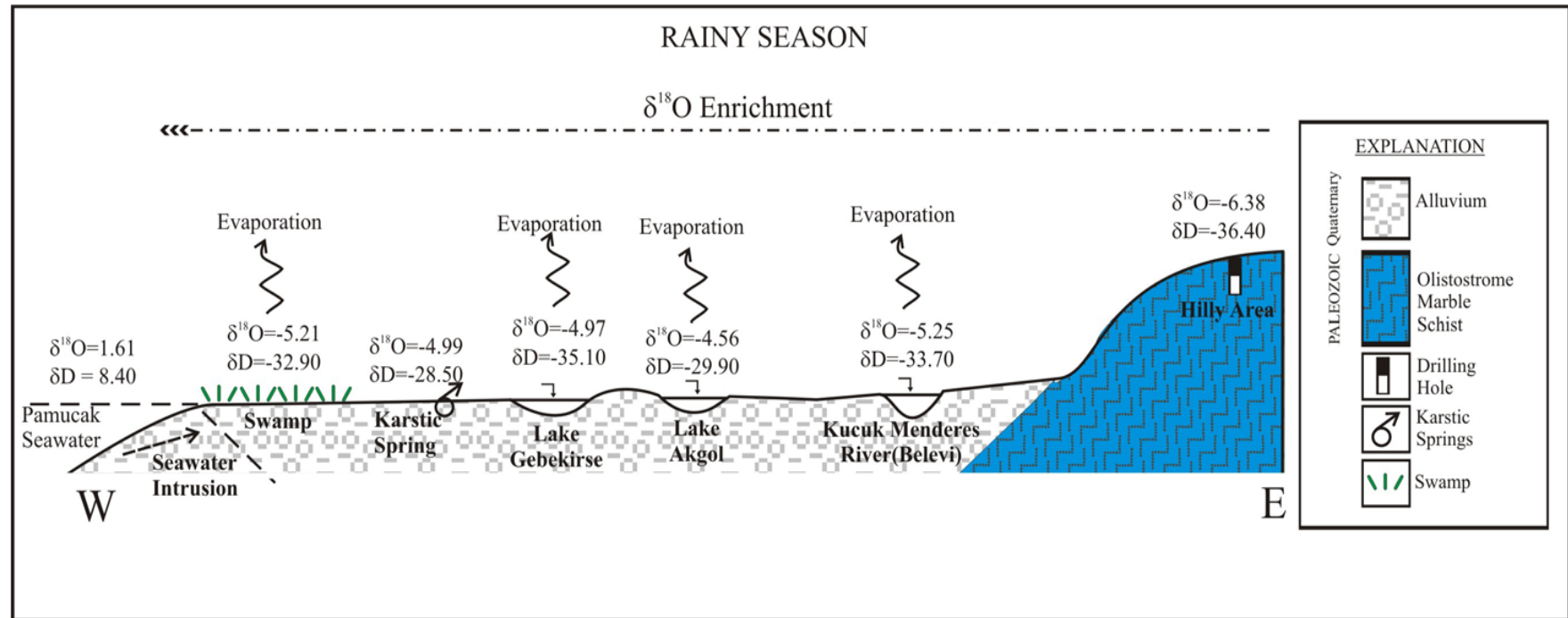


Figure 5.8. Schematic cross-section of Lower Küçük Menderes River Basin that represents the stable isotopes values (in rainy season).

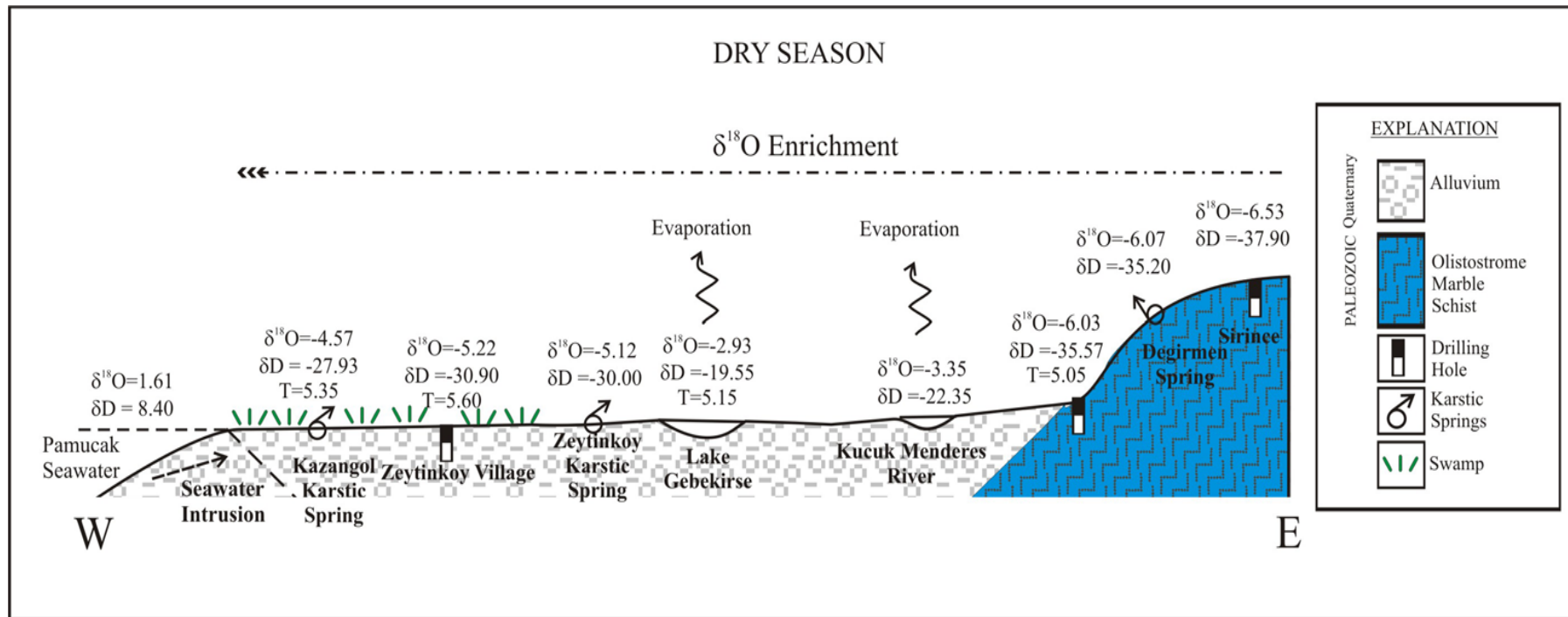


Figure 5.9. Schematic cross-section of Lower Küçük Menderes River Basin that represents the stable isotopes values (in dry season).

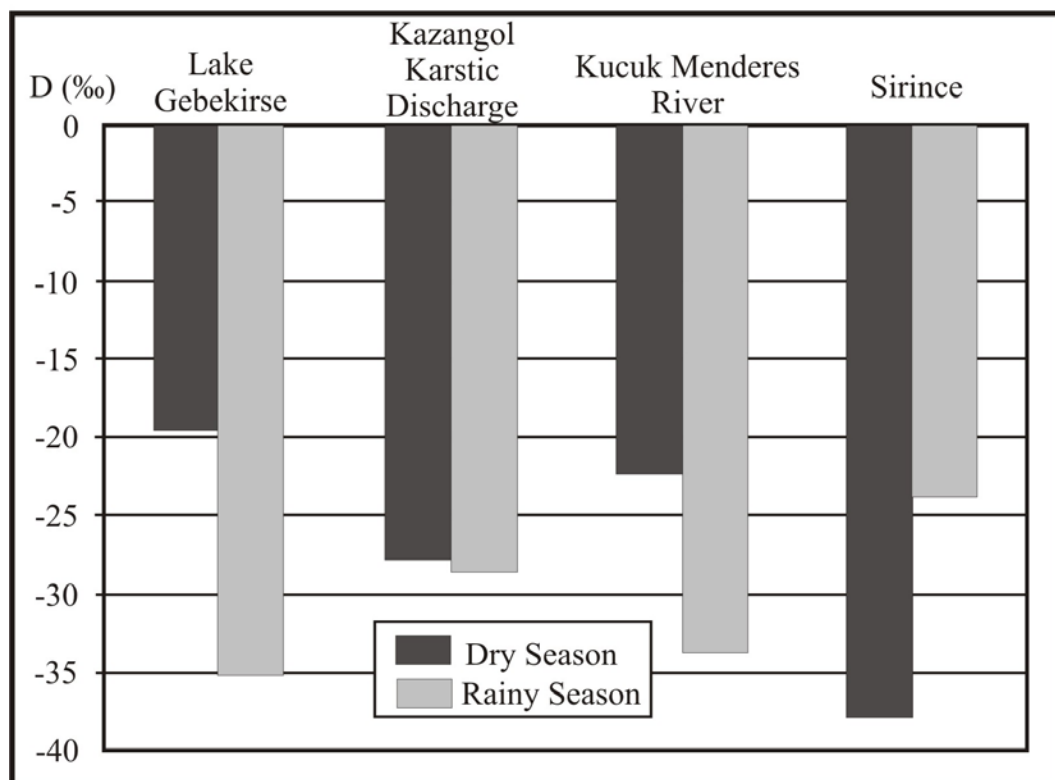
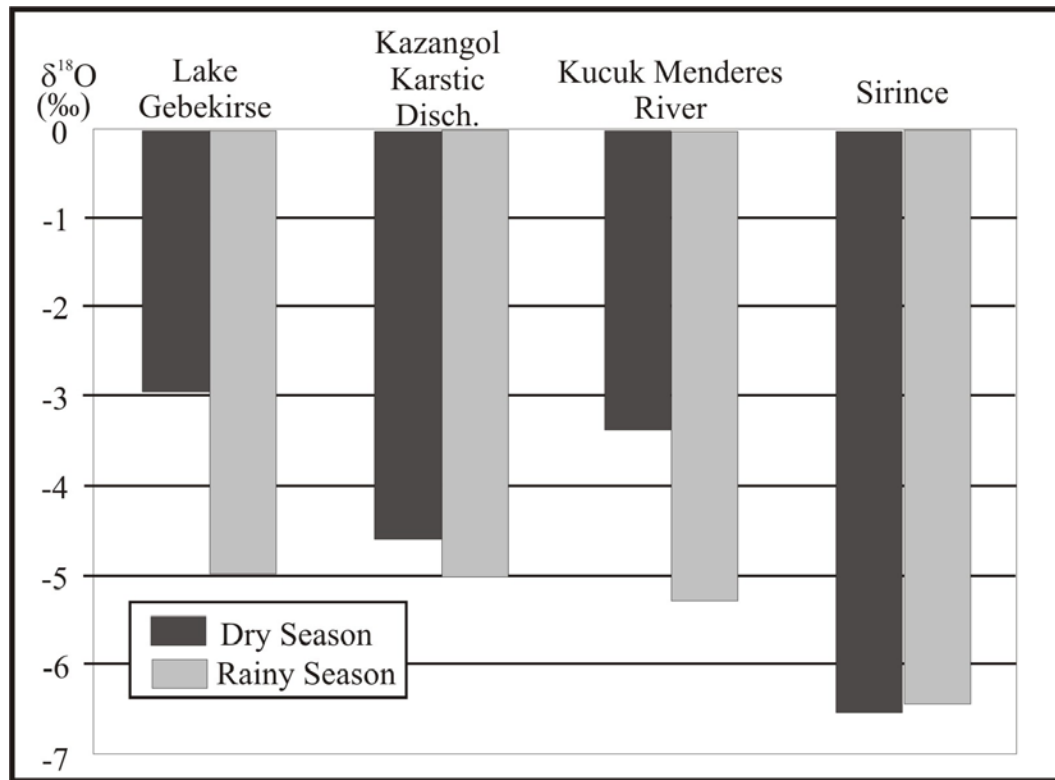


