# TYPES AND DISTRIBUTION OF LANDSLIDES IN THE EASTERN PARTS OF BUYUKCEKMECE LAKE, USING GIS



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**TUTANAK**

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**ABSTRACT**

**ALİ DEMİRCİ** **July 2001**

**TYPES AND DISTRIBUTION OF LANDSLIDES IN THE EASTERN PARTS OF BÜYÜKÇEKMECE LAKE, USING GIS**

Due to the geological and geomorphological features, landslides are more common in the eastern side of Büyükçekmece Lake along the coast near the Marmara Sea. All landslides have been caused by a number of factors based on the interaction of geology, geomorphology, hydrology, climate, and anthropogenic activities. Of these causative factors, the most important one is the presence of a thick unconsolidated deposit consisting of pebbles, clay, and marl. Apart from the geomorphologic evolution of the area, slope angle is the important factor that all unconsolidated materials tend to slide on where slope angle is between 5 and 25 degrees. Bad drainage conditions, soil moisture, and groundwater are the other factors that cause the landslide. Climatic conditions play an important role in the timing and intensity of landslides. As rainfall is an important trigger for landslides, the highest number of landslide events occurs during the rainy months between October and March. Apart from these physical effects, some anthropogenic factors including oversteepening of slope and adding weight to slope by building homes also promote slope movement.

Within the entire study area, nearly all landslides have been taking place in the coastal zone and rotational slide is the most common type of landslide. Rock fall, soil flow, and creep can only be seen in the western part of Gürpınar. In terms of spetial distribution, the highly hazardous area covers 11 square kilometers, making 27 % of the total area according to the landslide hazard map. The moderate hazardous area is 16 and the low hazardous area is 15 square kilometers. In the high hazard zone, many buildings and homes have been damaged by landslides. Especially along the costal zone of the area, properties sustained substantial damage because landslide hazard and risk were not accounted for during development. Assessment of potential landslide risk zones will assist in planning and precautionary measures aimed at reducing risk and for any future development projects.

**Key words:**

Landslide · Causative factors · Types of landslide

Geographic Information System (GIS) · Hazard zones

## KISA ÖZET

**ALİ DEMİRCİ** **July 2001**

## CBS KULLANIMI İLE, HEYELANLARIN BÜYÜKÇEKMECE DOĞUSUNDAKİ DAĞILIMI VE ÇEŞİTLERİ

Heyelanlar, jeolojik ve jeomorfolojik özelliklerine bağlı olarak Büyükçekmece Gölü'nün doğusunda, Marmara Denizi kıyısı boyunca uzanan alanlarda çok yaygındır. Sahada heyelanlar genel olarak; jeoloji, jeomorfoloji, hidroloji, iklim ve insan aktiviteleri gibi faktörlerin birbirleri ile etkileşimleri sonucunda meydana gelmektedir. Kum, çakıl, kil ve marndan oluşmuş tutturulmamış ve kalın litolojik yapı, bölgede heyelanlara neden olan en önemli faktördür. Sahanın jeomorfolojik gelişimi dışında yamaç eğimi de heyelan açısından önemlidir. Sahadaki heyelanlar genellikle eğimi 5 ile 25 derece arasında olan yamaçlarda meydana gelmektedir. Kötü drenaj şartları, toprak nemi ve yeraltı suyu, sahada heyelana neden olan hidrolojik faktörlerdir. İklim özellikleri özellikle heyelanın meydana gelme zamanı ve şiddeti üzerinde etkili olmaktadır. Nitekim heyelan olaylarının büyük çoğunluğu, yağış miktarındaki artışa bağlı olarak Ekim ve Mart ayları arasındaki dönemde meydana gelmektedir. Yamaç dengesini bozmaya yönelik kazı ve inşaat yapılması gibi bazı faaliyetler de sahada heyelanın oluşmasında yardımcı olan diğer faktörlerdir.

Çalışma alanında hemen hemen bütün heyelanlar kıyı boyunca meydana gelmektedir ve dönelsel kayma bu alanlarda en fazla gözlenen heyelan tipidir. Kaya düşmesi, toprak akması ve sürünmeden oluşan diğer heyelan tipleri de sadece Gürpınar'ın batı kıyı alanlarında görülmektedir. Heyelan risk haritasına göre sahada, yüksek riskli alanlar 11 km², orta derecede riskli alanlar 16 km² ve düşük riskli alanlar ise 15 km²'lik bir alan kaplamaktadır. Yüksek risk taşıyan bölgelerde pek çok bina günümüzde heyelan dolayısıyla zarar görmüş durumdadır. Özellikle kıyı boyunca uzanan alanların gelişiminde, heyelan riskinin dikkate alınmamasından dolayı, binalar büyük oranda zarar görmeye devam etmektedir. Potansiyel heyelan risk zonlarının oluşturulması, gelecekte bu alanlarda meydana gelebilecek olan zararların önlenmesine yönelik yapılacak olan planlar ve alınacak tedbirler için yardımcı olacaktır.

**Anahtar Kelimeler**

Heyelan | Nedensel faktörler | Heyelan tipleri

Coğrafi Bilgi Sistemi (CBS) | Risk zonları

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# PREFACE

This study was aimed to find out the types and distribution of landslides and to determine the causative factors of landslides in the eastern part of the Büyükçekmece Lake. As geologic, geomorphologic, hydrologic, and anthropogenic factors have been compared to each other using Geographic Information System and Remote Sensing, this study has distinct importance within other investigations. Although this study calls attention to the landslide phenomenon and includes valuable information about causative factors of landslide and landslide hazard zones, more detailed geologic, geophysics, geomorphologic and hydrologic investigations should also be done in the study area. However this study is an important source for planners, engineers, decision makers, and other researchers interested in planning, landuse, landslide and other related topics in the same area.

# CHAPTER 1

# INTRODUCTION

## 1.1 STUDY AREA

The study area, shown in Figure 1, is located in the southwest of Istanbul in the Marmara Region. It lies between the lakes of Büyükçekmece and Küçükçekmece near the Marmara Sea and covers an area of 42 square kilometers (Figure 1). The area has a rugged topography and the elevation decreases from north to south between 175 to 0 m. The area that has been devoid of vegetation cover due to prolonged human activities was mostly used for agriculture until 10-15 years ago. However, recently the area mostly experienced construction since that time. That is why, buildings, villas, and factories are covering more land day by day. The area is covered by three municipalities namely Gürpınar, Kavaklı, and Yakuplu. Because of the attractive scenic beauty, the coastal part of these municipalities is undergoing heavy construction.

## 1.2 OBJECTIVES OF THE STUDY

Landslides are common and cause damage to the buildings and roads in the eastern side of Buyukcekmece Lake near the Marmara Sea. To assess these landslide hazards, recognition and mapping of the landslides in the area is the main objective of this study. To identify the causative factors of landslide and to draw a landslide hazard zonation map that identifies geographic areas where future landslide is most likely to occur are the other objectives of the study. The landslide hazard map that is the final demonstration of the study is a derivative map compiled from a variety of data sources including geology, slope angle, distribution of landslide, and hydrologic conditions. Each separate topic was considered for different purposes contribute to landslides in the area.

In this study some questions have been chosen to answer. These are: What are the types of landslide in the area? On which part of the area can the old and recent landslides be seen? What are the causative factors of landslide in the area? Which are the landslide prone areas that future landslide is most likely to occur in?

These questions will help determine the safe ground for settlement or other construction purposes by knowing the different hazard zones which have been differentiated. Maps of the distribution of landslide and landslide hazard provide information that can be used to identify different level of risks and be utilized as a guideline for effective constructions and site selection for sustainable development in the landslide prone areas. Citizens, planners, engineers, and developers can use this landslide hazard zonation map as a tool for reducing losses from existing and future landslides through prevention and mitigation. Local municipalities can also use this landslide hazard zonation map to determine endangered settlements, and take early precautions to assure their safety.


Figure 1: Location map of the study area.

## 1.3 METHODOLOGY

In the study area, landslides are controlled by a large variety of factors including geology, geomorphology, slope angle, hydrology, climatology, and human impacts. To evaluate the combined effect of these factors the use of Geographic Information System and Remote Sensing were the essential tool for the usefulness of the study. The software ArcView and its extensions including 3D Analyst, Image Analyst and Spatial Analyst have been used to prepare Digital Elevation Model and various thematic maps. Remote sensing data, including air photos, have been used for determining the distribution of landslides in the study area.

The first chapter is the introductory chapter dealing with the general description of the study area, the purpose and methodology of the study, and literature review. The physical characteristics of the study area are described in the second chapter. Geologic, geomorphologic, hydrologic, climatic and tectonic characteristics of the study area were investigated and described in this chapter. Geologic, topographic, and slope map have been prepared at a scale of 1:5.000 using GIS (Arcview, 3D Analyst, Image Analyst and Spatial Analyst). The geologic map has been prepared utilizing 3 different maps made by different institutions and people.

To indicate the detailed slope characteristics, Digital Elevation Model (DEM) of the study area was prepared at the scale of 1:5.000. To prepare this model, first separate topographic maps at a scale of 1:5.000 were combined, scanned and input into the GIS. Then, each map was geometrically corrected for latitude and longitude by using Image Analyst. Finally, contour lines and drainage systems were digitized on the screen and the Digital Elevation Model was prepared with Arcview.

Hydrologic characteristics including drainage, surface and groundwater, and hydrogeologic conditions have also been investigated within the second chapter. To define the excess and loss of water of the ground (water budget), the Thorntwaite method has been used with meteorological data (1937-1990) including precipitation and temperature from Florya Meteorology Station.

In the third chapter, the types and distribution of landslide have been investigated. For this chapter, air photos at a scale of 1:5.000, and field investigations were used to indicate the distribution of landslide. Air photo interpretation technique was the most important method to find the landslides. Most of the rotational slide and soil flow areas especially, were determined by this method. To classify the landslide types, the Varnes (1978) classification system was used (Table 1). In the study area, all landslides have been divided into four types: Rotational landslide, rock fall, soil flow, and creep. In addition to these types of landslide, expansive clayey soil (vertisol) is also examined.

The main causative factors including geology, slope angle, hydrology and some triggering factors such as human intervention were investigated in the fourth chapter. In this chapter some laboratory test results made by the Municipality of Yakuplu and Gürpınar were used to indicate the susceptibilities of the main geologic formations. These are cohesion test, liquid and plastic limit tests, standard penetration test (SPT), and granulometric analysis test. The water absorbing capabilities of some samples of the main lithologic units also were investigated in the laboratory.

**TABLE 1: CLASSIFICATION OF LANDSLIDE SUGGESTED BY VARNES (1978)**

<table>
<tr><th colspan="2" rowspan="3">Type of movement</th><th colspan="3">Type of material</th></tr>
<tr><th rowspan="2">Bedrock</th><th colspan="2">Engineering soils</th></tr>
<tr><th>Predominantly coarse</th><th>Predominantly fine</th></tr>
<tr><td colspan="2">Falls</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="2">Topples</td><td>Rock topple</td><td>Debris topple</td><td>Earth topple</td></tr>
<tr><td rowspan="2">Slides</td><td>Rotational</td><td>Rock slump</td><td>Debris slump</td><td>Earth slump</td></tr>
<tr><td>Translational</td><td>Rock slide</td><td>Debris slide</td><td>Earth slide</td></tr>
<tr><td colspan="2">Lateral spreads</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td colspan="2">Flows</td><td>Rock flow<br>(deep creep)</td><td>Debris flow</td><td>Earth flow<br>(soil creep)</td></tr>
<tr><td colspan="2">Complex</td><td colspan="3">Combination of two or more principal types of movement</td></tr>
</table>

Within the same chapter, the slope ranges were classified into three groups according to their landslide susceptibilities. Because all landslides were not investigated separately, the areal distribution of the landslides was taken into account to determine the slope angles susceptible to landslide.

In the same chapter, all buildings, factories, and roads were indicated on a map to display construction. To prepare this map, air photos taken in 1996 at a scale of 1:5.000 were used within GIS (ArcView and Image Analyst).

In the fifth chapter, the study area was classified into three hazardous zones; low, moderate, and high hazard. The landslide hazard map has been prepared by comparing mainly geology and slope angle using ArcView and its Spatial Analyst extension. Apart from these maps, the distribution of old and active landslide areas, drainage characteristics and field investigations have also been used to prepare this map.

As a result, the study has been completed with different phases. Collecting data, preparing maps using GIS, interpreting and digitizing air photos, field investigations, taking photos, taking samples, laboratory tests and finally combining these data to produce a hazard map.

## 1.4 LITERATURE REVIEW

Landslide is a term which encompasses many phenomena involving lateral and downslope movement of earth materials such as, rock, soil, and/or artificial fill (Keefer, 1984). The term covers a broad category of events, generally including slides, falls, flows, and creep. Occurrence of landslide is affected by physiographic factors such as geology and geomorphology, as well as by the climatic and meteorological conditions.

Landslide investigations have been increasing throughout the world. New methods are being improved to understand causative factors of landslide and prevent or at least reduce the landslide risk and damage. Within such techniques, the use of Remote Sensing and Geographic Information Systems play an important role. As landslide is controlled by a large variety of factors, GIS and Remote Sensing allow us to combine, compare and map all these different kinds of data using models.

Landslide maps can be grouped into three classes including inventory maps, density maps, and hazard maps. Inventories are the simplest form of direct landslide mapping and show the location of known landslides. Furthermore, density maps attempt to portray the spatial abundance of landslides through direct mapping. Hazard maps show the inferred or computed degree of landslide hazard obtained by modeling or by direct mapping (Carrara *et al*, 1995).

As GIS and Remote Sensing are being used for various kinds of research throughout the world, they regard new techniques for landslide investigation especially for preparing hazard map in Turkey. If it is considered for study area, there is no any sample of landslide hazard map that was prepared by using GIS and Remote Sensing.