Figure 5.10. Seasonal $\delta^{18}\text{O}$ and δD changes in the Lake Gebekirse, Küçük Menderes River and Kazangöl Karstic Discharge.

Environmental isotopes were used also to characterize the salinization process in the study area. The relationship between deuterium (δD) and oxygen-18 ($\delta^{18}O$) provides the mixing process between fresh water and seawater along the straight line of the two mixing poles, with fresh water of the aquifer at one end seawater at the other end (Gat and Confiantini, 1981; Gonfiantini and Simonot, 1987; Gonfiantini and Araguas, 1988). Coastal zone and surface waters (lakes and river) are plotted towards to seawater. There are two probabilities why these waters are located on the mixing line: 1) due to seawater-fresh water mixing, 2) due to evaporation. To identify this dilemma, $\delta^{18}O$ -Cl relationship was used. The source of salination of brackish to highly mineralized groundwater and thermal water can be definitely detected by a $\delta^{18}O$ -Cl plot. Processes as dissolution and leaching of salt, enrichment by evaporation or mixing of fresh water with saline water or seawater can be clearly and quantitatively distinguished (Mook, 2001). The sample points that were taken from coastal zone are distributed on the mixing line between fresh and seawater (Figure 5.11A-B) and are formulated as below:

For rainy season: $\delta^{18}O = 0.0004 Cl - 5.7842$ ($r^2 = 0.97$) (Figure 5.11 A)

For dry season: $\delta^{18}O = 0.0004 Cl - 5.489$ ($r^2 = 0.85$) (Figure 5.11 B)

Groundwater from Belevi (sample 18), Virgin Mary House (sample 7), Acarlar (sample 8), Şirince and around (samples 19, 20, 21) and Tire (sample 22) represents freshwater samples that have no effect of seawater. The mixing waters that were plotted on the mixing line are taken from swamp (sample 1), karstic spring (samples 2, 11, 12), Lake Gebekirse (sample 4), Zeytinköy village (samples 9 and 10) and İzmir Gorge (sample 16).

If the groundwater is affected by evaporation, the samples will be distributed around an exponential line (Gonfiantini and Araguas, 1988). It can be clearly seen that from Figure 5.11(A-B); river (samples 5 and 15), Lake Kocagöz (sample 14) is plotted on the evaporation line. In addition, in rainy season lake Akgöl (sample 3) and in dry season lake Gebekirse (sample 13) are plotted between evaporation and mixing line that shows the effect the seawater on the lakes.

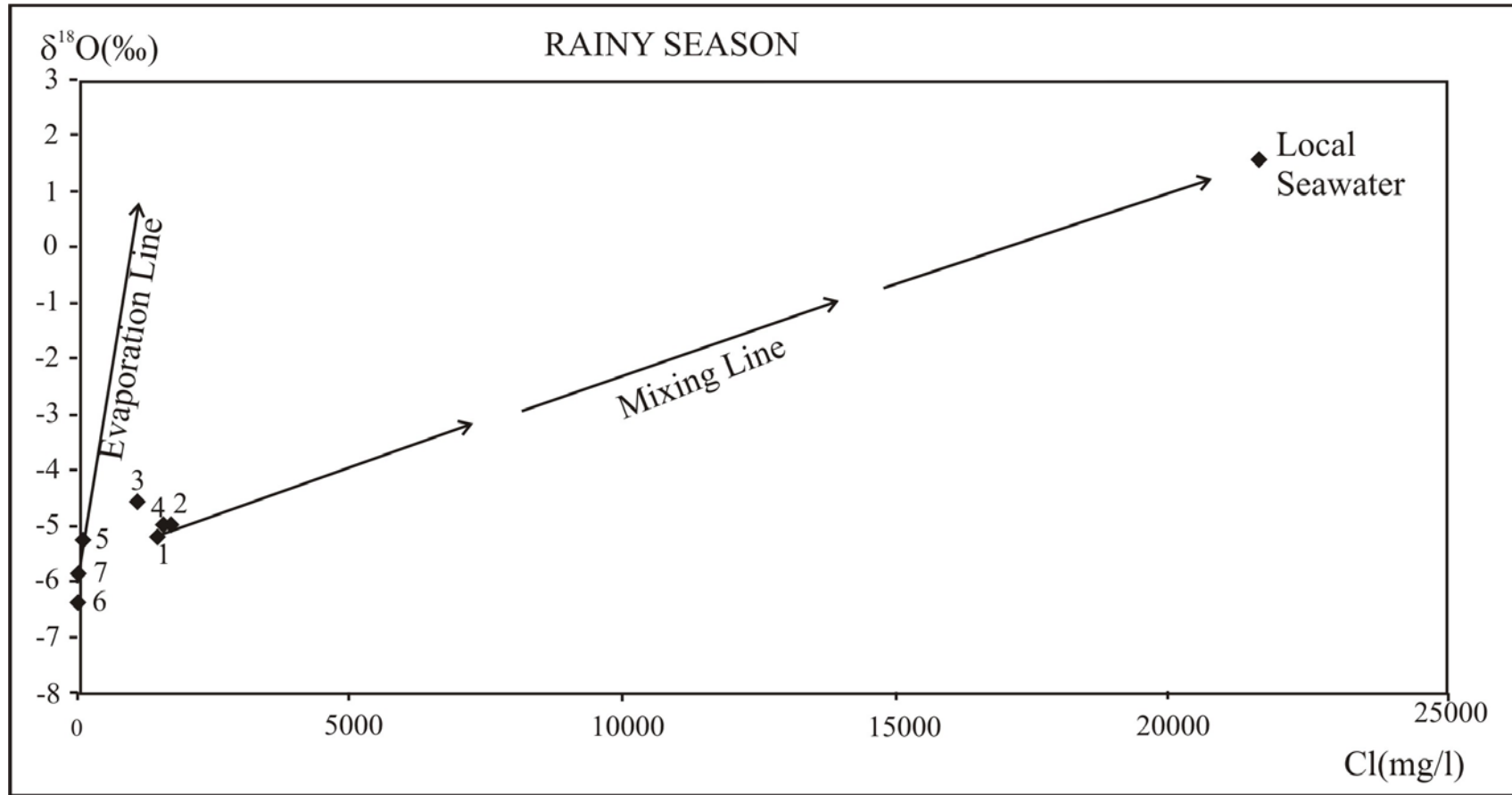


Figure 5.11-A. O-18 and Cl relationship of the waters in rainy season.

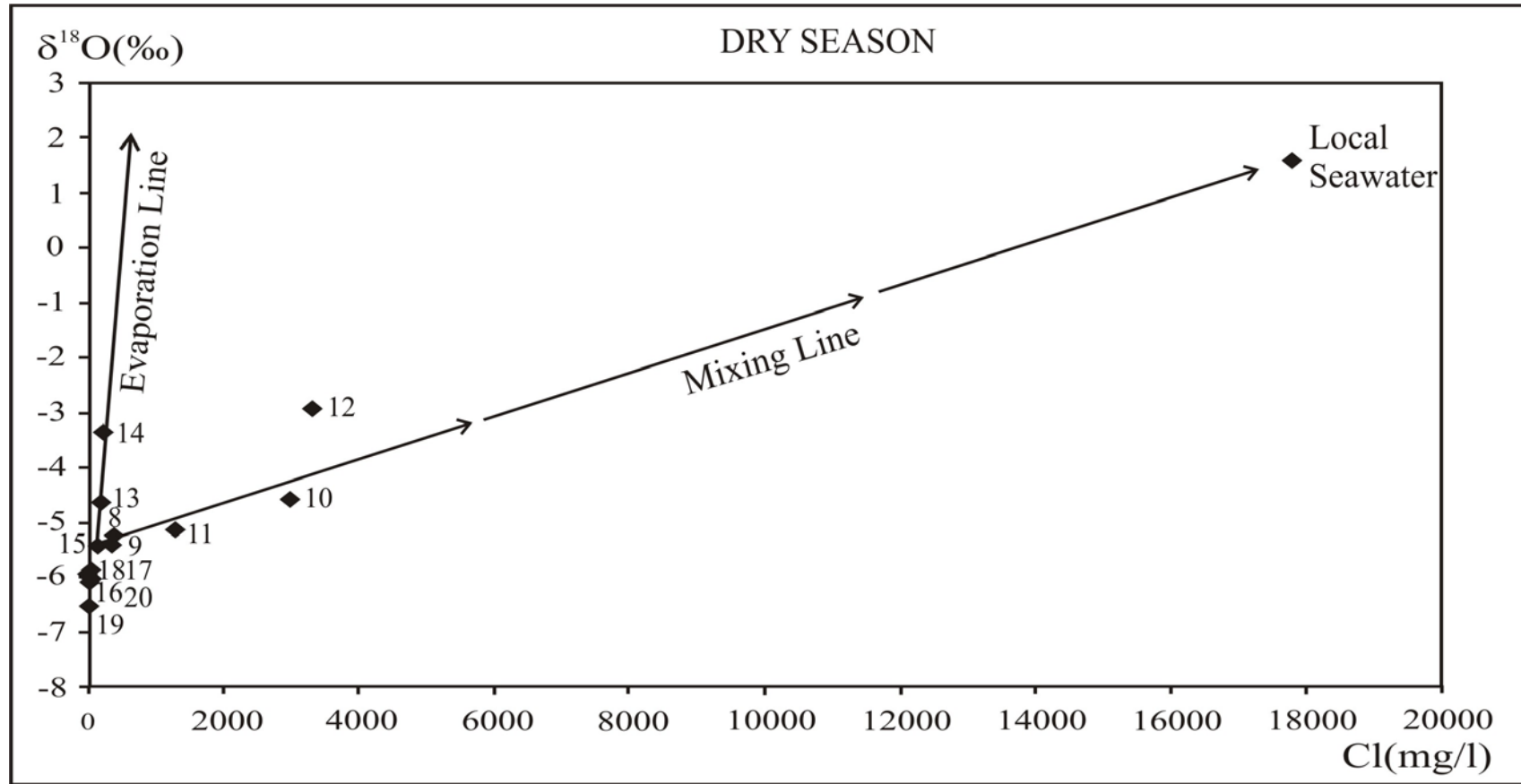
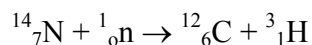


Figure 5.11-B. O-18 and Cl relationship of the waters in dry season.