There is limited research related to landslides in the study area. These are mostly about geology. The most important investigations are thesis and some geologic and geophysics reports made for municipalities. The most important ones were explained here.

**TEZCAN, S., 1977:** The area between Büyükçekmece and Küçükçekmece was investigated in this report under the title of "Geotechnic and Geodynamic Research of New Settlement Area in Istanbul". As a result of this study, the area was divided into different zones according to the slope susceptibility. The area characterized by Bakırköy limestones was indicated as an area most convenient to be settled. However, the areas where soft clay, silt and weak sand layers close to the surface were indicated as an areas where some precautions must be taken. In addition, afforestation of the landslide areas was recommended in this study.

**VARDAR, A. T., 1978:** In his master thesis titled "Long-Term Stability Analysis of Narural Slopes in Çekmece Regions" Vardar investigated the shear strength of consolidated clay and shales in landslides in the area between the çekmece lakes. The amount of water was found to be an important factor that affected the shear strength of the clay and shales. In this thesis, the total area (227 sq. km.) was divided into four groups according to their susceptibilities to landslide. These are active landslide areas, high potential-landslide areas, low potential-landslide areas and stable areas. Active landslide areas cover an area of 19.7 sq. km. or 8.7 % of the total area. High potential areas cover 94.6 sq. km., low potential areas cover 5.7 sq. km and stable areas cover an area of 107 sq. km. According to this thesis, landslide hazard extends over large areas, especially in the Haramidere region (southern part of Yakuplu). That is why they must be investigated in detail.

**ERCAN, A., 1990:** Within his research, an area covering 15 square kilometers was investigated in Gürpınar (western part of the study area) for the purpose of finding suitable places for settlement. While it is mostly related to the geology of the area, susceptibilities of the ground to landslide were also investigated in this report. According to this study 66 % of the total area has susceptible ground inconvenient for settlement. The remaining land is convenient for settlement. Because of its weak lithology, the Gürpınar formation was indicated as the most susceptible formation to landslide hazard in this study.

**ZARİF, İ.H., 1996:** In this doctoral thesis, slope stability problems were judged to result either by natural or the urbanization processes in the area between Küçükçekmece-Büyükçekmece lakes. According to this study, stability problems in the study area occur in the Gürpınar and Çukurçeşme formations. Slope angles, contact relations of lithological properties, and surface and groundwater were considered to be effective factors in the occurrences of landslide.

**NESLİOĞLU, M., 1996:** In this master thesis, Neslioğlu investigated landslides in the basin of the Küçükçekmece Lake. Geologic (lithology, stratigraphy, and tectonism) and geomorphologic factors especially slope were found to be the most important causative factor of landslides. In addition, climatic and anthropogenic factors also affected the occurrence of landslides by triggering them in that study.

**YAKUPLU BELEDİYESİ, 2000:** In this report, very detailed geologic and geotechnics investigations were done on the appropriateness of settlement within the boundaries of the local municipality of Yakuplu (eastern part of the study area). After a very detailed study (1:5.000), a map was prepared to indicate the suitable areas for settlement. According to the map, the southern part of the study area, mostly characterized by Gürpınar and Çukurçeşme formations, was found to be inconvenient for settlement because of the landslide risk. That area was mentioned as an active landslide area and the weak, unconsolidated lithologic characteristics were the most important causative factors of landslide in this report.

# CHAPTER 2

# PHYSICAL CHARACTERISTICS OF THE STUDY AREA

## 2.1 INTRODUCTION

The physical characteristics of the study area determine the susceptible areas to landslide risk and give the necessary information to find the causative factors of landslides. In this chapter, the general physical characteristics including geologic, geomorphologic, climatologic, and hydrologic conditions have been investigated in detail.

## 2.2 GEOLOGIC CHARACTERISTICS

The study area and its surroundings have been affected by tectonic movements, which have occurred since the Paleozoic. The area was uplifted and become land through the Alpine and Hersinien Orogenesis in the Paleozoic and Tertiary ages (Erol, 1991). However this area has also turned into the lake and sea environment through epirogenic and orogenic movements during the geologic ages.

The study area is located in the eastern part of the Thrace Basin which deposited during the Tertiary. The Thrace Formation, characterized by metamorphic and igneous rocks, underlies the section as bedrock. Although this formation is not visible in the study area, outcrops can be seen in the northern part of the Küçükçekmece Lake. This formation deposited into the sea environment and has been turned into the land by twisting and folding of the Hersinian Orogenic movements at the end of the Carboniferous age. However after the Middle Eocene, the area has subsided and turned into marine environment again due to tectonic activities. Through this, carbonate and mud components deposited on the both horsts and grabens of the area until Upper Eocene. These Eocene deposits, called the Kırklareli limestones, have been turned into the land and started to be eroded after Upper Eocene because of the orogenic movements (Şen, 1994).

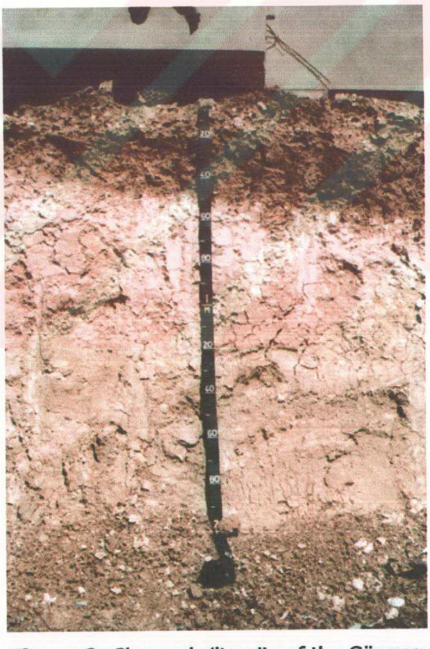

**Figure 2:** Clay and silt units of the Gürpınar Formation in the western part of the study area.

During the time between Upper Oligocene and Lower Miocene, the study area stayed as a terrestrial depositional area. Different kind of materials were eroded from the higher parts and deposited by rivers. Under these terrestrial conditions, the study area was covered by a thick depositional layer is known as the Gürpınar Formation. Although it changes from place to place, the thickness of this formation is greater than 200 meters. This formation includes the lignite as a thin layer in its structure. This indicates the fact that the Gürpınar Formation deposited under the fluvial, delta and shallow sea conditions (Sayar, 1977).

Apart from Gürpınar Formation, the other sedimentation period occurred during the Upper Miocene. This (Çukurçeşme Formation) deposition is generally characterized by pebbly sand which fines upward and lithology changes into clay and mud. This change in lithology indicates that the climatic and geomorphologic conditions of the area changed until the end of the Miocene and fine-grained clay and mud materials deposited in the lake environment (Zarif, 1996). This distinct deposition includes thin, sandy clay layers and is named the Güngören Formation. It was covered by the Bakırköy Formation during the Upper Miocene. The Bakırköy Formation is the youngest formation of the area and is characterized by limestone and marl units including thin clay layers.

### 2.2.1 General Stratigraphy

In the study area, The Paleozoic Thrace Formation, not visible above ground, is composed of metamorphic and igneous rocks which make up the regional bedrock. The thickness of this formation differs between 1000 and 1700 meters (Zarif, 1996). The Kırklareli Formation, composed of carbonated rocks, deposited above this formation during the Eocene (Figure 4). However this formation also can not be seen exposed in the study area. The other formations including Gürpınar, Çukurçeşme, Güngören, and Bakırköy fórmations can be seen on the ground and they were covered by Quaternary alluvium deposits in some parts of the study area.

#### *2.2.1.1 Gürpınar Formation*

The Gürpınar Formation is the oldest visible formation of the area. It is located in a very large area around Büyükçekmece and Küçükçekmece lakes (Figure 5). The largest distribution area of this formation is in Gürpınar and its surroundings in the western part of the study area. In that part, the width of this formation is higher than 2 kilometers from the coast to east. However the Gürpınar Formation can be seen in the smaller areas along the coastal zone and valleys in the other parts of the area (Figure 5). In particular this formation was covered by Holocene alluvium on the valley floors of the Kavaklı and Haramidere streams.

Because it can be typically seen around Gürpınar, this formation was named as the Gürpınar Formation (Arıç, 1955). It is composed of different lithologic units that have deposited under different conditions. Sometimes the fluvial conditions (meander environment) were dominant in the area and sometimes the formation units have deposited in the lake environment.

**Figure 3:** Sandstone in the Gürpınar Formation.

The Gürpınar Formation is generally characterized by light brown and greenish clay layers that include sand, sandstone, pebble, marl, silt, tufa, and limestone in different thicknesses (Figure 2, 3). This formation begins with clayey sand and pebble units. The pebbles derived from gneiss, quartzite, granite, schist units and include abundant quartz and feldspar minerals (Yakuplu Belediyesi, 2000). Fissured limestone layers overlie these light brown and weak consolidated pebble units. This clay layer includes sand, pebble units and thin lignite layer in different thickness. With the increasing of clay minerals, the formation totally turns into a clay deposit towards the middle and upper part of it (Figure 4).

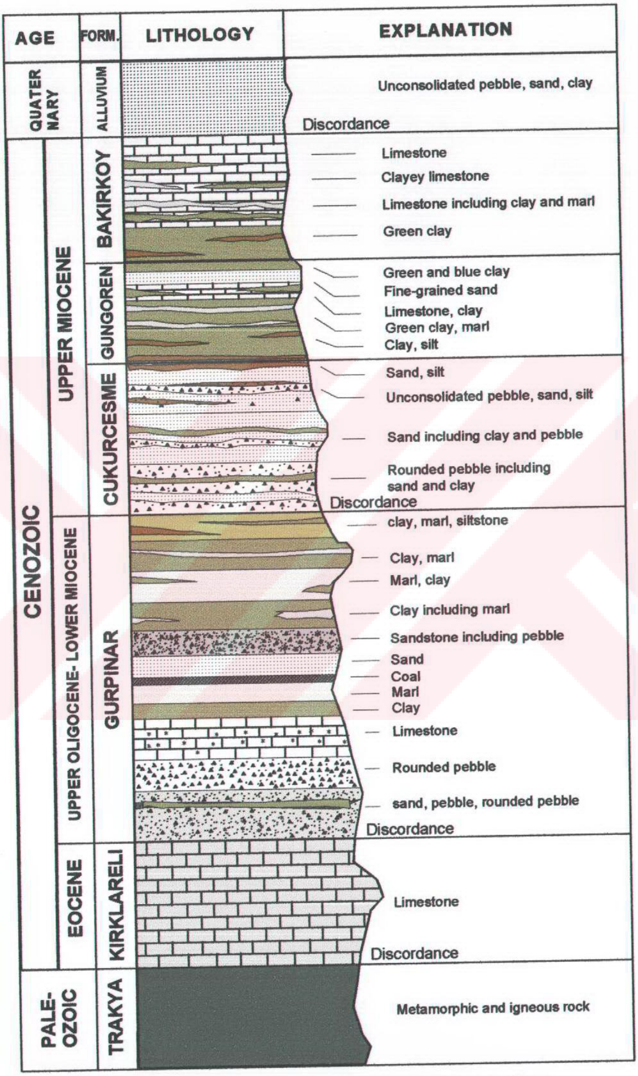


Figure 4: General stratigraphy of the study area and its surroundings.

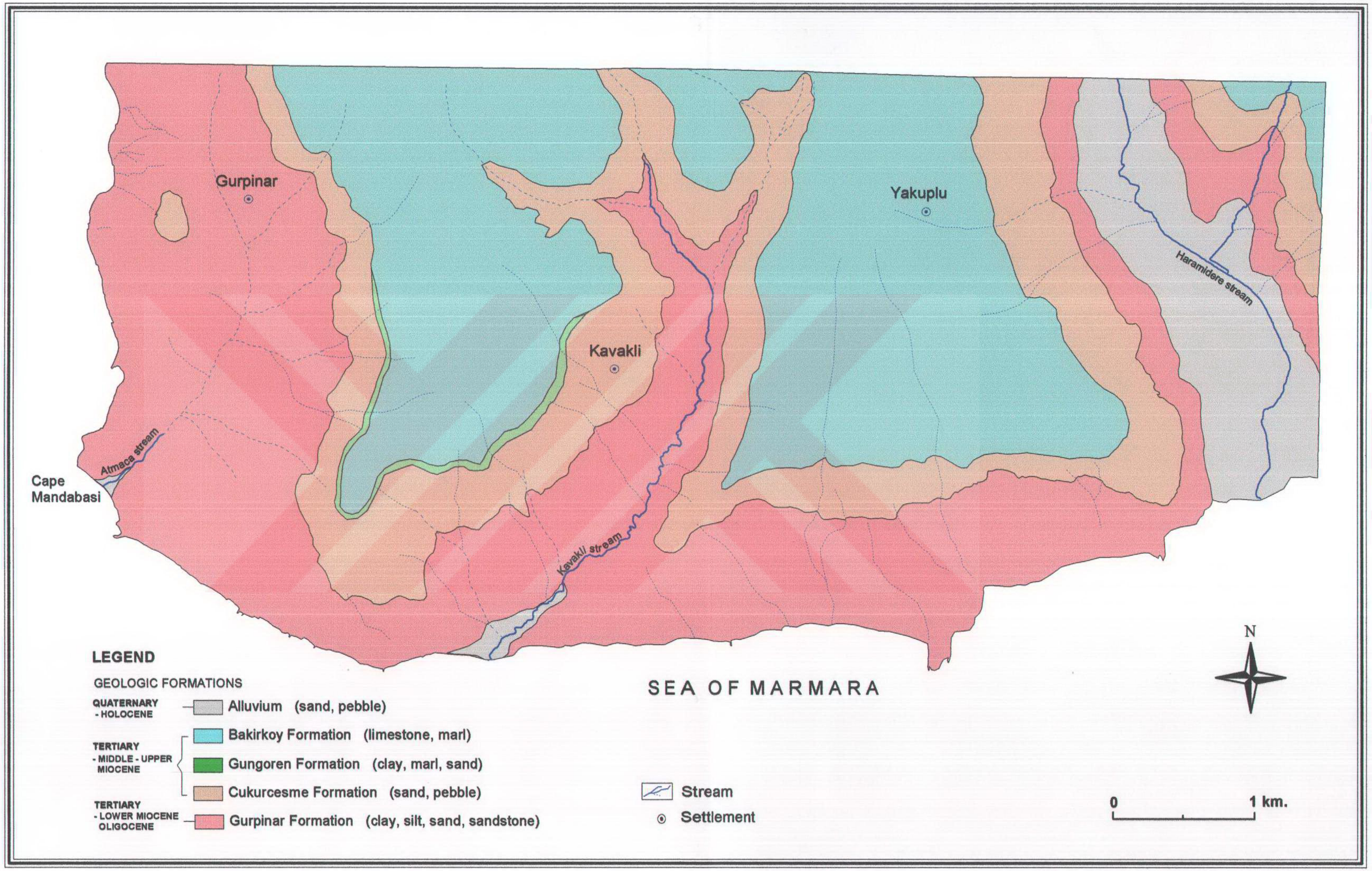


Figure 5: Geological map of the study area, modified from map made by Zarif, 1996.

The rounded pebbles in the lower part of the formation indicate fluvial processes that rivers carried and accumulated materials at that time. On the other hand, limestone, marl and shale layers indicate a shallow lagoon environment. The freshwater fossils in the weak consolidated sandstones indicate that the area turned into the lake after that time (Dalgıç, 1988).

The age of the formation was determined generally as Miocene and Oligocene by different researchers. The formation was aged as Miocene by Akartuna (1953) according to the fish fossils was found in the Karton shale. However Sönmez (1964) aged it as Oligocene according to the freshwater fish fossils (Melanopsis and Congeria) found in the limestone and sandstone.

Although it increases from north to south, the average thickness of the formation is approximately 200 meters (Çapkın, 1993). The lithologic units of the formation have accumulated horizontally on each other.

#### 2.2.1.2 *Çukurçeşme Formation*

The Çukurçeşme Formation exists discordantly on the Gürpınar Formation. This formation actually extends on the large areas around Kıraç and Çakmaklı villages outside of the study area. However, in the study area it extends along the Marmara Sea and valley slopes as thin bands. The Çukurçeşme Formation has undergone excessive erosion after the Upper Miocene due to tectonic rising of the study area (Ercan, 1990). That is why nearly all formation has been removed on the western and southern parts of the study area. Because its most typical features can be seen in

Gaziosmanpaşa-Çukurçeşme (northeast of the study area), this formation was named by Arıç (1955) as the Çukurçeşme Formation.

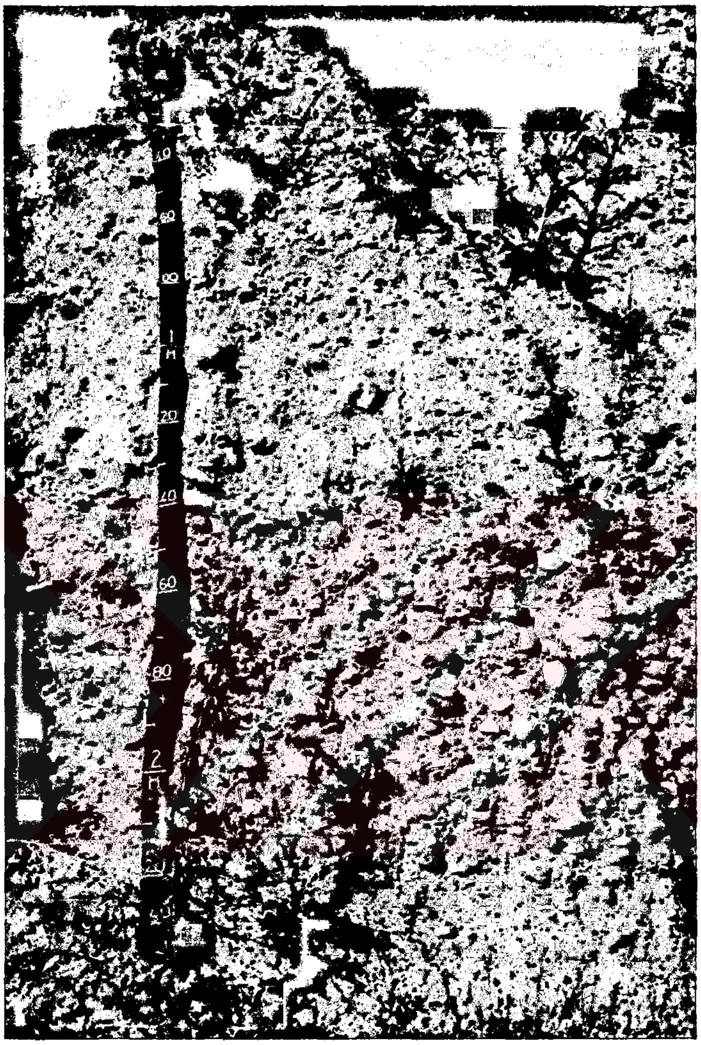

**Figure 6:** Sand and pebble units of the Çukurçeşme Formation in the southwest of Gürpınar.

The Çukurçeşme Formation is generally characterized by unconsolidated and weak consolidated pebble, sand and sandy clay layers that include silt (Figure 6). The grain size of the lithologic units of this formation generally differ from place to place however, the dominant lithology is sand (Figure 7).

**Figure 7:** Sand deposits of the Çukurçeşme formation

The formation generally begins with pebbles including red colored sand and clay layers. The pebbles are angular and weak consolidated and their sizes change from 1-2 cm to 15-20 cm (Figure 6). They generally are derived from quartzite, quartz, granite, andesite, arkose, mica, and schist units (Şen, 1994). The grain sizes become smaller and the lithology turns into the sand and silt upwards within the formation (Figure 7). The clay and mud units can be seen on the top of this formation. Many petrified trees were found within this formation in the southern part of Gürpınar.

The Çukurçeşme Formation has been aged by Arıç (1955) as Upper Miocene according to the vertebrate fossils found in the sand and pebble lithologic units. The grain sizes, petrified trees, vertebrate fossils, and yellowish-red colors indicate that this formation deposited in a terrestrial environment.

The thickness of the formation generally increases from north to south, however it is between 5-15 meters in the northern part of the study area. In the southern part of the area it increases up to 60 meters (Yakuplu Belediyesi, 2000). Within this formation there is no evident stratification.

#### *2.2.1.3 Güngören Formation*

Of the formations, the Güngören Formation has the smallest distribution in the study area. However it extends on the larger areas in the eastern part of the Küçükçekmece Lake. This formation can be seen in the eastern part of the Gürpınar as a thin band between Çukurçeşme and Bakırköy formations (Figure 5).

The Güngören Formation is generally composed of clay, marl, sand, and thin limestone units. The clay units are thin bedded and soft, with colors of green and blue (Atakan, 1996). The formation begins with clayey silts and goes on with clay, marl and sparse clayey limestone layers upwards (Figure 4).

The Güngören formation was named by Arıç (1955) because it can typically be seen around Güngören (northeast of the study area). In some studies this formation has been evaluated within the Bakırköy Formation because it is very thin and transitions to the Bakırköy Formation. Some fossils (Gastropoda, Mactra and leaf fossils) indicate that this formation was deposited in a swamp and lake environment. The thickness of this formation is between 10-15 meters on average and its age is Upper Miocene (Atakan, 1996).

#### *2.2.1.4 Bakırköy Formation*

The Bakırköy Formation constitutes the upper part of the Tertiary sedimentation and it can typically be seen in Bakırköy eastern side of the study area. This formation extends on the highest parts of the study area (Figure 5).

The formation is characterized by white and fissured limestone, which includes some fossils. Apart from the limestone, marl is also the other common unit (Figure 8). Greenish clay and silt units can be seen within the limestone and marl layers. The Bakırköy Formation begins with green clay layers including white marl and clayey limestone units. The thickness of this clay layer is approximately 5 meters. Above this layer, greenish-gray carbonated clay and clayey limestone have been deposited (Yakuplu Belediyesi, 2000). This formation is the most resistant formation to landslide if it is considered from the standpoint of slope stability. However these limestones include many fissured and some small cavities due to karstification.

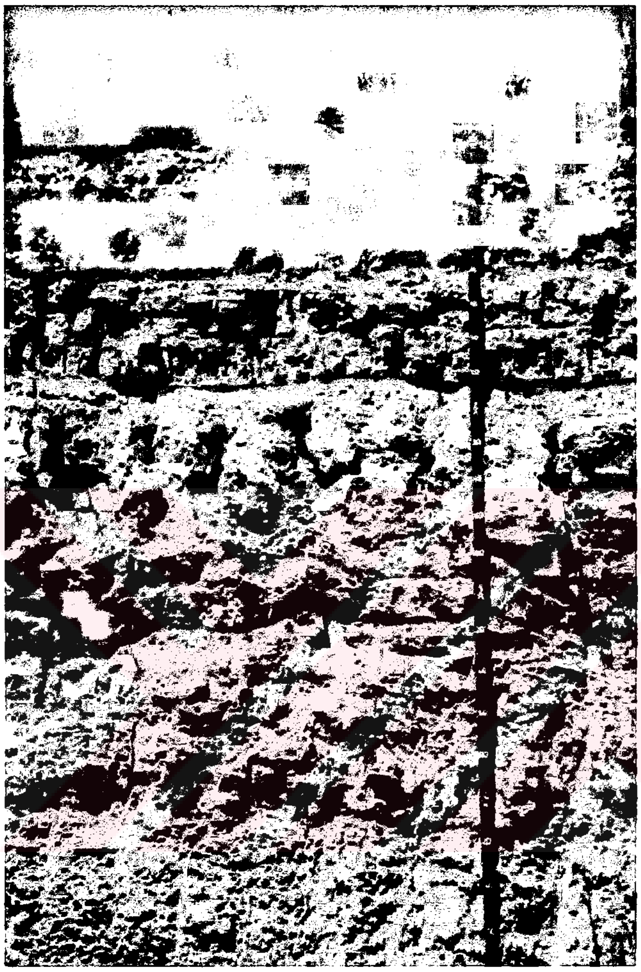

**Figure 8:** Marl and clay units of the Bakırköy formation

The age of this formation was found to be Upper Miocene by Ülkümen (1960) according to some fossils including Melanopsis, Congeria and Unio. According to its characteristics, The Bakırköy formation was deposited in a hot and shallow brackish water environment (Ercan, 1990). The thickness of this formation is approximately 15-20 meters and decreases towards the south (Zarif, 1996). This formation was covered by Quaternary age alluvium in some parts of the area.

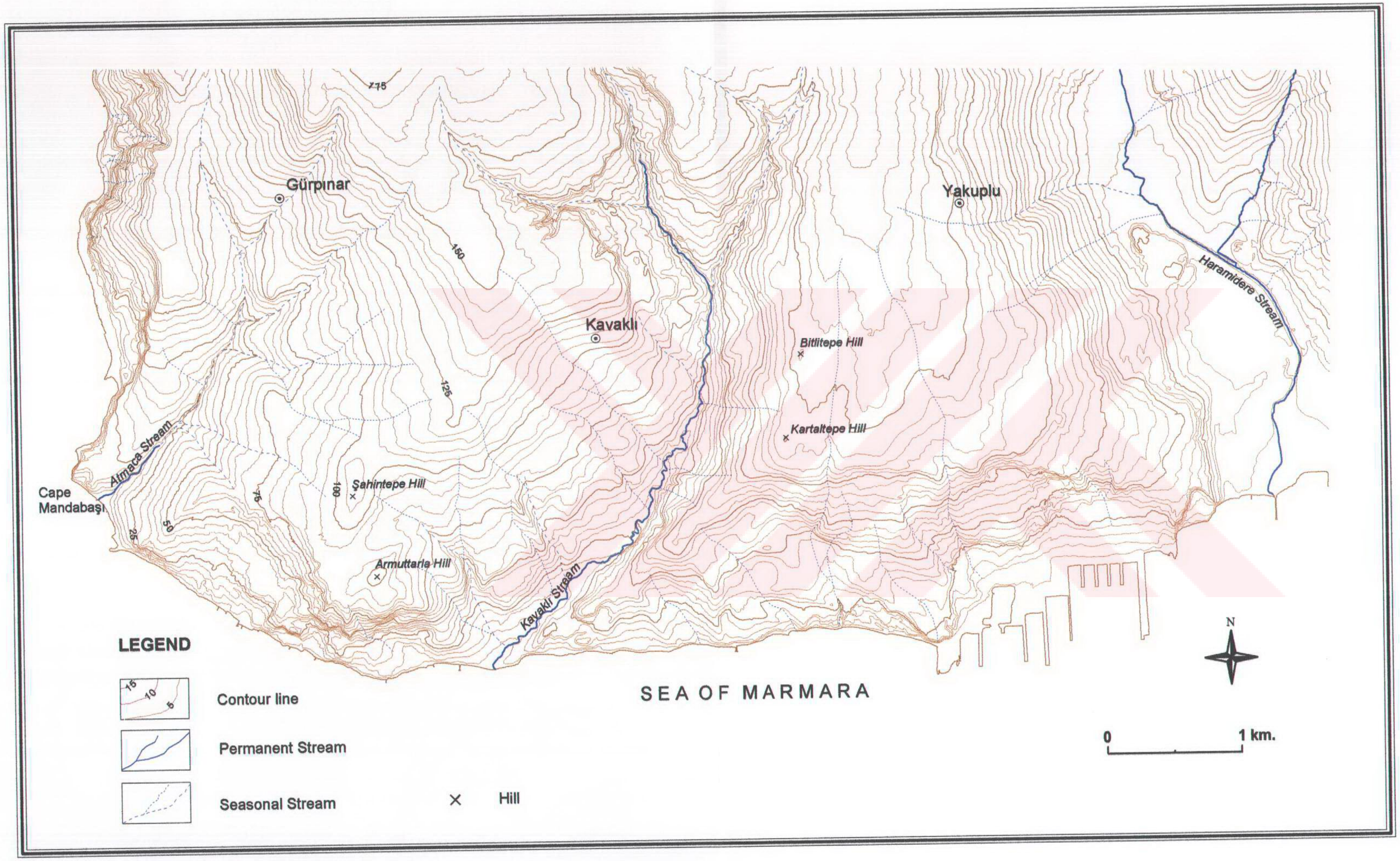


Figure 9: Topographic map of the study area.