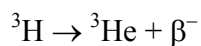
Tritium is probably the most commonly employed radioisotope used to identify the presence of modern recharge and, it is directly incorporated in to the water molecule and so is the only radioisotope that actually dates groundwater (Clark and Fritz, 1997). According to Clark and Fritz 1997; Tritium (^3H or T) is probably the most commonly employed radioisotope used to identify the presence of modern recharge. It is a short-lived isotope of hydrogen with a half-life of 12.43 years (Unterweger et al., 1980). It is directly incorporated into the water molecule ($^1\text{H}^3\text{HO}$ or ^1HTO) and so is the only radioisotope that actually dates groundwater. For most groundwaters, the strongest evidence that at least some active recharge occurs is the presence of measurable ^3H . Tritium is produced naturally by solar radiation, although much greater production accompanied the atmospheric testing of thermonuclear bombs between 1951 and 1980. Tritium's short half-life and recent anthropogenic production makes it an excellent indicator of modern groundwater recharge. It is easily sampled. Analysis is routine, and the interpretation is not necessarily complicated. Natural tritium is formed in the upper atmosphere from the bombardment of nitrogen by the flux of neutrons in cosmic radiation, following the reaction:



The tritium thus formed combines with stratospheric oxygen to form water:



Tritium decays to ^3He by beta release:



Tritium concentrations are expressed as tritium units (TU) where:

$$1 \text{ TU} = 1 \text{ } ^3\text{H} \text{ per } 10^{18} \text{ hydrogen atoms}$$

and $1 \text{ TU} = 0.118 \text{ Bq}\cdot\text{kg}^{-1}$ ($3.19 \text{ pCi}\cdot\text{kg}^{-1}$) in water (IAEA 1983).

Natural tritium levels in precipitation are very low and represent a secular equilibrium between natural production and the combination of decay in the atmosphere plus loss to the hydrosphere and oceans. Production rates and concentrations in precipitation are a function of geomagnetic latitude, with greater production at higher latitudes. Very few measurements exist of natural, pre-bomb tritium in precipitation.

In the light of the Tritium value that is helped us to identify the waters age, range between 5 and 6 TU that is noticed the groundwaters are recharges with modern rainfalls and have short circulation time in the ground.

5.5 Conclusion:

According to the stable isotope data, Selçuk Plain and Lower Küçük Menderes River coastal wetland take place on the evaporation-mixing line. $\delta^{18}\text{O}$ enrichment can be seen in the surface waters (lakes, swamp and river). Swamp, Kazangöl Karstic Spring and Lake Gebekirse that are under the seawater intrusion effect, were not influenced from evaporation in rainy season. But in dry season Lake Gebekirse are influenced from both evaporation and seawater intrusion.

Groundwater cycle of this basin has short time circulation that has 5-6 TU of tritium that explain the lakes recharge mainly from karstic springs.

CHAPTER SIX

GENERAL CONCLUSION AND RECOMMENDATIONS

Küçük Menderes River wetland is a marine/coastal wetland according to Ramsar classification and consists of 3 lakes (Lake Gebekirse, Lake Akgöl and Lake Kocagöz), swamp (Eleman Swamp) and riverine systems in Selçuk district, İzmir, Turkey.

Lakes are recharged from both precipitation and karstic springs (Kazangöl and Zeytinköy), and discharged from both evaporation and an outlet channel to Küçük Menderes River.

Two hydrogeochemical zones are defined in the study area and the processes that control the chemical compositions of waters are different in each zone. The water types from sea to the recharge area change from Na-Cl to Na-Ca-Cl-HCO₃, Ca-Mg-HCO₃-SO₄-Cl and Ca-Mg-HCO₃. First zone is seawater intrusion zone that the major ions are Na and Cl in the coastal part and the second zone is hilly-recharge area (Şirince, Acarlar, Andon Gorge, Belevi) and the dominant ions are HCO₃, Ca, Mg that they are derived from the weathering of Ca-Mg silicates, chiefly from calcite, plagioclase and feldspar in the schist. These waters are oversaturated with respect to boehmit, calcite, corundum, diaspor, dolomite, gibbsite, illite, K-Felspar, kaolinite, quartz that show the main hydrogeochemical process is weathering the different types of silicates in the recharge area.

The lakes are alkaline type with 8.00-7.50 pH values. EC values are more than recharge area that can be reached 11510 µS/cm at the Lake Gebekirse in dry season. The major species of Al is AlO₂⁻ in the lakes; the major specie of As is HAsO₄⁻²; Cu⁺² that is formed as CuCO₃ is the main ionic species; the major species of Fe is Fe⁺³; Mn is more than 80% is in the ionic form as Mn⁺² major species of Se is Se⁺⁴ with a selenite form in the wetland area. Wetland waters are saturated with respect to albite,

barite, boehmite, calcite, chromite, CuCr_2O_4 , dawsonite, dolomite, $\text{Fe}(\text{OH})_3$, gibbsite, goethite, illite, k-feldspar, kaolinite, MnHPO_4 , quartz, witherite. The main components of the wetlands waters are Na-Al silicates, Na-Al carbonates, Ba sulfate that are due to sea-water intrusion processes, and $\text{Fe}(\text{OH})_3$ and MnHPO_4 that are due to the high biological activities.

The salinization process is investigated by several methods such as relationships of ions, major and minor ion ratios and mixing ratios. According to the correlation coefficient between Na-Cl, Na- SO_4 and Cl- SO_4 ($r^2=0.99$) it can be clearly said that these ions are derived from seawater intrusion and evaporation in the wetland.

In the Na/Cl mixed model it has been seen that most of the saline groundwater samples that were taken from coastal area plot very close or slightly below the conservation line indicating some depletion of Na through ion exchange reactions during mixing process.

HCO_3/Cl diagram is suggesting that high TDS groundwaters (coastal zone) are typically enriched in chloride ion, mainly due to seawater mixing. Specific trend in a TDS vs. Na/Ca diagram is suggesting that Na/Ca ratios are controlled by seawater mixing process. In addition to these data, in the coastal zone, all of the groundwater has greater than 1 Mg/Ca molar ratio that are indicating the seawater intrusion. According to SO_4/Cl ratios, coastal zone takes places on the “Seawater Influence” line in both seasons that was proved the coastal zone is under seawater effect.

The mixing ratio was calculated and it can be easily said that in the rainy season maximum sea water mixing areas are swamp, karstic discharge points and the nearest lake, Gebekirse with 9.55 % value. In the dry season same places have maximum values than hilly area especially in Lake Gebekirse and Kazangöl karstic spring with 17.68 % mixing value.

The Br/Cl molar ratio as 0.028 (seawater) can be determined in Zeytinköy village, Lake Gebekirse, Lake Akgöl, Zeytinköy karstic discharge, Küçük Menderes River (Pamucak Bridge) and İzmir Gorge. The mixing of intruded seawater with fresh water caused only a slight change in the Br/Cl ratio. Lake Gebekirse and Akgöl, karstic spring shows the same B/Cl ratios in both season with seawater. In addition, in dry season the river, swamp, Zeytinköy village groundwater and İzmir Gorge show the similar ratios with seawater. The lithium concentration of swamp, karstic discharges, lakes and river are greater than other parts of the study area. Except swamp water, all other waters show perfect correlation with boron and lithium that suggests a common origin as seawater. In the coastal zone Lake Gebekise, Kazangöl and Zeytinköy karstic springs, swamp and Lake Akgöl in rainy season; swamp, Kazangöl and Zeytinköy karstic springs in dry season are exceeded 1‰ Sr/Ca molar ratio due to the sea-water effect.

A GIS-based method is developed related with major ion ratios (Na/Cl, Na/Ca, Mg/Ca), mixing ratios (MR), measured EC values and calculated SAR to determine the “Saline” and “Fresh” water zones at the Selçuk Plain in both dry and rainy seasons. This “Salinization Zone Map” is explained the saline/fresh zone in Selçuk Plain. Saline zone in both dry and rainy season covers Lake Gebekirse and Kazangöl and Zeytinköy karstic springs. But fresh zone can be widen or narrowed based on the chemical reactions, dilution and evaporation in the study area.

To investigate the relationship of the waters the fingerprints of the waters were used. The $\delta^{18}\text{O}$ and δD composition of wetland area samples range between -5.40‰ and -2.93‰ in rainy season, and -35.1‰ and -19.55‰ in dry season. The hilly area $\delta^{18}\text{O}$ and δD values are more negative due to the high elevation and more terrestrial effects than wetland area. These waters scatter on the Meteoric water line explaining that the groundwaters are originated from meteoric waters.