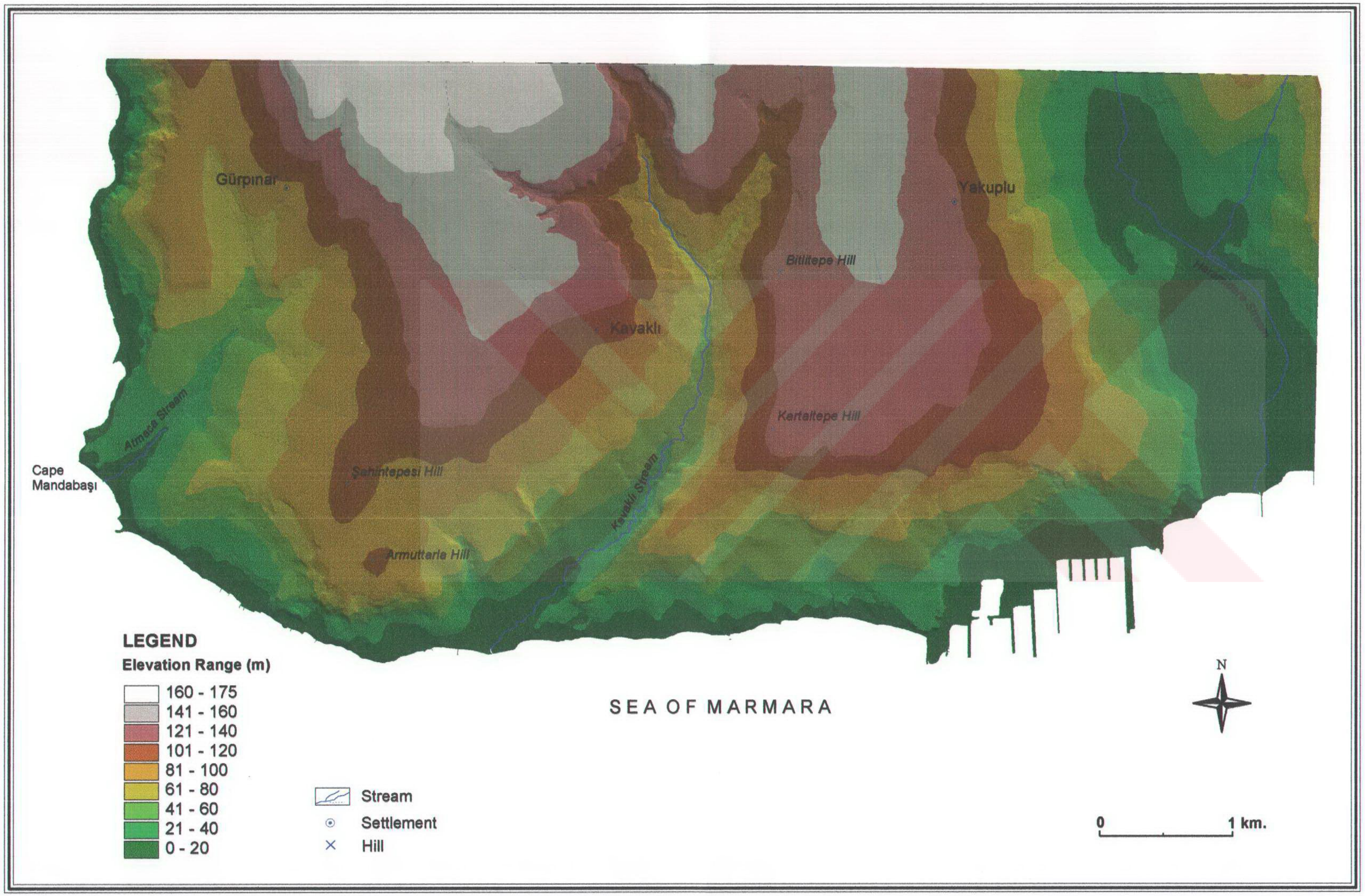


Figure 10: Elevation map of the study area.

#### *2.2.1.5 Alluvium*

The youngest sedimentation in the study area is the Pleistocene and Holocene aged alluvium that is characterized by unconsolidated pebble, sand, silt and clay. Alluvium generally extends on the valley floors of the Atmaca, Kavaklı and Haramidere streams (Figure 5). However the largest distribution area of alluvium is on the Haramidere valley floor. The source of these deposits are the Gürpınar and Çukurçeşme formations. Because of the lithologic characteristics of these formations, fine-grained materials are common in the alluvium. The thickness of alluvium is between 0-10 meters on the Atmaca and Kavaklıdere valley floor (Ercan, 1990). However on the Haramidere valley floor, it is between 15-20 meters (Yakuplu Belediyesi, 2000). The Alluvium has been covered by soil and current filling materials in some part of the study area.

### 2.2.2 Seismicity and Tectonics

The study area and its surroundings have been mostly affected by tectonic activities during the geologic ages. Apart from the Hercinian Orogeny in the Paleozoic age and Alpine Orogeny in the Tertiary, some tectonic activities including sea level transgressions and regressions have affected the study area especially in the Quaternary age.

The present topographic and geomorphologic aspect of the study area and its surroundings has been formed by prolonged tectonic and fluvial proceses. In particular, tectonic activities have played an important role on the uplift and subsidence of the land according to the sea level since the Paleozoic. Tectonic activities have caused the area to become either an area where sedimentation was dominant like sea, lake, and delta or an area where weathering processes were eroding the surface. The oldest tectonism in the area was the Hersinian Orogeny (Ercan, 1990). Because of this movement, the study area has become land by deformation and uplift. However it subsided and returned into a marine state due to folding in the Middle Eocene. The study area turned into a terrestrial environment again by folding after the Upper Eocene. After that time, the study area remained a sedimentation area between the Upper Oligocene and Lower Miocene (Ercan 1990). However the area rose up with the Alpine tectonic movements and turned into an erosional environment. Finally, the study area formed and turned into its present shape by fluvial and tectonic activities especially after Lower and Middle Miocene.

The study area not only rose up but also twisted and deformed by tectonic activities since the Pliocene. The horizontal structure of the sedimentation has been twisted and gained a slope angle of 20 degrees towards the southwest as monoclinal (Ercan, 1990). This condition can be understood by looking at the valleys of the Atmaca and Kavaklıdere streams that they developed towards southwest (Figure 9).

The most important morpho-tectonic movements occurred in the Pliocene, Pleistocene, and Holocene (Erol *et al*, 1991). In particular, sea level regression, in the Black Sea and Sea of Marmara, has caused the rivers to deepen their valleys since the Early Pliocene. However after the Quaternary, the sea level rose up almost two meters because of the Flandrien Transgression which was the last sea level rising (Ardos, 1994). That is why the lower parts of the some streams flowing through the Marmara Sea have been occupied by sea water. The Büyükçekmece and Küçükçekmece lakes have been formed by this transgression.

There is no active fault line in the study area. However it is not clear, some slope steepnesses can be related with fault lines in the study area. These slopes lie northeast to southwest and can be seen on the topographic map (Figure 9). The most important feature of the study area from the standpoint of tectonism is that it is very close to the North Anatolian Fault Line (NAF), one of the most active seismic zones of the world. As the NAF passes approximately 15 kilometers away from the coast in the Marmara Sea, the study area exists in the 1st degree seismic zone.

The North Anatolian Fault is a right lateral, strike-slip fault that is approximately 1350 kilometers in length, extending from Eastern Turkey (Karlıova) to the Aegean Sea. According to seismological investigations, the slip-rate of the NAF varies between 20-40 mm/yr. The total slip-rate of the NAF is between 25 and 80 kilometers (Efe, 2001). It branches out at Mudurnu and it divides into three separate branches. The northern branch follows the Sea of Marmara and Gallipoli Peninsula. The middle branch follows along Geyve-İznik Lake and arrives at the Sea of Marmara at the Gulf of Gemlik. The southern branch follows along the Geyve, Yenişehir, Bursa, Ulubat, Kemalpaşa, Manyas and Gönen basins and reaches the Gulf of Edremit (Efe, 2001).

Historically, the fault line has provided considerable seismic activity. Along the North Anatolian fault, many destructive earthquakes have occurred and caused loss of life and property. In particular, the earthquakes that occurred in the western part of the NAF between Adapazarı and Mürefte, affected also Istanbul. Istanbul and its surroundings were affected by 130 earthquakes with intensities greater than VI prior to 1900 (Ergin et al, 1967). In particular, the 1509 and 1897 earthquakes caused serious loss of life and property. The most important recent one was the Gölcük Earthquake that occurred on August 17, 1999. Because of this earthquake, more than 30 buildings collapsed and approximately 900 people died in the Avcılar area, which is located near the study area.

## 2.3 GEOMORPHOLOGIC CHARACTERISTICS

The study area is located in the southern part of the Çatalca Peninsula. This is characterized by a low plateau with an average elevation of 100-200 meters. The topography descends from north to south in the Çatalca Peninsula. The northern side of this peninsula has been cut deeply by rivers. However in the southern part of the peninsula that the study area also exists in, the aspect of the topography is different. In this part, more rounded topography can be seen. The distinct lithologic units have caused this difference. The northern part of the Çatalca Peninsula is mostly composed of Paleozoic metamorphic and igneous rocks. However, the southern part of the peninsula is characterized by Upper Miocene aged sedimentation units.

The study area has gentle topography that has been cut by the streams. The average elevation is between 80-90 meters (Figure 9, 10). The highest parts of the study area exist in the northeast of Gürpınar with an elevation of 175 meters. The topography decreases from north to south with a slope angle between 3-5 degrees and has been especially lowered by both wave erosion in the coastal zone and by fluvial process in the inner part of the study area (Figure 9, 12). The areas that have elevation between 0-20 meters extend along the coast as a thin band. However these areas rise up to 500-800 meters inland from the valley of the Atmaca and Kavaklı streams. This area extends up to 3 kilometers into the Haramidere stream. This difference has been caused by the power of the Haramidere stream. As Haramidere is longest and biggest stream of the study area it has had more runoff and erosion power during the rainy Quaternary period. This caused the valley to be eroded and the river to flatten its bed.

As mentioned in the following section, it is striking and evident in the topographic map and elevation map that landslide scarps extend on the western and southern part of the area (Figure 9, 10).

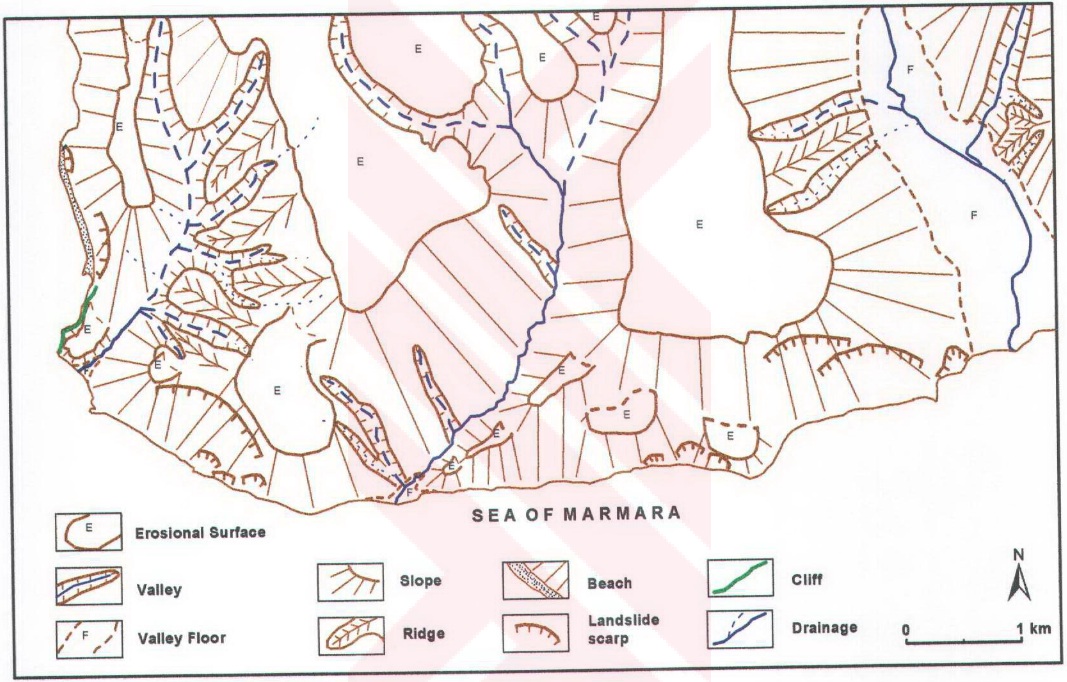


Figure 11: Geomorphological map of the study area.

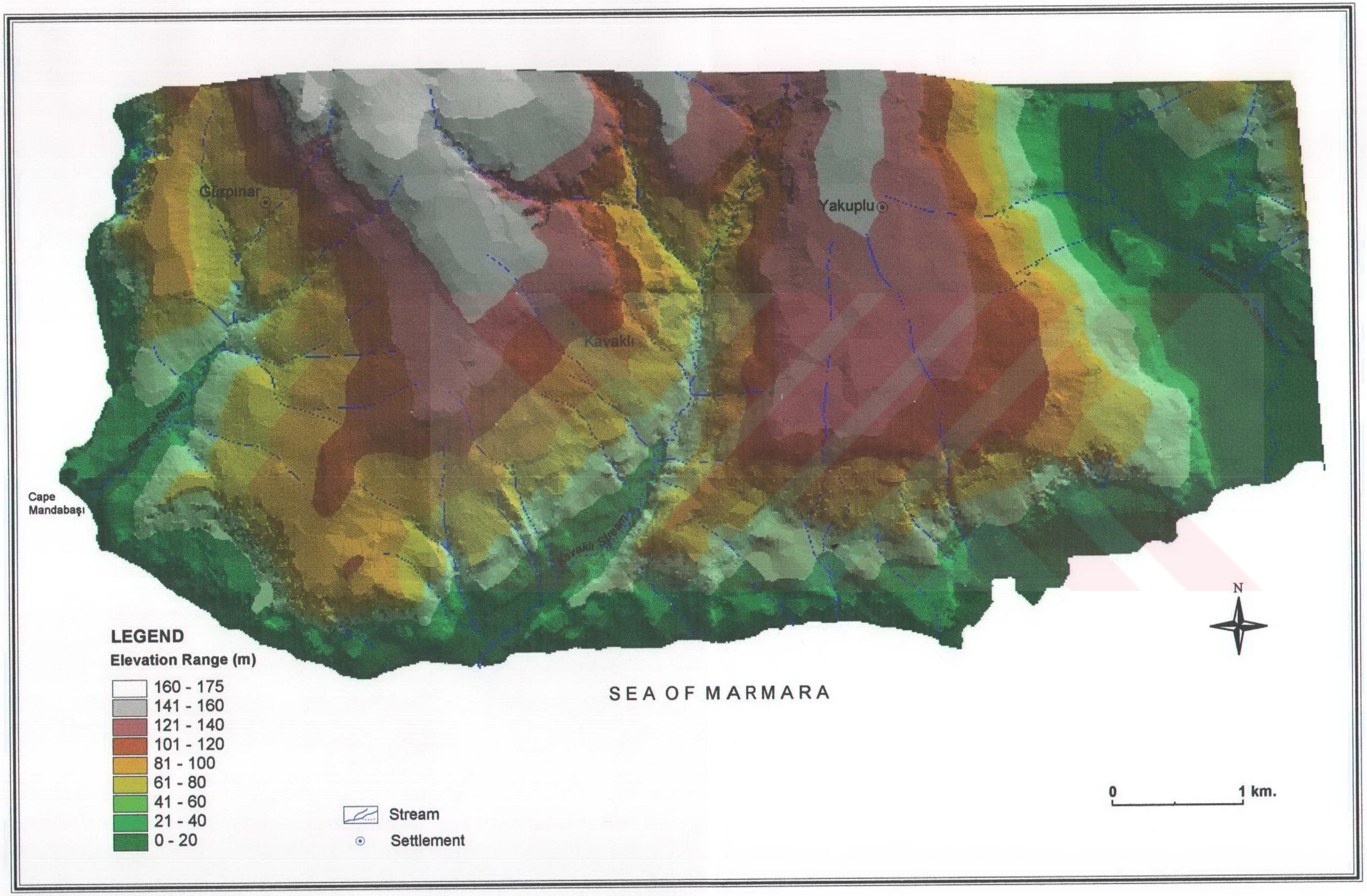


Figure 12: Three dimensional view of the study area

**Figure 13:** Cape Mandabaşı in the southwest of the study area

### 2.3.1 Geomorphologic Units

The main geomorphologic units in the area can be divided as erosional surfaces (Miocene surfaces), valleys, valley floors, slopes, ridges, beaches and coastal landforms including cliffs.

#### *2.3.1.1 Erosional Surfaces (Miocene Surfaces)*

The study area that is located between Büyükçekmece and Küçükçekmece lakes is characterized by Cenozoic (Tertiary, Quaternary) sediments. These sediments, generally deposited during Miocene, rose up by tectonic activities since the Lower Pliocene. After that time these Miocene surfaces have undergone excessive erosion. The rivers that formed after the Pliocene and Pleistocene eroded the surfaces by cutting the land from north to south, while waves have been especially effective on eroding the coastal zone. Thus, younger formations have been removed from the top the older Gürpınar formation has become visible on the ground along certain areas. The Bakırköy Formation that constitutes the present Miocene sufaces of the area exists in the area which generally has an elevation higher than 100 meters.

Miocene erosional surfaces generally exist on the ridges that extend from north to south in the middle and upper side of the study area (Figure 11). One of them exists between Atmaca and Kavaklı streams and extends from the eastern part of Gürpınar to the southern part towards Armuttarla hill. The northern part of this ridge also constitutes the highest part of the study area with an elevation of 175 meters. The other ridge extends between Kavaklı and Haramidere streams from north to south in the eastern part of the study area. The elevation varies between 125-130 meters in the northern part of this ridge and it decreases towards south with a slope angle of 1-5 degrees. These Miocene erosional surfaces have been eroded by Kavaklı streams and its tributaries in the northern part of the study area.

Apart from fluvial process and wave erosion, lithology has also been effective on the eroding and removing of the Miocene surfaces. As the lithology is very susceptible to weathering process, valley slopes have been widened and all Miocene surfaces have been removed from these areas by gully erosion.

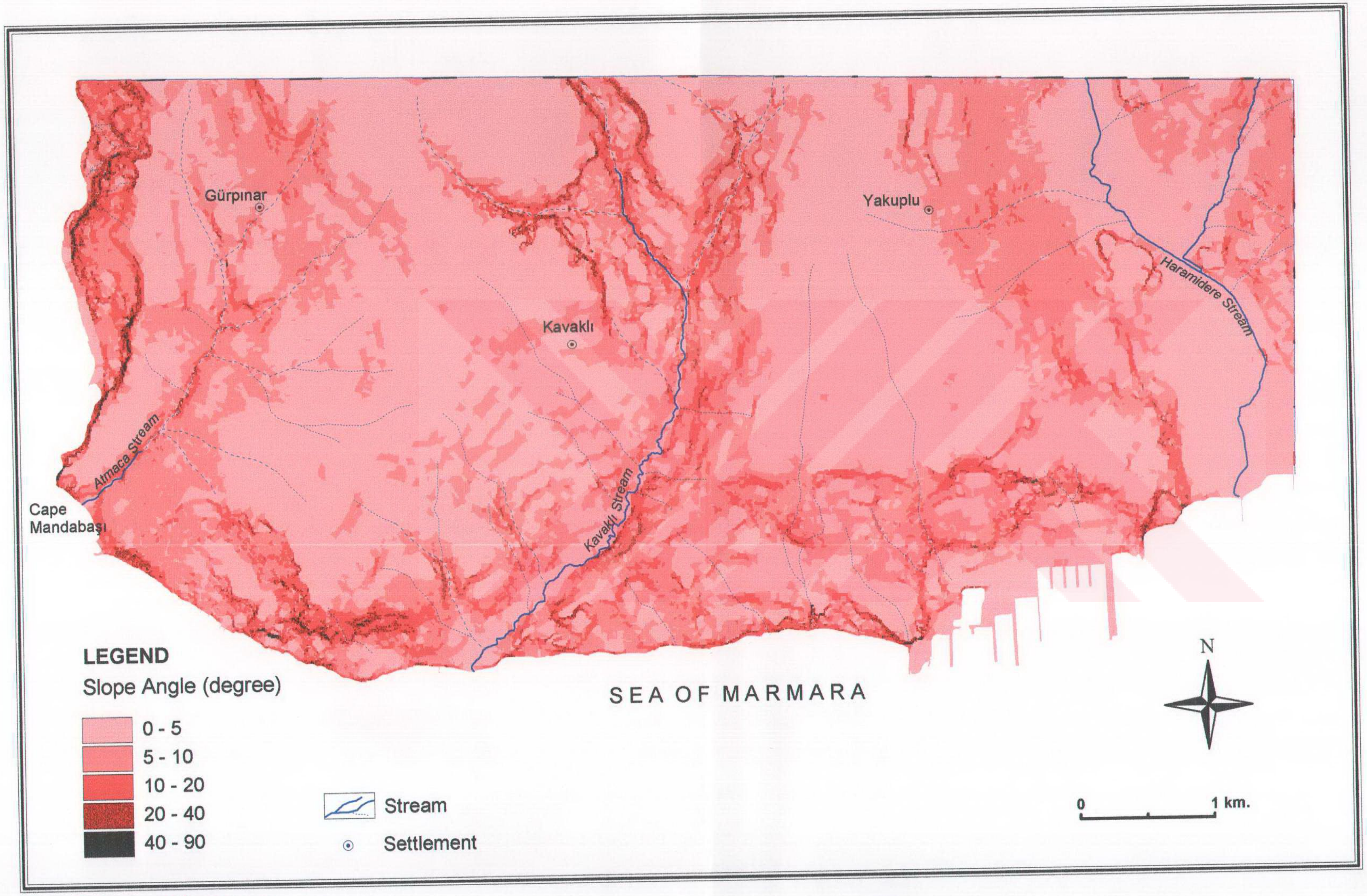


Figure 14: Slope map of the study area.

The other erosional surfaces are generally younger and exist in the western and southern part of the study area near the coast. In particular, fluvial process, tectonism, sea level transgression and regression, and landslide have affected the forming of these small surfaces.

### *2.3.1.2 Valleys*

There are three main river valleys in the study area: Atmaca, Kavaklıdere, and Haramidere. Nearly the entire valley systems of the Atmaca and Kavaklı streams are located within the boundary of the study area. However only the southern part of the Haramidere stream is located in the study area.

The valleys of the Atmaca and Kavaklı streams and their tributaries are "V" shaped valleys (Figure 15). On the other hand, the Haramidere stream flows as meander in a wide valley that has very gentle slopes.

The valleys of Atmaca and Kavaklı streams developed from northeast to southwest on the topography. Slope angle varies between 1 and 5 degrees on their valley floors. In particular, the Kavaklı stream meanders in the lower part of the valley which the slope angle is lower than 3 degrees. The angles of valley slopes of the Haramidere stream also differ between 5 and 10 degrees (Figure 14). It is evident in the topographic map and three dimensional view of the area that there is a big differences between the slope angle of east facing slopes and west facing slopes of the Atmaca and Kavaklı streams (Figure 9, 12). The slope angle suddenly increases on the west and northwest facing slopes of these streams. Slope angle reaches up to 25-30 degrees on some part of the west and northwest facing slopes of the Atmaca stream's valley. However it increases up to 40 degrees on some part of the valley slopes of the Kavaklı stream.

**Figure 15**: "V" shaped valley of the Atmaca Stream.

Tectonic movements and fluvial process have been effective on the evolution of the valleys. The rivers that flow towards Marmara Sea have been affected by sea level changing in the glacial and interglacial period in Quaternary. In particular the last glacial period has caused the sea level to decrease in the Marmara Sea. During that period, all rivers and streams deepened their valleys. After that period, within the interglacial period, the last transgression (Flandrien Transgression) took place and caused the deeper part of the big river valleys to be inundated (Erol *et al*, 1991). Apart from the rivers, all the other streams have also been affected by sea level changing. The Atmaca, Kavaklı, and Haramidere streams have formed their valleys mostly within the last glacial period. Because they could not have formed their valleys under the present climatic and geomorphologic conditions.

The lithology is the other important factor that affects the evolution of the valleys in the study area. To be well understood, a comparison can be done between the different lithology of the study area and the other area from northern part of Istanbul. In general, the rivers have cut the topography deeply on the north facing slopes of the Çatalca Peninsula, characterized by Paleozoic metamorphic rocks. However in the southern part of the Çatalca Peninsula which includes also study area, rivers have created more gentle slopes because the study area and its surroundings have weak and generally unconsolidated lithologic units.

#### *2.3.1.3 Valley Floors*

The Atmaca and Kavaklı streams flows in a V shaped valleys. That's why the valley floors of these streams exist where they discharge to the Sea of Marmara. Valley floors cover small areas in that part of these streams. However, the valley floor of the Haramidere stream is very large in the eastern part of the study area. It lies from north to south with an angle of 1-3 degrees. The Valley floors are mostly characterized by alluvium consisting of sand, pebble, silt and clay.

#### 2.3.1.4 Slopes

Within the study area, slopes can be divided into two groups; valley slopes and coastal slopes. The valley slopes lie from north to south adjacent to stream valleys and the slope angles vary between 5 and 30. In some part of the valley slopes, especially in the upper site of the Kavaklı stream the slope angles reach up to 45 degrees. The lowest slope angle (between 3 and 10 degrees) can be seen on the valley slopes of the Haramidere stream.

Slopes become steeper towards the west and south coast. In particular, the slope angle is the greatest on the slopes where in the western part of the study area. It is generally between 5 and 25 degrees, however on some part of the coast the slope angle is higher than 25 degrees.

#### 2.3.1.5 Ridges

In the study area ridges can be generally seen between the tributaries of the Atmaca and Haramidere streams. However they are very gentle and the slope angle varies between 5 and 15 along these ridges.

#### 2.3.1.6 Beaches

Although the western coast of the study area is characterized by high cliffs, there is also a beach which extends from north to south on this part (Figure 11). It forms a very thin band and covers very small area.