A low slope as 5.5-5.8 between δD and $\delta^{18}\text{O}$ can be produced by evaporation and/or mixing of groundwater and seawater. To certain the salinization process that

causes due to evaporation or seawater intrusion, the $\delta^{18}\text{O}$ -Cl relationship was used. For rainy season, $\delta^{18}\text{O}=0.0004 \text{ Cl}-5.7842$ and for dry season $\delta^{18}\text{O}=0.0004 \text{ Cl}-5.489$. It can be clearly seen from $\delta^{18}\text{O}$ -Cl diagram, Küçük Menderes River (Belevi bridge), Lake Kocagöz are plotted on the evaporation line. In addition, in rainy season lake Akgöl and in dry season Lake Gebekirse are plotted between evaporation and mixing line that shows the effect the seawater on the lakes.

In the light of the Tritium value that is helped us to identify the waters age, that is noticed the groundwaters are recharges with modern rainfalls and have short circulation time in the ground with 5-6 TU.

Contamination levels in wetland and Selçuk Plain were investigated at this study. At the wetland area copper, selenium and iron (except Lake Gebekirse) ions are exceed the tolerance limits of CWQG (2005) aquatic life standards.

Selçuk Plain is the last sub-basin of Küçük Menderes River Basin. River rises from Beydag and passes through Odemis, Tire, Torbalı and Belevi. Belevi is the last settlement that the river passes. But this river is collected very different types of contamination from the industrial zones (e.g. Tire, Torbalı etc.) and from mining products by stream.

Küçük Menderes River are already contaminated when comes to the Belevi district that has high level of Al, As, Fe and Mn ions that can be reached the drinking water standards by ten or twelve times.

In addition to this situation two different locations were sampled the risk of high heavy metal content: i) Selçuk waste disposal site that is located center of the Selçuk plain; ii) Selçuk municipality water treatment plant is located near the Küçük Menderes River and discharged the treatment water to the river. The heavy metal values of the aluminum, arsenic, copper, iron and zinc concentrations are found to exceed the standards limits in both places.

From what has been discussed above, we may safely draw the conclusion that Küçük Menderes River wetland is a kind of geological and archeological heritage for human. At recent, only the sea water intrusion effect the wetland but if the releasing of the disposal site waters and the treatment waters were not prevented this case may become a very dangerous situation in the future.

For wise using of the wetland, the main protection areas of lakes must be determined. The one of the environmental problem is contaminated Küçük Menderes River. To prevent the distribution of the contamination, the industrial and domestic wastes must be under controlled by authorities and treatment systems must be worked regularly and also to determined the pollution distribution area the Sismic Geophysics Method can be used. The second environmental problem is salinization. The certain seawater intrusion line should be determined by “Self (Spontaneous) Potential (SP) Geophysics Method”. To manage the salinization problem in Selçuk Plain, the inspection of the unauthorized wells must be the major mission by authorities. The artificial recharge may be the second solution for Selçuk Plain.

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APPENDICES

APPENDIX- I: GLOSSARY FOR WETLANDS (Ramsar, 2004).

ANAEROBIC	(Of organisms) ability to live anoxically i.e. in the absence of free (gaseous or dissolved) oxygen. (Of processes) occurring in the absence of such oxygen.
ANTHROPOGENIC	Involving the impact of man on nature: induced or altered by the presence and activities of man.
ARTIFICIAL WETLAND	(1) <i>Aquaculture/mariculture</i> a. Aquaculture ponds, including fish ponds and shrimp ponds. (2) <i>Agriculture</i> a. Ponds, including farm ponds, stock ponds and small tanks. b. Irrigated land and irrigation canals, including rice fields, canals and ditches. c. Seasonally flooded arable land. (3) <i>Salt exploitation</i> a. Salt pans and evaporation ponds. (4) <i>Urban/Industrial</i> . a. Excavations, including gravel pits, borrow pits and mining pools. b. wastewater treatment areas, including sewage farms, settling ponds and oxidation basins. (5) <i>Water storage areas</i> a. Reservoirs holding water for irrigation and/or human consumption with a pattern of gradual, seasonal drawdown of water level. b. Hydro-dams with regular fluctuations in water level on a weekly or monthly basis. c. Flood balancing ponds.
BIOCHEMICAL OXYGEN DEMAND (BOD)	The amount of dissolved oxygen (in mg per litre) used by micro-organisms feeding on the organic content of water measured over 5 days at 20°C. This is useful measure of organic pollution: <3mg/l indicates clean water, 30mg/l indicates gross pollution. (See also chemical oxygen demand [cod] and permanganate value [pv]). The magnitude of the results obtained is usually PV < BOD < COD.
BIODIVERSITY	The variety of all life on earth: the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.
BLACK ALKALI	A deposit of sodium carbonate that has formed on or near the surface in arid to semiarid areas.
BOG	A plant community that develops and grows in areas with permanently waterlogged peat substrates. Also known as moor; quagmire.
DENITRIFICATION	Process carried out by various facultative and anaerobic soil bacteria, in which nitrate ions act as alternative electron acceptors to oxygen during respiration, resulting in release of gaseous nitrogen. This nitrogen loss accounts in part for the lack of fertility of constantly wet soils that support nitrate-reducing anaerobes and for lowered soil fertility generally, products of denitrification not being assimilable by higher plants or most organisms. Bacteria such as <i>Pseudomonas</i> , <i>Achromobacter</i> and <i>Bacillus</i> are particularly important. See nitrogen fixation, nitrogen mineralization.
ESTUARINE WETLAND	(1) <i>Subtidal</i> a. Estuarine waters: permanent waters of estuaries and estuarine systems of deltas. (2) <i>Intertidal</i> a. Intertidal mud, sand or salt flats, with limited vegetation. b. Intertidal marshes, including salt meadows, tidal brackish and freshwater marshes. c. Intertidal forested wetlands (rare or non-existent in the Mediterranean).
FRESHWATER MARSH	Marsh containing water with no significant amount of salts, such as water derived from rainfall, rivers, freshwater lakes.
FRESHWATER WETLAND	See riverine wetland, lacustrine wetland and palustrine wetland.
HABITAT (NATURAL)	Definition in the Habitat Directive of the EU: terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, either entirely natural or semi-natural.

HYDRIC OR HYDROMORPHIC SOILS	Inadequately drained soil whose profile down to a depth of 45cm or less is saturated with water for a considerable part of the growth period of natural vegetation and which is dominated by reduction phenomena. These soils belong to the Aquic subclasses of the US Soil Taxonomy System
LACUSTRINE	(1) Of, relating to, or formed in lakes (~waters) (~deposits). (2) Growing or living in lakes (~flora) (~fish).
LACUSTRINE WETLAND	(1) <i>Permanent</i> a. Permanent freshwater lakes (>8ha), including shores subject to seasonal or irregular inundation. b. Permanent freshwater ponds (<8ha). (2) <i>Seasonal</i> a. Seasonal freshwater lakes (>8ha) including floodplain lakes.
LAGOONAL WETLAND	Brackish to salty lagoons with one or more relatively narrow connections to the sea.
MARINE WETLAND	(1) <i>Subtidal wetlands</i> a. Permanent unvegetated shallow waters less than 6m deep at low tide, including sea bays and straits. b. Subtidal aquatic vegetation, including sea grasses and tropical marine meadows. c. Coral reefs. (2) <i>Intertidal wetlands</i> a. Rocky marine shores, including cliffs and rocky shores. b. Shores of mobile stones and shingle. c. Intertidal unvegetated mud, sand or saltflats. d. Intertidal vegetated sediments, including mangroves, or sheltered coasts.
MARSH	A transitional land-water area, covered at least part of the time by surface water or saturated by groundwater at, or near the surface. Characterized by aquatic and glass-like vegetation, usually without peat accumulation.
MEDWET	Concerted action for stopping the loss and degradation of wetlands around the Mediterranean basin. Conceived in February 1991 at an international conference in Grado, Italy. Initially implemented in 1992 as an EU initiative with four Mediterranean member states and a number of NGOs. This first phase aimed to analyze the wetland situation around the Mediterranean and to prepare and test methods and tools for the wise use and conservation of wetlands.
ORNITHOLOGY	The scientific study of birds.
PALUSTRINE WETLAND	(1) <i>Emergent</i> a. Permanent freshwater marshes and swamps on inorganic soils with emergent vegetation that has its base below the water table for at least most of the growing season. b. Permanent peat-forming freshwater swamps, including tropical upland valley swamps dominated by <i>Papyrus</i> and <i>Typha</i> . c. Seasonal freshwater marshes on inorganic soil, including sloughs, potholes, seasonally flooded meadows and sedge marshes. d. Peatlands, including acidophilous, ombrogenous, or soligenous mires covered by moss, herbs, dwarf shrub vegetation or different types of ferns. e. Alpine and polar wetlands, including seasonally flooded meadows moistened by temporary waters from snowmelt f. Freshwater springs and oases with surrounding vegetation. g. Volcanic fumaroles continually moistened by emerging and condensing water vapour. (2) <i>Forested</i> a. Shrub swamps, including shrub-dominated freshwater marsh on inorganic soils. b. Freshwater swamp forest, including seasonally flooded forest on inorganic soils. c. Forested peatlands, including peat swamp forest.
PEAT BOG	Bog formed through the growth of hydrophytes which accumulate in large amounts. Eventually peat forms after partial decay, with up to 50% carbon. Topogenic peat bogs occur in swampy valleys. These depressions may be filled by vegetative accumulations, in which case raised peat bogs or ombrogenic mires may form. These wetlands are colonized by mosses of the genus <i>Sphagnum</i> e.g Dar Fatma in the Atlas mountains of Northern Tunisia.
RIPARIAN	Of, inhabiting, or situated on the bank of a river.
RIVERINE	Situated beside or of a river. (1) <i>Perennial</i> a. Permanent rivers and streams, also waterfalls. b. Inland deltas. (2) <i>Temporary</i> b. Seasonal and irregularly flowing rivers and streams. c. Riverine floodplains, including river flats, flooded river basins and seasonally flooded grasslands.