### 2.3.1.7 Coastal Landforms

In the study area, the evolution of the coasts has been affected by many factors including wave, physical and chemical weathering, currents, rivers, sea level changing, wind and landslide. Among these factors the most important one is the sea level change in the Quaternary age. Within this period, sea level decreased in the oceans and seas throughout the world. As the glacial age advanced, the Marmara Sea could not take water from the Black Sea and the Aegean. During that time, the precipitation amount also decreased. Under these conditions, the sea level in the Marmara Basin decreased almost 110 meters and all rivers started to incise their valleys (Yakuplu Belediyesi, 2000). However with the interglacial period, the conditions changed as the sea level of the Marmara Sea rose up to its present level almost 10 thousand years ago. With this Flandrien Transgression, the lower parts of the coast of the study area and its surroundings were occupied by seawater. Büyükçekmece and Küçükçekmece bays formed by sea level rising. Before the Flandrien Transgression, some rivers including the Karasu, Kördere, Beylikçayır, and Tepecik rivers, discharged to the Marmara Sea from the place occupied by Büyükçekmece bay at present.

The waves have very important effects on the forming and shaping of the coast. In particular the weak and unconsolidated lithologic structure (sand, sandstone, clay, silt, and marl) exacerbated the effect of the wave erosion especially on the cliffs in the western coast of the study area. The height of the waves in the Sea of Marmara varies between 20 centimeters and 2 meters. In stormy weather, the waves reach up to 2 meters high with the wind. The dominant wind direction is southwest and northeast. In particular very high winds blow from south, which cause the sea level to rise almost 1 meter along the northern coast of the Marmara Sea. During that time the effect of the wave erosion increases on the coast of the study area.

**Figure 16:** Artificial fill in the western cost of Gürpınar.

One of the important factors affecting the aspect of the coast are landslides. Some physical characteristics of the coast are very susceptible to landslide. Because the coast is generally composed of clayey unconsolidated materials, many landslides have been taking place along the coast. As can be seen on the three dimensional view of the study area, landslides deformed the real aspect of the topography especially in the coastal zone of the study area (Figure 12).

In the western part of the study area, the coast is generally characterized by cliffs whose heights vary between 15 and 25 meters. However most of the cliffs are not active at present due to natural and anthropogenic impacts. Because the cliffs are composed of weak and unconsolidated sandstone, siltstone and clay, they have been easily eroded by weathering process. The materials that have been eroded, accumulated in front of the cliffs and prevented the waves from reaching the cliff base. In addition, some parts of the coast have been filled with materials and turned into the land in order to prevent waves to reach cliffs (Figure 16). That is why most of the cliffs are inactive in the western coast. The current cliffs can only be seen on the Cape Mandabaşı, located in the southwest of the study area (Figure 13).

Low coasts are dominant in the southern part of the study area (Figure 17). However there are small beaches in the area where Atmaca and Kavaklı streams discharge into the Sea of Marmara, and the alluvium extends over larger areas downstream of the Haramidere.

### 2.3.2 Slope Angles

The study area has very different slope angle ranges. The topography that is generally decreasing from north to south with slight slope (2-5 degrees) becomes steep along the coastal zone and valley slopes in the study area (Figure 14). The western parts of Gürpınar have the greatest slope angle.

While the slope angles vary between 10 and 30 degrees, there are two distinct lines that slope angle decreases on. On these areas that can be identified in the slope map as thin dark coloured lines, the slope angles are between 30 and 55 degrees (Figure 14). On the other hand, in the northwest facing slopes of the Cape Mandabaşı that constitutes the steepest place of the study area, slope angle reaches up to 90 degrees especially on the cliffs. The southern coast of the study area is the other place where the slope angle is high. As they can be seen in the slope map as dark lines (Figure 14), the slope angle can be reach up to 40 and 50 degrees in the southern part of the Armuttarla hill, however average slope angle varies between 10 and 20 degrees. Apart from these places, the valley slopes of the Kavaklı stream and the southern part of the Yakuplu are the other areas where slope angle is high.

It can be understood by looking at the general slope angle ranges on the slope map why the slope steepness decreases along the coast (Figure 14). If it is considered that the topography decreasing from north to south with an angle of 2 and 5 degrees without any disturbance until coast, the coast would be steeper than present. However, many landslides have occurred on the large areas along the coastal zone due to combination of some factors including tectonic activities, steep slopes, wave erosion and weak, unconsolidated lithology of the area.

**Figure 17:** A view from the southern coast of the study area.

Apart from the coastal zone, the slope angle increases on the valley slopes. The Atmaca and Kavaklı streams flow from north to south within their valleys with an angle of between 2 and 7 degrees. However slope angles increases on their valley slopes. Especially west and northwest facing slopes of these two streams are steeper than east and southeast facing slopes. The average slope angle is between 2 and 10 degrees on the east and southeast facing slopes of these streams, however on the opposite slopes, the slope angle is between 5 and 25 degrees.

In the study area the ridges and valley floors constitute the areas that slope angle is the lowest. Slope angle varies between 1 and 5 degrees on these places. The largest area that slope angle is lowest is the Haramidere valley floor. The slope angle is between 1 and 2 degrees on this valley floor.

## 2.4 CLIMATE CHARACTERISTICS

The study area is characterized by hot-dry summer and cool-rainy winter. With its characteristic features, the Marmara climate dominates in the study area. Altough the Black Sea climate conditions are dominant in the northern part of the Istanbul, the study area is under impact of the Mediterranean climate.

The main differences between Mediterranean and Marmara climate can be understood by looking at precipitation and temperature regimes. Compared with the Mediterranean climate, the Marmara climate has more precipitation in the summer. The temperature is also lower during the summer.

### 2.4.1 Temperature

In the study area the mean annual temperature from 1936-1990 is 13.8 C° according to Florya Meteorological Service. The hottest months are July (23.2 C°) and August (23.7 C°). The coldest months are January (5.3 C°) and February (5.5 C°). The temperature generally starts to decrease after September and the lowest temperatures recorded in January. After April the temperature starts to increase and peaks in August (Table 2).

### 2.4.2 Precipitation

The mean annual precipitation from 1936-1990 is 642.4 mm according to Florya Meteorological Station (Table 2). However it was measured as 557 mm in Büyükçekmece Meteorological Station.

**TABLE 2: METEOROLOGIC DATA OF THE STUDY AREA (1937-1990, Florya Meteorological Station).**

| MONTHS | Jan. | Fab. | Mar. | Apr. | May | Jun | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual AV. TOT. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature ( °C ) | 5,3 | 5,5 | 6,9 | 11,1 | 15,9 | 20,6 | 23,2 | 23,7 | 19,7 | 15,4 | 11,5 | 8 | **13,8** |
| Precipitation (mm) | 90,6 | 65,4 | 60,3 | 44,8 | 29,5 | 25,8 | 20,8 | 22,4 | 34,4 | 60 | 86,4 | 102 | **642,4** |
| Relative Humidity (%) | 78 | 77 | 76 | 74 | 75 | 71 | 68 | 69 | 72 | 75 | 77 | 78 | **74** |
| Duration of Insolation (hours/min) | 2,47 | 3,3 | 4,34 | 6,26 | 8,39 | 10,36 | 11,3 | 10,44 | 8,22 | 5,58 | 4 | 2,48 | **6,43** |

**TABLE 3: WATER BUDGET OF THE STUDY AREA ACCORDING TO THE THORNTHWAITE METHOD.**

| MONTHS | Jen. | Feb. | Mar. | Apr. | May | June | July | August | Sept. | Oct. | Nov. | Dec. | Annual Av. Tot. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature (°C)** | 5,3 | 5,5 | 6,9 | 11,1 | 15,9 | 20,6 | 23,2 | 23,7 | 19,7 | 15,4 | 11,5 | 8 | **13,8** |
| **Pot. Evapot. (mm)** | 10 | 10,4 | 18,5 | 41 | 76 | 113,4 | 132 | 126 | 88,4 | 57,6 | 31 | 18,4 | **722,7** |
| **Rainfall (mm)** | 90,6 | 65,4 | 60,3 | 44,8 | 29,5 | 25,8 | 20,8 | 22,4 | 34,4 | 60 | 86,4 | 102 | **642,4** |
| **Accrued water (mm)** | 100 | 100 | 100 | 100 | 53,5 | 0 | 0 | 0 | 0 | 2,4 | 57,8 | 100 | **--** |
| **Real Evapot. (mm)** | 10 | 10,4 | 18,5 | 41 | 76 | 25,8 | 20,8 | 22,4 | 34,4 | 57,6 | 31 | 18,4 | **366,3** |
| **Lack of water (mm)** | 0 | 0 | 0 | 0 | 0 | 87,6 | 111,2 | 103,6 | 54 | 0 | 0 | 0 | **356,4** |
| **Excess water (mm)** | 80,6 | 55 | 41,8 | 3,8 | 0 | 0 | 0 | 0 | 0 | 0 | 13,2 | 83,6 | **278** |
| **Runoff (mm)** | 62,9 | 59 | 50,4 | 27 | 13,5 | 6,8 | 3,4 | 1,7 | 0,8 | 0,4 | 6,6 | 45,1 | **278** |
| **Moisturre (%)** | 8 | 5,3 | 2,3 | 0,1 | -0,6 | -0,8 | -0,8 | -0,8 | -0,6 | 0 | 1,8 | 4,5 | **--** |

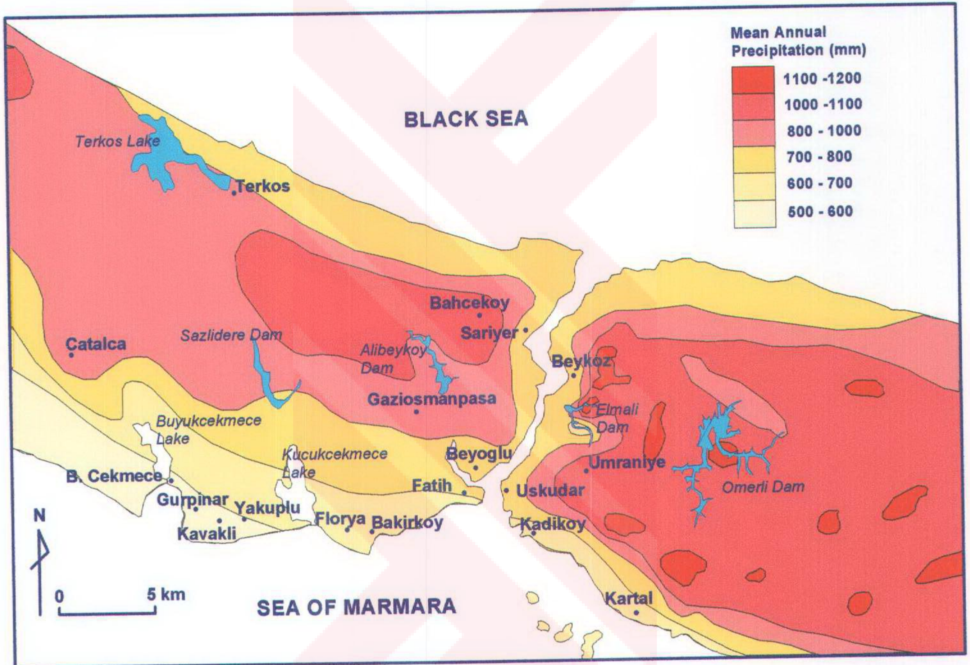


Figure 18: Distribution of the mean annual precipitation in the vicinity of Istanbul (Erinç, 1980).

According to the distribution map of the mean annual precipitation in Istanbul, the precipitation decreases from north to south and the study area has the least precipitation amount (Figure 18). That is why the annual precipitation amount of the study area should be around 600 mm according to the map (Erinç, 1980).

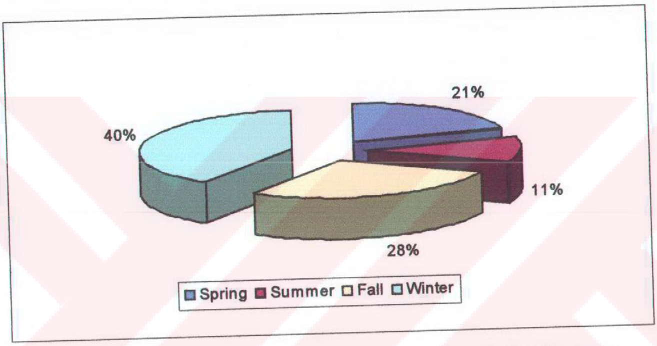


**Figure 19:** Mean Annual Precipitation According to the Seasons (1936-1990)

In the study area, winter is the rainiest season. 40.2 % of the precipitation falls in this season (Figure 19). The driest season is the summer with the percentage of 10.7 %. The rainiest month is December with precipitation amount of 102 mm. July is the driest month. 20.8 mm precipitation falls in this month (Figure 19).

## 2.5 HYDROLOGIC CHARACTERISTICS

The evolution of the drainage patterns and valley shapes of the study area have been affected by the combination of some factors including tectonic movements, lithologic structure, and geomorphologic evolution. In particular, sea level changing caused some interruption on the evolution of the drainage systems and created new drainage pattern on the study area.

The present drainage system of the area has started to form since the Upper Miocene (Erol *et al*, 1991). Initially, rivers were located on the area that rose up by tectonic activities as consequent within the new slope conditions. In the course of time new tributaries and their valleys formed and they created a dendritic drainage pattern on the area because the study area is generally characterized by horizontal and discordant structure.

Tectonism has been effective in the evolution of the valleys initially. It can be understood by looking at the valley directions on the topographic map of the study area that the lower parts of the Atmaca and Kavaklı stream valleys lie in the direction of northeast-southwest (Figure 9). However the upper parts of these valleys formed towards north under the new slope conditions. This condition indicates that initially these streams were located in the valleys that were created by tectonism, then they eroded their valleys backward towards north.