RIVERINE WETLAND	Wetland systems of less than 0.5 ppt ocean salts, exposed to channelized flow regimes. Riverine wetlands are categorized according to flow regimes such as tidal waters, with well-developed floodplains, fast-moving waters with little floodplain, and intermittent systems.
SALT MARSH	Commonly, a maritime habitat found in temperate regions, but typically associated with tropical and subtropical mangrove swamps, in which excess sodium chloride is the predominant environmental feature. In the Mediterranean it may be found in areas with some tidal influence e.g. Gulf of Gabbes/Iles de Kneiss in Tunisia, in deltas such as the Axios Delta in Northern Greece or in areas with saline ground water such as the sansouires of the Camargue.
SALT MEADOW	Land containing high concentration of minerals.
SALT WATER WETLAND	See marine wetland, estuarine wetland, lagoonal wetland.
SUSTAINABLE USE OF WETLANDS	Human use (of a wetland) so that it may yield the greatest continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations
SWAMP	Whilst authorities differ, a swamp may be defined as a vegetated area perennially flooded or saturated with groundwater. It differs from a marsh in that the latter normally has a period of desiccation.
TIDAL MARSH	Salt or brackish wetland systems subject to tidal flow patterns. Estuarine marshes are subdivided into subtidal (permanently flooded) or intertidal (temporarily flooded) wetland systems.
WETLAND	Ramsar definition : "Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static, flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six meters". U.S. EPA definition: "Wetlands are lands inundated or saturated by surface or ground water, at a frequency and duration sufficient to support, and that under normal circumstances do support a prevalence of vegetation, typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas". See salt water wetland, freshwater wetland, artificial wetland.
WETLAND HYDROLOGY	The scientific field of hydrology dealing with wetlands. It is characterised by a focus upon storages and water levels in storages rather than water flow which is the main focus of hydrology undertaken in river basins.
WETLANDS	Natural or semi-natural stretches of land and/or water which link together wetlands allowing migration and movement of non-flighted species between the sites.
WISE USE OF WETLANDS	Sustainable utilization of wetlands for the benefit of mankind in a way compatible with the maintenance of the natural properties of the ecosystem.

APPENDIX II- MAJOR ION COMPOSITION OF WATERS

NO	GPS Locations		EC	pH	Na ⁺	K ⁺	Ca ⁺²	Mg ⁺²	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻²	Water Type (IAH, 1979)
	X	Y	μS/cm		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	+ CO ₃ ⁻²	(mg/l)	
1	0528715	4205525	6740	8.01	1094.8	37.5	205.6	144.4	2150	248.9	537.4	Na-Cl
2	0527550	4203125	2100	7.67	305.0	34.0	102.0	47.0	490	580	100.0	Na-Ca-Cl-HCO3
3	0526525	4204500	6230	8.25	1008.6	40.4	158.4	127.8	2000	309.9	299.2	Na-Cl
4	0527075	4204450	6240	8.30	1051.7	40.4	152.4	123.4	2000	297.7	359.9	Na-Cl
5	0527875	4202500	1903	7.69	313.9	27.5	63.6	42.0	441	405	111.9	Na-Cl-HCO3
6	0525175	4203475	1416	7.60	158.6	13.6	102.0	42.8	295	390.4	60.9	Na-Ca-Mg-Cl-HCO3
7	0525465	4203500	1388	7.75	198.4	20.2	67.2	40.8	279	407.5	55.1	Na-Mg-Ca-Cl-HCO3
8	0525725	4204025	4510	7.20	736.3	27.5	140.0	96.7	1350	361.1	265.8	Na-Cl
10	0531200	4203250	2210	7.73	320.7	19.3	96.8	49.1	541	339.2	78.2	Na-Ca-Cl-HCO3
11	0531700	4203625	734	7.26	70.3	14.3	63.2	15.6	98	266	45.3	Ca-Na-HCO3-Cl
12	0530200	4203700	1470	7.40	144.3	10.0	130.8	22.0	270	439.2	73.2	Ca-Na-HCO3-Cl
13	0530175	4204850	1124	7.00	98.6	7.2	134.8	21.6	176	429.2	73.2	Ca-Na-HCO3-Cl
14	0530050	4205000	944	7.52	41.9	2.4	134.8	27.2	105	436.8	42.4	Ca-Mg-HCO3-Cl
15	0530075	4204925	963	7.05	46.3	2.1	141.6	26.7	105	441.6	35.8	Ca-HCO3-Cl
16	0530375	4204475	1004	7.05	74.6	4.3	119.6	23.6	142	412.4	35.0	Ca-Na-HCO3-Cl
17	0528800	4205375	776	7.60	31.1	2.4	124.0	21.6	69	417.2	17.7	Ca-HCO3-Cl
18	0528750	4206250	786	7.17	31.1	2.1	116.4	7.3	68.0	339.6	16.5	Ca-HCO3-Cl
19	0524625	4204675	4470	7.25	775.7	27.6	127.6	90.2	1500	290.4	177.4	Na-Cl
20	0530150	4199875	952	7.43	44.1	4.6	106.8	45.9	74	478.2	40.8	Ca-Mg-HCO3

NO	GPS Locations		EC μS/cm	Ph	Na ⁺ (mg/l)	K ⁺ (mg/l)	Ca ⁺² (mg/l)	Mg ⁺² (mg/l)	Cl ⁻ (mg/l)	HCO ₃ ⁻ + CO ₃ ⁻²	SO ₄ ⁻² (mg/l)	Water Type (IAH, 1979)
	X	Y										
21	0529100	4199650	2070	7.5	220.0	21.3	234.0	37.2	363	707.6	181.1	Ca-Na-HCO3-Cl
22	0528775	4199850	1586	7.52	180.0	12.5	94.8	53.0	320	375.6	97.5	Na-Ca-Mg-Cl-HCO3
23	0529050	4200350	1546	7.68	150.0	12.5	112.0	53.5	296	453.8	84.4	Na-Ca-Mg-Cl-HCO3
24	0529925	4200450	1451	7.70	150.0	10.0	140.0	60.0	225	514.8	111.5	Ca-Na-Mg-HCO3-Cl
25	0529825	4200650	2940	7.65	390.0	18.8	138.8	74.8	775	431.9	111.5	Na-Ca-Mg-Cl-HCO3
26	0528525	4201050	4780	9.45	790.0	47.0	135.0	105.0	1500	110.0	410.0	Na-Cl
27	0527250	4200775	5350	8.08	1100.0	40.0	43.6	51.3	1630	588.1	144.0	Na-Cl
28	0526525	4200450	1288	8.30	150.0	11.3	104.0	38.9	375	139.1	42.0	Na-Ca-Mg-Cl
29	0526950	4199100	1390	7.51	120.0	12.0	150.0	50.0	300	427.0	36.2	Ca-Na-Mg-Cl-HCO3
30	0527125	4200075	2760	7.58	320.0	16.3	220.0	63.2	800	441.4	113.2	Na-Ca-Cl-HCO3
31	0538150	4199700	390	7.40	8.4	1.1	58.4	15.8	25	231.8	15.6	Ca-Mg-HCO3
32	0537050	4200925	690	7.05	17.4	3.2	105.6	28.7	36	414.8	8.6	Ca-Mg-HCO3
33	0538325	4199550	934	7.14	17.9	17.2	109.6	57.4	57	583.2	34.6	Ca-Mg-HCO3
34	0536825	4200800	781	8.28	23.0	3.4	80.0	60.0	58	350.0	58.9	Mg-Ca-HCO3
35	0535975	4201550	516	7.70	13.5	1.5	74.0	23.6	39	295.2	23.6	Ca-Mg-HCO3
36	0534725	4201675	830	7.15	28.8	3.0	105.2	44.7	66	441.6	60.1	Ca-Mg-HCO3
37	0534925	4201525	842	7.20	29.7	2.8	109.2	43.5	66	451.4	70.0	Ca-Mg-HCO3
38	0534475	4201650	845	7.26	29.9	3.2	107.6	44.0	67	453.8	73.3	Ca-Mg-HCO3
39	0534150	4201500	741	7.24	24.2	2.6	98.8	35.7	58	409.9	53.1	Ca-Mg-HCO3
40	0534075	4201550	1234	7.49	34.0	4.0	155.6	60.0	278	344.0	80.7	Ca-Mg-Cl-HCO3
41	0531525	4196550	604	7.49	12.7	2.8	82.4	33.8	47	300.0	65.4	Ca-Mg-HCO3

NO	GPS Locations		EC	pH	Na ⁺	K ⁺	Ca ⁺²	Mg ⁺²	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻²	Water Type
	X	Y	μS/cm		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	+ CO ₃ ⁻²	(mg/l)	(IAH, 1979)
42	0532450	4194575	865	8.36	21.0	5.1	41.0	100.0	46	490.0	70.0	Mg-HCO ₃
43	0530350	4198450	1255	7.51	97.4	7.1	105.6	44.2	254	348.9	77.0	Ca-Na-Mg-Cl-HCO ₃
44	0528409	4200943	4180	7.79	612.7	61.5	119.7	104.3	1080	490.6	273.5	Na-Mg-Cl
45	0527275	4200773	5540	7.74	1048.7	43.6	41.3	50.8	1580	577.6	190.1	Na-Cl
46	0529121	4199618	1608	7.43	180.2	14.6	97.9	45.7	326	356.8	125.4	Na-Ca-Mg-Cl-HCO ₃
47	0532751	4201059	1667	7.33	48.3	3.8	145.1	112.3	226	468.3	108.1	Mg-Ca-HCO ₃ -Cl
48	0531141	4203559	659	7.55	54.3	6.4	57.7	24.3	72	220.8	80.4	Ca-Na-Mg- HCO ₃ -Cl-SO ₄
49	0530126	4204934	1067	7.36	47.0	1.9	131.4	39.1	97	446.0	53.8	Ca-Mg-HCO ₃ -Cl
50	0526600	4205153	2190	7.50	248.4	10.4	142.7	47.1	480	383.6	113.1	Na-Ca-Cl- HCO ₃
51	0526560	4204600	9700	7.75	1537.0	61.5	204.8	195.1	2780	325.6	447.4	Na-Cl
52	0524214	4204569	8560	7.15	1368.3	55.3	166.9	184.7	2500	347.9	392.3	Na-Cl
53	0538000	4199840	333	7.68	6.7	0.7	49.1	11.9	40	151.7	13.4	Ca-Mg- HCO ₃ -Cl
54	0537938	4207800	2460	7.66	121.4	9.9	321.2	78.6	235	706.9	498.0	Ca-Mg- HCO ₃ -SO ₄ -Cl
55	0528600	4205153	2020	7.38	202.5	7.4	142.5	33.3	391	446.0	75.0	Na-Ca-Cl-HCO ₃
56	0526560	4204600	11510	8.13	1873.2	66.1	217.4	199.6	3340	266.0	471.0	Na-Cl
57	0524282	4200512	1717	7.44	174.7	5.4	111.3	30.0	381	254.2	45.0	Na-Ca-Cl-HCO ₃
58	0524165	4204396	10250	7.25	1489.1	56.2	183.7	193.8	2980	276.5	432.0	Na-Cl
59	0528409	4200943	4550	8.52	657.8	42.5	132.5	115.7	1230	480.7	84.0	Na-Mg-Cl
60	0527214	4200599	5790	7.90	1126.9	37.2	39.8	54.1	1500	671.0	174.0	Na-Cl
61	0526440	4200259	5490	7.43	533.2	12.1	337.9	147.2	1580	312.2	192.0	Na-Ca-Mg-Cl
62	0531935	4196438	652	7.77	10.5	3.4	76.6	29.7	32	334.5	48.0	Ca-Mg-HCO ₃

NO	GPS Locations		EC $\mu\text{S/cm}$	pH	Na^+ (mg/l)	K^+ (mg/l)	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	Cl^- (mg/l)	HCO_3^- + CO_3^{-2}	SO_4^{-2} (mg/l)	Water Type (IAH, 1979)
	X	Y										
63	0535145	4201467	813	7.43	26.3	2.9	94.3	33.0	64	394.7	60.0	Ca-Mg- HCO_3
64	0538033	4199538	305	8.00	5.8	0.4	43.6	9.5	15	160.6	15.0	Ca-Mg- HCO_3
65	0537885	4205566	997	7.35	2.4	0.8	104.2	5.6	7	350.9	12.0	Ca- HCO_3
66	0538210	4207313	1600	7.95	92.1	7.9	192.0	11.4	103	305.0	356.2	Ca-Na- SO_4 - HCO_3
67	0527197	4200633	5360	7.61	1267.7	35.0	14.4	15.6	1090	556.3	114.4	Na-Cl
68	0527376	4200592	5450	7.94	1220.0	47.6	23.6	42.5	1110	507.5	122.1	Na-Cl
69	0524839	4201836	2850	7.98	431.8	15.3	104.0	53.5	450	458.7	109.5	Na-Cl- HCO_3
70	0524126	4204452	5800	7.13	1070.8	25.9	134.0	121.0	1270	778.4	190.2	Na-Cl- HCO_3
71	0524140	4199607	58800	8.28	12720.0	398.8	476.0	48.1	17800	156.2	2920.7	Na-Cl
72	0529387	4196129	645	7.26	8.9	0.3	74.8	32.8	131	356.2	40.6	Ca-Mg- HCO_3
73	0531944	4196472	624	7.44	9.5	2.4	108.0	7.3	16	317.7	46.4	Ca- HCO_3
74	0538151	4199552	472	7.41	8.6	1.5	60.8	19.4	15	236.7	26.6	Ca-Mg- HCO_3
75	0526560	4204600	2255	7.72	1107.4	34.5	130.4	105.0	1720	235.9	290.0	Na-Cl
76	0528600	9205153	1586	7.99	740.0	19.0	135.0	74.0	1125	300.0	250.0	Na-Cl
77	0530240	4203222	565	7.83	43.9	100.8	54.0	19.7	120	295.2	24.0	Ca-K-Na- HCO_3 -Cl
78	0529121	4199618	1488	6.69	158.2	13.9	90.3	48.0	206	453.8	104.8	Na-Ca-Mg- HCO_3 -Cl
79	0524839	4201836	2900	7.90	506.8	16.1	145.1	59.2	745	522.2	175.6	Na-Ca-Cl- HCO_3
80	0524605	4204525	4150	6.76	672.0	19.6	153.6	90.8	1290	366.0	168.5	Na-Cl
81	0524712	4204530	1684	7.28	205.8	4.7	114.0	32.8	360	400.2	56.5	Na-Ca-Cl- HCO_3
82	0524715	4204535	2530	7.84	373.2	10.0	105.8	48.1	635	353.8	90.6	Na-Ca-Cl- HCO_3
83	0524643	4206425	977	6.83	80.6	2.1	97.6	24.5	151	356.2	29.1	Ca-Na- HCO_3 -Cl

NO	GPS Locations		EC $\mu\text{S/cm}$	pH	Na ⁺ (mg/l)	K ⁺ (mg/l)	Ca ⁺² (mg/l)	Mg ⁺² (mg/l)	Cl ⁻ (mg/l)	HCO ₃ ⁻ + CO ₃ ⁻²	SO ₄ ⁻² (mg/l)	Water Type (IAH, 1979)
	X	Y										
84	0530456	4205808	780	6.85	25.8	1.8	121.6	17.5	57	419.7	21.1	Ca-HCO ₃
85	0536564	4201383	773	7.20	21.3	2.1	76.9	46.3	39	430.0	61.2	Ca-Mg-HCO ₃
86			430	6.83	4.6	0.5	67.6	6.1	12	233.9	15.0	Ca-HCO ₃
87	0524547	4204641	4020	7.05	638.0	19.0	136.7	83.1	1107	366.0	168.0	Na-Cl
88	0537885	4205566	922	7.02	20.5	7.7	101.5	44.1	46	434.3	63.0	Ca-Mg-HCO ₃
89	0536870	4218585	1534	7.98	179.0	12.8	91.0	36.0	198	478.2	100.0	Na-Ca-HCO ₃ -Cl
90	0546505	4219269	1853	7.75	193.3	35.0	105.5	27.1	250	507.5	12.0	Na-Ca-HCO ₃ -Cl
92	0562770	4221771	1524	7.64	135.5	29.5	85.8	23.3	178	517.7	21.0	Na-Ca-HCO ₃ -Cl
93	0590692	4233682	230	7.28	8.7	2.6	18.6	8.9	10	87.8	27.0	Ca-Mg-HCO ₃ -SO ₄
94	0593324	4235146	393	7.85	16.1	5.0	34.9	18.3	12	178.1	60.0	Ca-Mg-HCO ₃ -SO ₄
95	0605508	4218090	759	6.57	69.3	21.1	57.0	14.3	96	231.8	33.0	Na-Ca-HCO ₃ -Cl
96	0606314	4216874	537	7.93	21.4	6.5	37.9	28.3	23	229.4	66.0	Mg-Ca-HCO ₃ -SO ₄
97	0606041	4216101	236	6.85	11.0	3.1	21.6	6.4	12	93.2	24.0	Ca-Mg-Na-HCO ₃ -SO ₄

APPENDIX- III: HEAVY METAL CONTENTS OF THE WATERS (Units are in ppb; n.d.=not detected).

NO	Ag	Al	As	B	Ba	Br	Cd	Cr	Cu	Fe	Li	Mn	Ni	Pb	Rb	Sb	Se	Si	Sr	U	Zn
54	0.14	154	28.2	52	134.61	1216	n.d.	1.4	5.3	1049	5.8	2374.1	11.4	1.5	3.34	2.58	1.9	9862	804.4	5.81	9.1
55	0.10	39	3.6	89	29.00	1655	n.d.	0.7	5.3	103	7.3	41.3	n.d.	2.3	2.40	0.37	1.9	5820	264.8	1.36	25.7
56	0.66	50	12.8	695	43.98	14627	n.d.	2.2	37.9	138	40.3	36.1	n.d.	6.3	17.8	0.32	17.2	749	1363.2	1.64	9.9
57	0.31	9	1.8	51	19.57	1388	n.d.	0.9	5.8	1006	4.1	5.0	0.3	1.1	1.77	0.16	1.7	4880	228.2	0.91	8.7
58	0.17	15	10.6	570	33.81	12390	n.d.	2.4	20.2	n.d.	30.7	1.5	n.d.	4.2	17.8	0.2	13.7	5233	1202.7	1.31	10.6
59	0.14	250	22.4	589	52.03	4788	0.51	3.8	13.3	893	11.1	262.1	2.9	4.5	13.1	1.42	5.8	2854	758.4	2.22	356.4
60	0.46	20	5.7	1332	137.07	6261	0.22	3.6	15.6	95	18.5	8.3	n.d.	4.2	2.75	0.19	8.8	8937	482.8	1.30	123.1
61	0.54	24	8.2	268	241.01	6338	1.12	1.8	7.9	325	15.0	392.8	n.d.	11.3	3.44	0.2	7.3	11443	1693.7	2.45	19.4
62	0.21	9	2.8	n.d.	52.06	100	0.15	0.6	1.6	n.d.	3.4	1.2	n.d.	1.2	4.22	0.65	n.d.	7144	187.9	1.65	6.2
63	n.d.	42	0.9	31	18.23	208	0.12	1.4	1.9	11	6.1	16.7	2.3	1.7	0.80	0.15	0.6	11041	308.7	1.61	127.0
64	0.37	6	n.d.	n.d.	5.87	36	0.15	0.7	4.5	n.d.	0.5	0.4	n.d.	1.5	0.23	0.14	n.d.	3485	47.8	0.64	6.4
65	n.d.	1	n.d.	n.d.	3.80	22	0.12	3.2	0.3	n.d.	1.4	0.1	n.d.	0.3	0.01	n.d.	n.d.	1585	55.4	0.14	6.4
66	0.23	187	6.6	47	69.53	466	0.08	1.9	8.0	858	4.0	502.7	4.9	2.5	2.13	1.5	2.4	8456	509.4	4.84	16.1
67	0.65	38	5.1	1553	100.82	4394	0.94	0.7	13.4	303	19.8	9.6	0.5	6.4	2.35	0.2	16.1	9861	371.4	1.52	989.3
68	0.51	314	183.9	1820	154.16	4455	0.63	4.0	98.2	764	19.2	300.8	16.2	5.1	6.30	1.41	107.8	8656	367.3	1.07	50.1
69	0.22	72	23.1	285	57.33	1356	n.d.	2.4	4.6	1035	9.9	309.7	2.9	1.5	6.61	1.87	6.3	8150	343.2	1.22	11.6
70	n.d.	49	7.2	283	21.18	4161	n.d.	8.7	4.5	118	16.0	1.0	n.d.	0.1	7.64	0.13	16.0	5421	547.1	0.26	n.d.
71	1.46	121	84.1	3923	8.99	60984	n.d.	n.d.	75.3	n.d.	169.3	n.d.	n.d.	13.3	105	n.d.	223.4	0.5	7184.2	3.49	13.2
72	0.07	9	n.d.	n.d.	4.56	44	0.09	0.9	10.6	225	2.3	2.3	2.8	1.2	0.50	0.15	n.d.	7006	164.6	0.47	1019.6
73	0.12	9	2.1	n.d.	42.25	55	0.07	1.1	6.0	163	2.8	1.8	2.5	0.9	2.84	0.47	0.6	6911	142.9	1.49	144.4
74	0.11	13.5	n.d.	n.d.	5.78	37	n.d.	1.2	10.3	130	3.4	0.5	0.5	0.9	2.97	0.09	n.d.	11334	230.6	0.67	21.7