### 2.5.1 Water Budget

To prepare the water budget of the study area, temperature and precipitation data including years between 1937 and 1990 were used. Initially the monthly evapotranspration values were calculated according to the Thorntwaite method. Then these values were corrected by the insolation coefficient determined according to the latitude of the Florya Meteorological Station. Finally, the excess water, lack of water, runoff, and moisture in the soil were calculated using these three kinds of data. All these data are finally given in the table and diagram (Table 3, Figure 20).

As can be seen in Table 3 and Figure 20, the precipitation becomes more than evapotranspration after October and the excess accumulates in the soil. After evapotranspiration, the remaining water is not enough to saturate the soil during the November. That is why, during October and November there is water accumulating in the soil. The soil becomes saturated in December because of both increasing precipitation and decreasing evapotranspration. Because the soil is already saturated, the excess water starts to flow as both groundwater or surface water after December. This period continues until April. In May, the potential evapotranspiration becomes more than precipitation. Because the precipitation amount is not enough for evapotranspiration, the accumulated water is used during May. There is no accumulated water in the soil during June and this condition continues until October when precipitation becomes more than potential evapotranspiration. Thus, between June and October there is a lack of water in the soil.

As can be seen in the diagram, between November and March is the period that excess water starts to flow on or in the saturated ground. With the rainfall, average 278 mm/yr water flows and arrives the Sea of Marmara by the streams or percolates into the soil during these months.

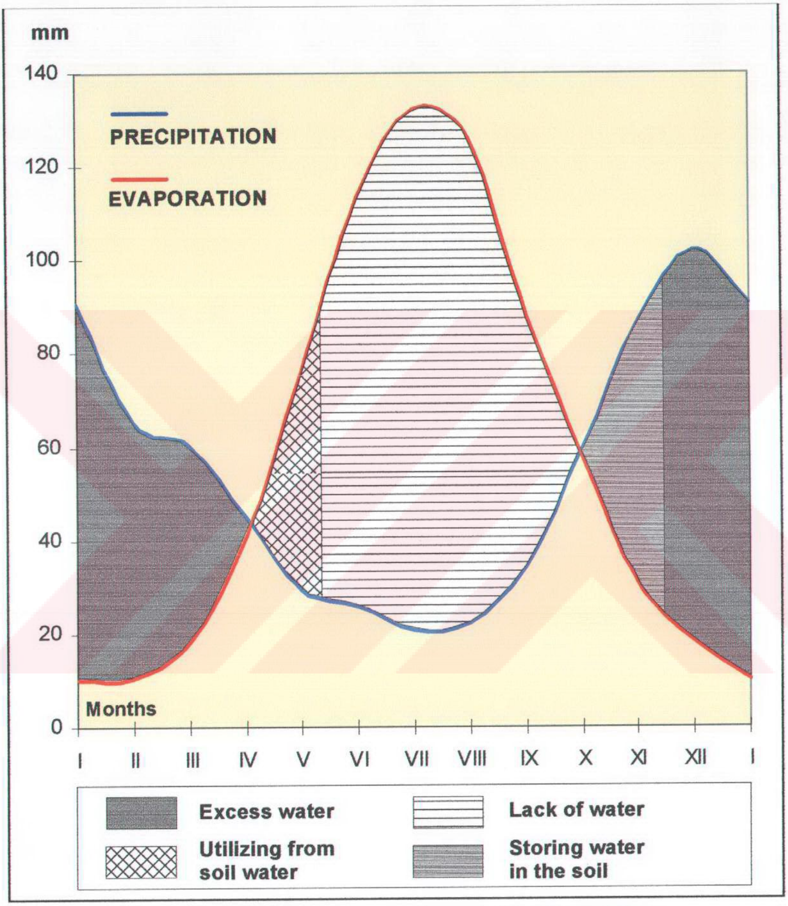


Figure 20: The water budget of the study area according to the Thornthwaite Method

### 2.5.2 Surface Water

Surface waters are mostly collected by the three streams in the study area. The Atmaca stream, located in the western part of the study area, flows from north to south-southwest and discharges into the Marmara Sea from the east of Cape Mandabaşı (Figure 9). It has seasonal runoff and totally dries out during the summer. The Atmaca stream has three main tributaries which originate from the eastern ridges. Its total length with its tributaries is 6 km. The Atmaca stream constitutes the smallest stream of the study area and has a basin covering 5.5 square kilometers.

The Kavaklı stream flows roughly from north to south. It has three main tributaries in the upper side. The total length of this stream with its tributaries is 10 km. While there is water in its valley in the spring, fall and winters, the stream dries out during the summer. Its basin covers an area of 12 square kilometers.

The biggest stream of the study area is Haramidere stream, located in the eastern part of the study area. The lower part of this stream (7.5 km) exists in the study area. Its basin covers around 100 $km^2$ area. While it meanders, the Haramidere stream has been constrained by artificial channels in many places.

Apart from these main streams, the surface water of the western and southern part of the study area is carried by several small creeks and channels formed by rainfall. There is an area approximately 8 $km^2$ that has no proper drainage system. These areas can be divided into three groups. One of them is located in the western part of the study area. The others extend along the southern coast. The most important feature of these areas is that nearly all landslide have been taking place on these areas.

### 2.5.3 Hydrogeologic Characteristics and Groundwater

The geologic formations can be classified into two groups: permeable or impermeable. The Gürpınar Formation is generally impermeable according to its lithology. As its dominant lithology is composed of clay and silt, Gürpınar Formation does not have high hydraulic conductivities. However its sand, pebble and carbonate units include much water. Althouh it varies from season to season, the groundwater level fluctuating between 3 and 15 meters. The average groundwater level is 7.50 meters according to drill hole data (Gürpınar Belediyesi, 2000).

As it is mainly composed of sand and pebble units, Çukurçeşme Formation is considered permeable. Since it is mostly covered by the clay layers of the Güngören Formation, the catchment area of this formation is small. There is much groundwater in this formation where thick sand and pebble units exist. Some seasonal springs exist at the boundary between the Gürpınar and Çukurçeşme formations. According to drill hole data from the western part of the study area, the groundwater level changes from 1.5 to 8 meters. The average groundwater level is 5 meters (Gürpınar Belediyesi, 2000).

The Güngören Formation is regarded as impermeable due to its clay and marl units. The permeability of the Bakırköy formation changes according to its different lithologic units. Its limestone level is permeable, while the clay and marl units are impermeable and prevent vertical water movement. The groundwater level is between 1.30 and 13.50 meters according to drill hole data from the eastern part of Gürpınar (Gürpınar Belediyesi, 2000).

## 2.6 VEGETATION COVER

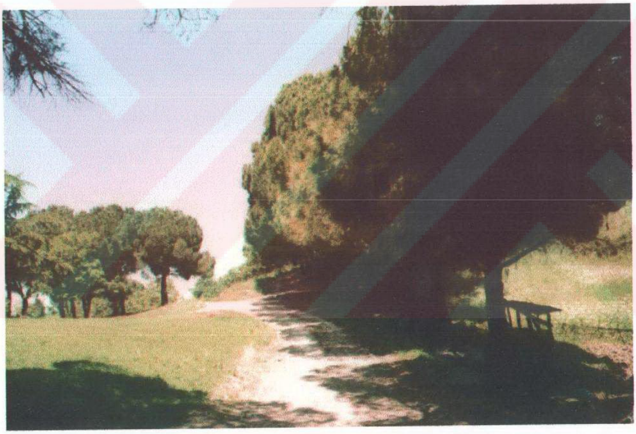

**Figure 21:** Red pine (Pinus brutia) trees in the western part of the study area.

Due to prolonged human impacts, the study area and its surroundings are totally deprived of vegetation cover at present. Actually the study area should has been covered by red pine and oak trees, as prior to human intervention. After deforestation, initially the area was covered mostly by maquis species. However continuous human intervention caused nearly all vegetation cover to be removed from the area. Initially the area was used for agriculture. For the last 10-15 years, the area has been mostly used for building home, villas and factories. A unique vegetated area is located in the western part of Gürpınar. Almost 60-70 trees including red pine and cedar, have been preserved for recreational purposes (Photo 21). In addition, along the valley of Atmaca and Kavaklı stream some poplar and plane trees can be seen on the valley floors.

## 2.7 CONCLUSION

The study area is characterized by different lithologic units deposited under different conditions including mostly clay, marl, silt, sand, pebble, sandstone, and limestone. Because of the tectonic activities the study area sometimes stayed under water, and sometimes it turned the land. In particular, the last sea level transgression (Flandrien Transgression) has affected not only coastal zone but also the evolution of the drainage patterns and valley shapes. The topography generally extends from north to south with an angle of between 0-5 degrees. However along the coastal zone and valleys, the slope angle increases. The cliffs, located in the southwestern part of the study area, have the steepest slopes with an angle of 90 degrees. The climate of the study area is characterized by hot-dry summer and cool-rainy winter that is called as Marmara climate. The winter is the rainiest season (42.2 %) however the least rainfall can be seen in the summer (10.7 %). As the ground is saturated, the waters from rainfall start to flow as either surface water or groundwater during the time between November and March. Annual 278 mm water flows like that. Most of water is being removed towards Sea of Marmara by three streams including Atmaca, Kavaklı, and Haramidere. Within these streams, only Haramidere has continuous runoff. The others dry out during the summer. The vegetation cover was removed on a large scale due to prolonged human impacts in the study area.

# CHAPTER 3

# TYPES AND DISTRIBUTION OF LANDSLIDES

## 3.1 INTRODUCTION

Landslides are a severe problem and have caused abundant damage on the buildings especially along the coastal zone of the study area. Generally, four types of landslide can be seen in the study area. They can be classified as slide, fall, flow, and creep from the most common type to the least common. Besides these landslide types there is also other soil movement causing severe structural damage to houses. This is the expansion of clayey soil especially under the pressure of constructions. This type of mass movement is explained as a distinct subjection in this chapter. The main objective of this chapter is to describe the landslide types and their distributions in the study area.

## 3.2 ROTATIONAL SLIDE

A Rotational slide, also called slump, rotational slip, and multiple rotational slide according to their different forms, is characterized by the movement of a mass of weak soil and sediment as a block unit along a curved concave slip plane (Dikau *et al.*, 1996). The material from the slide may be broken into a number of pieces or remain as a single, intact block.

**Figure 22:** Small size rotational slide in the western part of Gürpınar.

**Figure 23:** Concave scarp of a rotational slide in the southern part of Gürpınar.

Rotational slide is the most common type of landslide in the study area. There are two important points related to rotational slides. One of them is about old slides whose scarps are long and extend on the large areas. The other one is about the newer slides that are smaller in size. Most of the movement on these old rotational slides has stopped, but some backward movement of the slopes is still ongoing especially on the top of the slopes. This type of landslide can also be recognized on the three dimensional view of the area (Figure 12). In that figure the curved, spoon-shaped slides are easily visible in the western and southern parts of the area.

In the study area, new small spoon-shaped slides can be seen on the collapsed part of the old rotational slides. These slides are commonly initiated when the bottom of slopes are removed by human activities such as building homes and roads. Before failure begins, some cracks start to form on the slope transversely. After that, the slide blocks start to move down along transverse cracks. In the head area, the blocks may tilt backward and the lower part moves over the toe area. These small rotational landslides develop slowly and commonly require several months or even years to reach stability; however, they may move rapidly especially due to heavy rainfall (Figure 22, 23).

The rotational slides form in different shapes on the study area. However most of them have single scarp and slide block, some of them have two or more transversely oriented scarps that form a stair-step pattern of displaced block. This type of landslide is called as "multiple rotational slide" and the most typical example of it can be observed on the southern part of the Yakuplu, at the west of the harbour.

The Rotational slides can be seen in the western and southern parts of the study area (Figure 25). Their scarps can also be recognized on the topographic map by the irregular, wavy and closely curved contour lines (Figure 9). Within this figure, two long scarps extending from north to south can be easily seen. These main and primary scarps on the slope have been formed by rotational slides in the past. There are many secondary scarps on the lower part of these slopes too. These old rotational slides took place on the larger areas if we compare them with both of the other type of landslides and new rotational slides. On some part of the scarps these rotational slides are still ongoing, causing some damage especially to buildings and roads.

Along the southern coast of the area, there are two important landslide parts divided by the Kavaklı stream. The area located in the southern part of Gürpınar has been deformed by rotational slides. These rotational slides have occurred gradually disturbing the normal aspect of the slope. The scarps of these rotational slides can be seen on the upper slopes of this area. This area is also evident on the topographic and slope map of the area with its large curved shape looks like half-moon on the area between Atmaca and Kavaklı streams (Figure 9, 14). They formed towards north by gradual slides. Although this area is very susceptible to slide, many buildings especially villas have been built on that coasts. The cracks on the land and buildings indicate the fact that the rotational slides are still active and they cause much damage on the constructions.

The area between Kavaklı and Haramidere streams constitutes the largest landslide part of the study area. It covers almost 3,5 $km^2$ area from east to west. On these coastal zone there are many rotational slides that formed separately. The back ones, through the upper slopes, took place first and formed long curved scarps from west to east. On the other hand, along the coastal zones, there are also many new slides that formed as multiple rotational landslide. The most typical example of this type of landslide can be seen on the both west and east side of the harbour. As they can be easily recognized on the slope and topographic map of the study area, they include more than two separate curved scarps from north to south.

The rotational slide is the most significant problem especially on the west and southern parts of the Gürpınar. They have destroyed or damaged roads, buildings and sewer systems. In particular many new villas have been damaged by landslides, to the extent that retaining walls were constructed near them as a precaution. It is very important to note that nearly all damaged buildings have been constructed on areas which had slid in the past. The worst thing is that people are still building new homes on that hazardous areas even though neighbouring buildings have been damaged.