NO	Ag	Al	As	B	Ba	Br	Cd	Cr	Cu	Fe	Li	Mn	Ni	Pb	Rb	Sb	Se	Si	Sr	U	Zn
75	0.89	180	8.7	365	42.37	6324	0.35	1.8	16.0	137	27.1	47.1	0.3	4.7	11.4	3.55	31.3	4673	779.6	1.52	24.3
76	0.13	160	7.7	205	52.05	3884	n.d.	2.6	10.7	464	15.2	135.2	n.d.	3.9	5.46	1.97	20.4	6174	551.7	1.58	6.7
77	0.63	1097	10.2	124	52.47	177	0.10	3.5	8.9	1604	5.2	245.1	8.1	5.8	10.8	4.92	1.2	10153	195.5	0.83	22.3
78	0.06	76	11.1	128	55.15	943	n.d.	1.5	7.4	500	8.8	549.5	4.0	2.8	5.77	0.42	4.8	7173	338.5	0.8	5.8
79	0.09	199	44.2	296	95.98	2018	n.d.	3.9	11.7	1247	15.2	630.4	0.6	1.2	7.74	4.17	11.1	9053	501.6	1.69	8.4
80	0.20	19	4.9	219	25.93	3689	n.d.	2.9	8.9	16	13.8	0.6	n.d.	1.5	7.16	0.29	19.4	5832	548.1	1.2	6.6
81	0.20	10	2.1	56	17.17	1112	n.d.	1.2	3.5	22	4.3	1.9	0.6	0.7	1.91	0.16	5.7	5137	217.4	0.99	3.9
82	0.14	98	11	119	25.31	1977	n.d.	1.2	5.0	275	7.9	40.0	0.6	0.3	3.29	1.99	10.2	3476	311.7	1.13	2.1
83	0.09	11	2.3	29	23.06	461	n.d.	1.1	2.0	n.d.	2.1	0.6	0.7	0.4	1.01	0.14	2.5	5870	135.7	0.75	3.1
84	0.07	20	1.1	29	13.99	144	0.06	1.0	3.9	n.d.	2.1	1.2	2	2.6	0.95	0.15	0.9	5942	92.0	0.68	7.5
85	0.08	8	1.3	21	11.19	124	n.d.	0.8	2.3	n.d.	5.7	0.7	1.4	1.1	1.40	0.17	0.7	14929	307.4	1.69	3.0
86	n.d.	34	n.d.	15	7.29	26	0.23	n.d.	1.3	n.d.	0.3	1.6	n.d.	1.1	0.33	0.06	n.d.	4463	159.9	0.85	21.0
87	n.d.	14	n.d.	223	22.11	4168	0.01	0.1	4.9	n.d.	13.0	3.5	n.d.	n.d.	6.75	n.d.	19.5	5231	530.1	1.18	7.9
88	n.d.	9	0.9	37	32.15	171	0.18	21.9	3.0	n.d.	11.6	1.0	n.d.	0.4	0.15	0.31	2.2	12204	460.6	1.48	9.7
89	0.13	472	75.8	3102	71.99	558	0.10	8.4	11.6	2066	10.8	970.9	0.8	3.1	6.76	0.90	3.2	8469	960.5	4.56	85.3
90	n.d.	683	39.5	1560	91.71	191	0.07	14.8	6.3	3029	8.7	277.1	2.5	2.2	21.59	3.88	1.0	17318	356.6	0.37	14.4
92	0.14	103	19.6	1368	322.97	151	0.09	9.0	40.1	462	20.3	294.6	2.3	3.2	18.23	2.31	0.9	13887	310.6	0.52	31.2
93	n.d.	14	1.9	n.d.	52.34	24	0.06	3.0	4.7	63	6.9	2.8	0.3	0.9	0.27	n.d.	n.d.	13564	129.1	0.07	90.2
94	n.d.	989	6.6	n.d.	66.03	33	n.d.	4.9	4.7	2403	16.6	94.7	2.4	1.0	6.30	0.60	0.5	12869	235.0	0.29	18.9
95	0.15	43	9.5	93	218.26	71	0.07	3.5	32.8	2114	23.8	404.1	2.3	5.0	11.84	0.44	n.d.	8955	150.4	0.23	29.5
96	0.08	299	5.6	85	38.95	55	0.06	4.6	5.4	1027	7.3	121.6	6.1	1.4	4.30	0.36	0.5	11728	150.0	3.97	39.6
97	0.10	29	0.9	25	21.99	31	n.d.	2.9	2.3	20	2.0	3.0	0.4	0.6	0.33	0.09	n.d.	10521	97.1	0.36	15.8

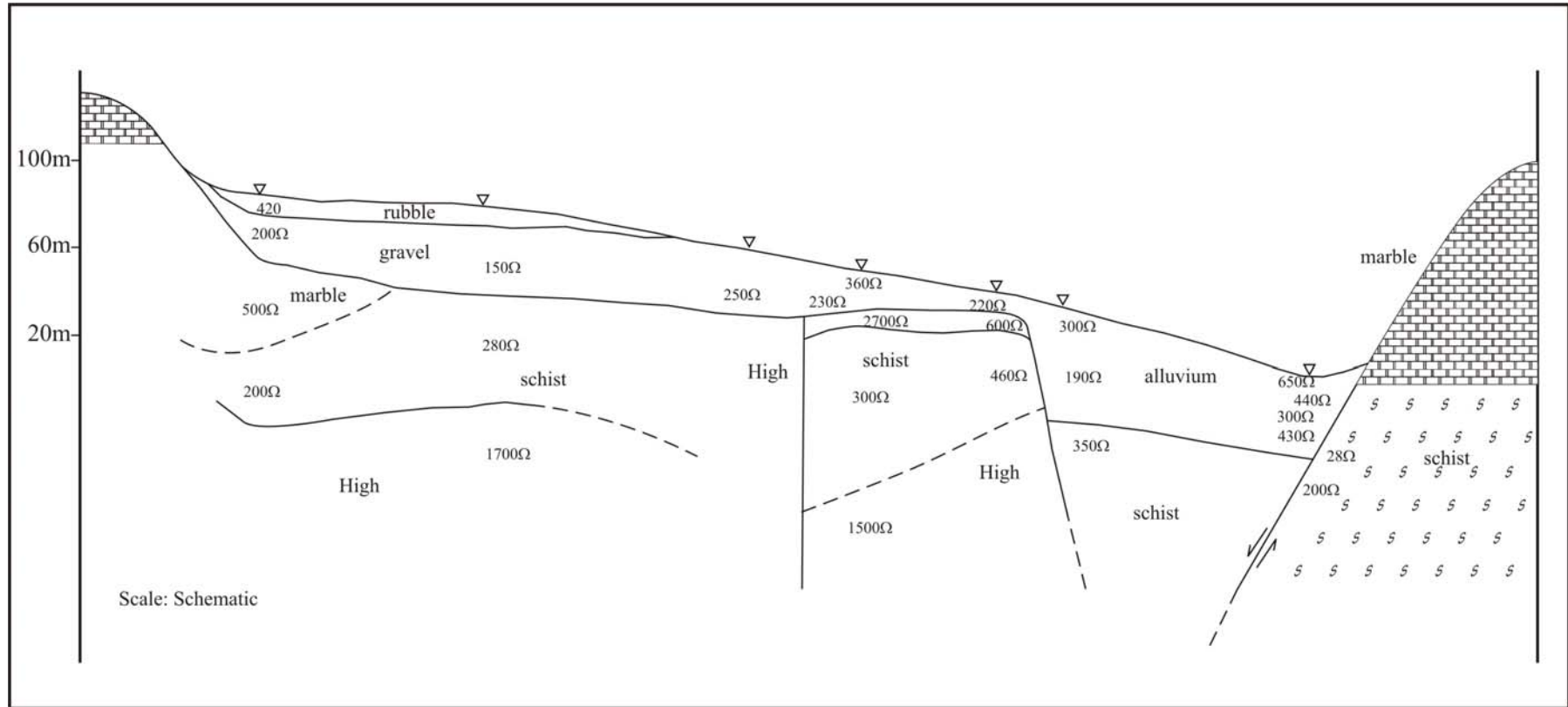
APPENDIX IV- REPORT CARD OF THE RESISTIVITY VALUES FOR İZMİR GORGE (DSİ. 1990b)

Point No	1	36	37	39	40	43	44	45	46	47	48	55	56	57	58	59
Map section	L18-c4	M18-bl	M18-bl	M18-bl	M18-bl	L18-c4	L18-c4	L18-c4	L18-c4	L18-c4	L18-c4	L18-c4	L18-c4	L18-c4	M18-bl	M18-bl
AB/2 (m)	EXTERNAL RESISTIVITY VALUES (ohm-m)															
2	217	8.6	18.2	59	63.7	163	236	425	274	212	98.8	73.7	164		48.1	25.5
2.5	248	9.8	17.8	51.7	75.2	118	270	385	277	251	103	70.5	164.5	94	42.6	25.4
3	258	10.8	18.1	43.3	84.3	121	291	371	323	264	105	76.7	168		44	23.8
4	297	12.1	16.2	39.6	97.3	143	297	383	485	301	109	92.8	179		70.1	22
5	300	13.2	14.3	35.4	100	161	319	407	404	311	116	103	194.5		48.6	20.7
6	308	12.8	12.6	33.6	113	186	324	373		319	154	115	212.5	106	48.1	20.4
7	300	12	11.8	34.1	100	211	325	520	642	316	128	130	229		50.5	20.1
8.5	276	12.4	10.5	36.1	92.6	248	316	407	507	299	138	152	235		51.2	20.1
10	247	11.4	10.3	39.4	79.8	293	350	469		300	158.5	166	244		53.9	20.8
12	271	11.5	8.7	40.6	63.2	336	357	566	497	289	153	194	274		54.2	22.8
15	285	11.6	6.2	47.6	68.2	423	372		595	217	169	260	322		55.5	
18	305	12.2	5.5	51.8	53.3	498	355	540	649	301	169	270	364		58.7	
21	309	13.5	5.1	54	55.4	533	354	575	680	309	190	322	411	169	63.7	
25	330	14.5	5.2	58.8	61.8	608	405	615		325	208	402	466	172	64.1	61.8
30	360	15.1	4.3	65	68.7	650	420	654		332	249		537	177	69.2	47.7
35	415	15.6	4.9	69.2	70.2	702	513	673		354	304		609	176	73.1	53.2
40	393	17.4	5.3	58	71.5	671	410	585	746	365	323		641	171	106	55.5
45	431	17.4	5.7	65	77.7	676	447	599	947	322	363		730	179	110	61.3
50	472	18.7	6.4	68.2	81.6	718	494	591		348	414	829	858	290	117	67.7
60	548	21.5	7.7	78.7	96.9	743	628	666	884		563	1016	1041	232	134	72.6
70	644	23	8.5	84.3	109	794	728	738	1039		719	1278	1301	268	151	76.7
80	752	25.4	9.5	102	121	827	882	842	1170	558	915		1535	306	190	86.9
90	857	26.3	11.1	107	141	964	978	867	1030	317	1143	1968	1859	362	190	87.8
100	929	28.1	12.1	121	162	1031	1095	1064	1150	331	1254	2326	2248	376	196	94.1
120			14.6	150	182	1129	1190	1112	1355	405	1619		2648	452	213	90.3
140			16.6	167	215	1230	1395	1162	1230	432	2087			484	288	112
160				192	238	1322	1507		1406	519	2181		3817	522	326	120
180				213	270	1398	1500	1271	1504	515			4133	559	340	134

APPENDIX IV- REPORT CARD OF THE RESISTIVITY VALUES FOR SAKIZLI GORGE (DSİ, 1990b)

Point No	2	3	49	50	51	53	54
Map section	L18-c4	L18-c4	L18-c4	L18-c4	L18-c4	L18-c4	L18-c4
AB/2 (m)	EXTERNAL RESISTIVITY VALUES (ohm-m)						
2	495	377	391	209	2625	786	206
2.5	496	368	389	218	2256	846	225
3	540	391	419	239	2303	880	234
4	556	316	495	270	2640	895	272
5	521	306	459	292	1365	868	297
6	545	263	466	291	1148	846	319
7	581	249	474	306	956	829	332
8.5	560	244	527	310	960	783	345
10	532	250	572	338	774	730	356
12	519	265	587	346	665	663	373
15	515	292	635	323	470	576	341
18	467	329	519	318	463	471	324
21	422	327	526	363	463	363	316
25	431	353	451	425	353	321	307
30	412	374	393	443		250	289
35	407	361		369	423	231	277
40	344	290	316	445	249	178	236
45	345	291	368	473	266	173	244
50		308		511	312	180	251
60	211	314		541	260	187	
70	176	335		655	268	195	335
80	190	376	263	693	275	200	288
90	184	388	259	613	297	225	302
100	182	423	267	554	305	242	297
120			280	517	335	268	385
140				551	372	312	360
160				569	377	352	428
180				593	426	387	477

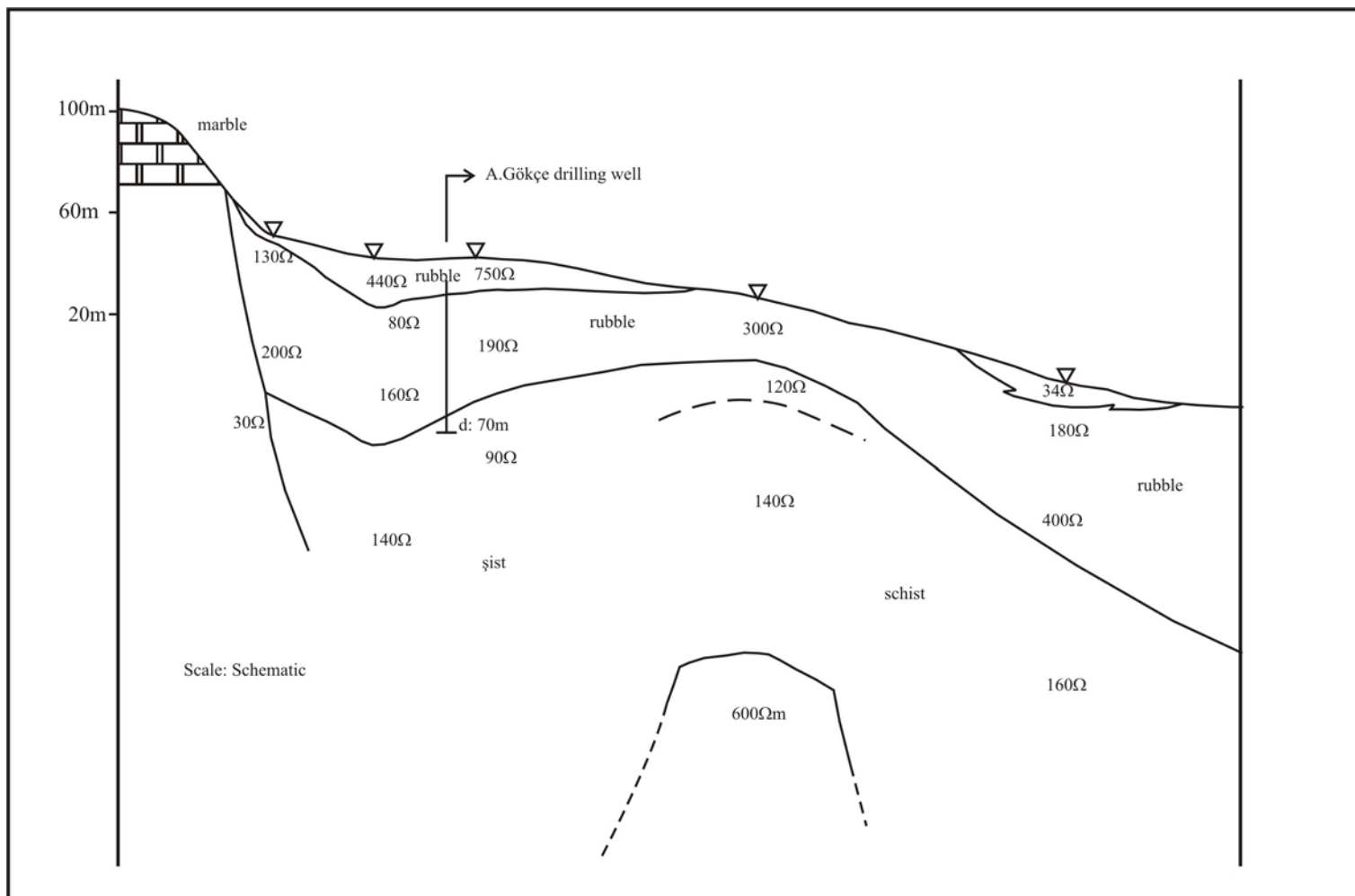
APPENDIX IV- CROSS-SECTION FOR SAKIZLI GORGE (DSİ. 1990b)



APPENDIX IV- REPORT CARD OF THE RESISTIVITY VALUES FOR ÇAKAL GORGE (DSİ, 1990b)

Point No	63	64	65	66	67
Map section	L18- c4	L18- c4	L18- c4	L18- c4	L18- c4
AB/2 (m)	EXTERNAL RESISTIVITY VALUES (ohm-m)				
2	495	377	391	209	2625
2.5	496	368	389	218	2256
3	540	391	419	239	2303
4	556	316	495	270	2640
5	521	306	459	292	1365
6	545	263	466	291	1148
7	581	249	474	306	956
8.5	560	244	527	310	960
10	532	250	572	338	774
12	519	265	587	346	665
15	515	292	635	323	470
18	467	329	519	318	463
21	422	327	526	363	463
25	431	353	451	425	353
30	412	374	393	443	
35	407	361		369	423
40	344	290	316	445	249
45	345	291	368	473	266
50		308		511	312
60	211	314		541	260
70	176	335		655	268
80	190	376	263	693	275
90	184	388	259	613	297
100	182	423	267	554	305
120			280	517	335
140				551	372
160				569	377
180				593	426

APPENDIX IV- CROSS-SECTION FOR ÇAKAL GORGE (DSİ. 1990b)



APPENDIX IV- REPORT CARD OF THE RESISTIVITY VALUES FOR ANDON GORGE (DSİ. 1990b)

Point No	12	14	15	16	18	60	61
Map section	M18-b1	M18-b1	M18-b1	M18-b1	M18-b1	L18-c4	L18-c4
AB/2 (m)	EXTERNAL RESISTIVITY VALUES (ohm-m)						
2	12.4	7.2	5.3	53.1	151	175	141
2.5	12.7	7.7	4.1	50.7	169	163	156
3	12.3	8.2	3.9	46.7	165	189	181
4	9.9	7.6	3.1	38.7	181	225	231
5	9.5	7.2	2.9	37.3	171	307	276
6	8.0	6.7	2.3	37.5	176	357	334
7	7.6	6.5	2.1	36.7	183	342	387
8.5	5.3	6	2.2	37.8	189	339	477
10	4.1	5.4	2.5	38.1	197		518
12	3.6	4.7	2.6	42.9	213		632
15	2.5	3.6	2.8	46.7	229	423	762
18	1.7	2.8	3.1	50.8	272	474	813
21	1.2	2.3	3.1	59.5	290	471	803
25	0.9	1.5	3	66.7	307	424	863
30	0.8	1.2	3.2	76.3	318	420	920
35	0.8	1	3.4	84.6	247	484	849
40	0.7		3.6	88.3	249	361	875
45	0.8		3.6	95.9	246	386	867
50	0.8		3.8	107	257	351	916
60	0.8		4.1	127	257	328	1013
70			4.4	144	268	330	1048
80				158	260	326	1186
90				174	273	334	1428
100				184	286	314	1509
120				214	316	381	
140				241	343	441	1895
160				268	367	497	2204
180				299	394	540	
200						549	

APPENDIX IV- CROSS-SECTION FOR ANDON GORGE (DSİ. 1990b)