## 3.3 ROCK FALL

Rockfall is an extremely rapid, and potentially dangerous, downslope movement of earth materials. Large blocks of massive bedrock may suddenly become detached from cliff or steep hillside and travel downslope in free fall or rolling, bonding or sliding until a position of stability is achieved.

**Figure 24:** Current rock fall on the northeast coast of the Cape Mandabaşı.

In the study area rock falls can only be seen on the west coast of Gürpınar, because the coast is characterized by high cliffs whose heights vary between 20 and 25 meters (Figure 24, 26). There is no other example of this type of landslide on other coasts or in the other part of the study area (Figure 25).

The cliffs are composed of sandstones that are very fine-grained and have poor cohesion. As the waves eroded the underside of the cliffs, the sandstones start to fall from the top of the cliffs. But this type of rock fall is not common on the cliffs at present due to human intervention. The seawater in front of the cliffs have been filled and turned into the land both for gaining land for recreational activities and preventing the rock falls. Nearly all previously collapsed materials, are covered by grass and brush species at the moment. Whether this condition indicates that rock fall is over, on some part of the cliffs there are still some rock movements in small sizes. These small rock falls mostly originate from water that penetrates into the sandstone through cracks and causes failure especially in the rainy seasons.

Cape Mandabaşı is the only place that current rock falls can be seen on both its west and northwest facing slopes (Figure 24). In that part of the area there are no obstacles to prevent the sea waves from reaching the foot of cliffs. That is why the slopes composed of sandstone erode back daily.

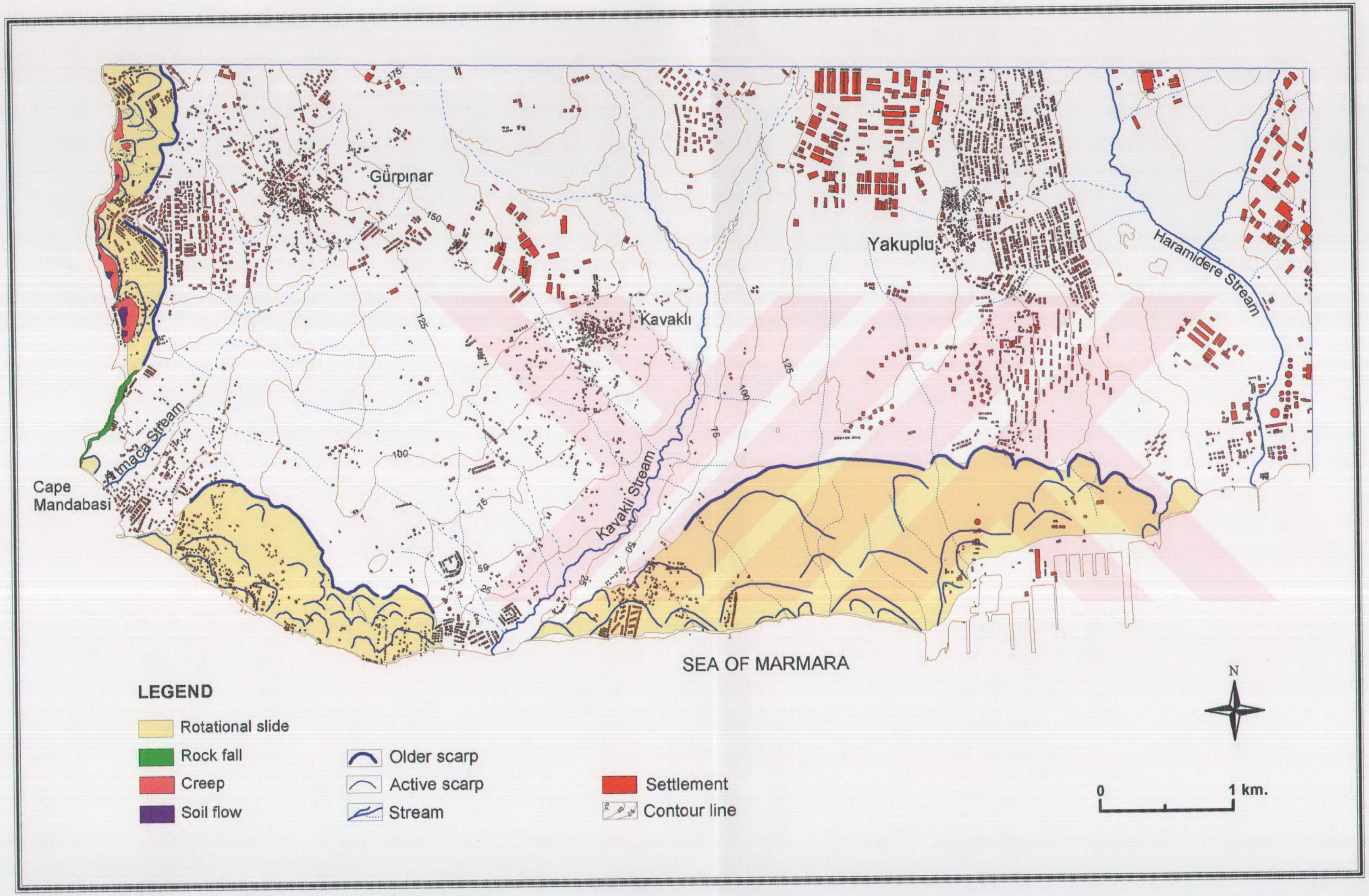


Figure 25: Areas showing the types of landslides and their distributions.

On some parts of the cliffs, many villas have been built due to the very attractive sceneries. Before the littoral zone was turned into the land, rock falls were threatening these homes. But now this threatening movement stopped because the seawater can not reach and erode the bottom of the cliffs (Figure 26).

**Figure 26:** Inactive cliffs on the west coast of Gürpınar.

## 3.4 SOIL FLOW

A soil flow is a very slow to very rapid, wet flow of relatively cohesive earth material that contains at least 50 % sand, silt and clay sized particles (Varnes, 1978). They are distinguished from slides by having a high water content. In this type of landslide, downslope movement of materials act as a viscous mass. Because of that they travel further than other slides. They generally occur when slope material becomes saturated, resulting in a loss of cohesion.

Although flows are not a severe problem in the area, they can be seen especially along the slopes of western coast of the Gürpınar (Figure 25). In the study area, soil flows usually take place on slopes covered by slightly consolidated or unconsolidated mud and earth material including clay, sand, silt, and marl especially where the vegetative cover has been removed.

Soil flows are commonly triggered by presence of water in the study area. Rainfall intensity and duration and soil moisture conditions are strong controls for soil flow on the weak fine-grained material that is very susceptible to slides. When rain starts to fall, the fine-grained sediments on the slope become saturated and move downward like a viscous fluid. The flows commonly follow pre-existing drainage ways, and tracks have a V-shape or rectangular cross-section (Figure 27, 28).

Soil flows are very small in size and can be seen on very limited parts in the study area. Most of them occur due to human interventions. Because when the material is removed from the top of the slope for building home and road, the sediments on the surface become very susceptible to flow. With excavation not only the top of the soil but also the vegetation cover which keeps the slopes stable are removed from slopes. Thus, all weak materials flow downward with water especially if excavation is made on the small valley slopes.

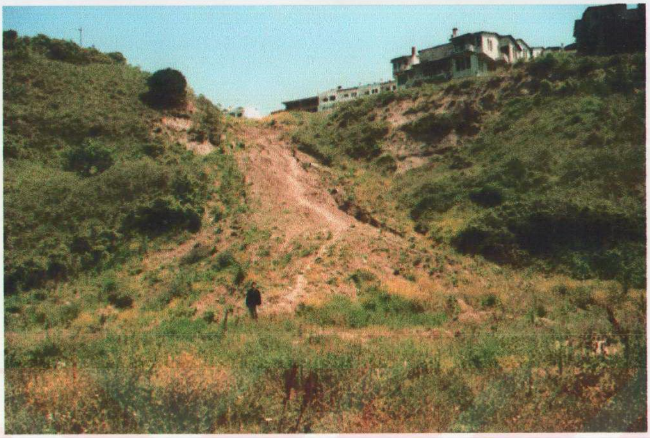

**Figure 27:** Soil flow in the western part of Gürpınar.

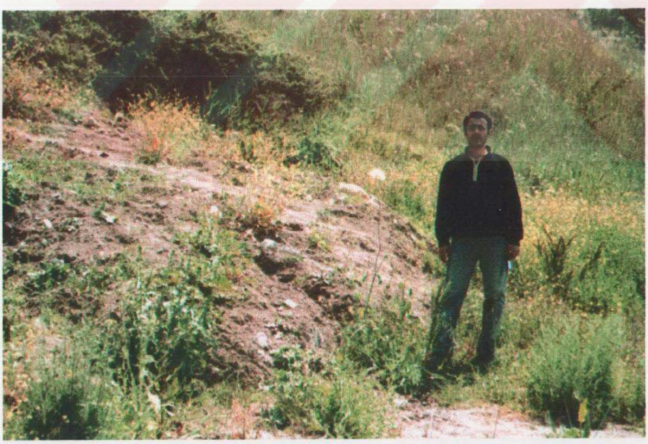

**Figure 28:** The toe part of the soil flow in the western part of Gürpınar.

Until now, soil flows have not caused any damage to both people or their properties in the study area. They can be dangerous if they occur near homes. For example, one of the most typical example of soil flow took place on the western coast of Gürpınar. The sediment composed of very fine-grained clay, silt and marl minerals was very susceptible to flow and moved downward with heavy rainfall. Although there were no damages to the buildings constructed near the hazardous area, this flow might cause other slides or flows which will damage the buildings if precautions are not taken. Because this soil flow also disturbed the balance of upper part of the slope. And it is more likely to move again in the rainy seasons.

## 3.5 CREEP

Soil creep is very slow and continuous downhill movement of soil over long periods of time. It is distinguished from soil flow with its extremely slow and steady process. It can easily be recognized by bent fences, trees, and walls on the land.

Creep is common phenomenon especially on the western coast of the study area (Figure 25). Actually it is difficult to recognize this slow type of flow in the area as there are no trees or constructions on going. That is why all the occurrence of creep couldn't be identified in the whole study area. However, the most typical example of creep was observed in the vegetated area used for recreational activities by people around the west coast of Gürpınar. Nearly all trees have been bent by creep (Figure 29, 30). Some trees became bent from their roots totally, while some trees are bent in different shapes in the same area. In general, they have a vertical shape at the moment but their trunks have a curvature 150-200 centimeters above from surface. These distinct shapes of trees indicate that different types of landslide had taken place in the same area until about 15-20 years ago. Before that time, all these areas were standing near the sea and some landslide took place in some part of the area. Because of these landslides some trees became bent on the previously affected area. Then, when the seawater filled with sediment and turned into land, the movement of slide stopped and the trees started to grow vertically again (Figure 31). Creep is still on going and causing the trees to bend in that part of the study area.

The most important processes contributing to the soil creep in that part of the study area are expansion and contraction of clay minerals in the soil. The soil which includes clay, marl and silt is very susceptible to flow (Figure 32). With water, the clayey minerals expand and push the other component of soil around. Then the soil moves downward very slowly because of the gravitational force.

The soil creep is very significant problem for people who built their homes on the area susceptible to creep. After they build their homes some cracks form on the walls. As the cracks expand day by day, people have to repair their home and after a while they move to other places.

**Figure 29:** Curved trees due to creep in the western coast of Gürpınar.

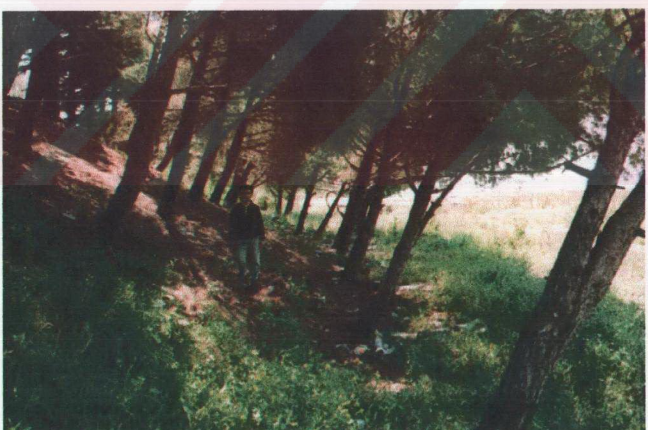

**Figure 30:** Tilted trees due to creep in the western coast of Gürpınar

## 3.6 OTHER MASS MOVEMENTS

Apart from landslide types mentioned above, there is other mass movement that causes damage to the buildings and roads in the study area. It is the behaviour of clay minerals in the soil of vertisol under the different conditions. Vertisol is very common along the coastal zone and it includes much clay.


**Figure 31:** Abandoned and damaged building due to expansion and contraction of the clayey soil in the southern part of Gürpınar.

Clay has large capacity to absorb moisture between its particles. When water is added to these expansive clays (by rainfall or watering), the water molecules are pulled into gaps between the clay plates. As more water is absorbed, the plates are forced further apart, leading to an increase in soil pressure or an expansion of the soil's volume. On the other hand when soil dries out, the clay minerals contract in dry seasons. Excessive wetting and drying of the clayey soil deteriorate structures progressively on the land over the years. This excessive wetting and drying causes damage due to differential settlement within buildings and other improvements.

Soils containing expansive clay minerals are very widespread in the western and southern parts of the study area. Especially the Gürpınar and Güngören formations, which are characterized by mostly clay, sand, marl, and silt components, are very capable of expansion and contraction. That is why in the southwestern part of Gürpınar, expansion of clay minerals caused abundant building cracks. Over time, the repeated swelling and shrinkage made some houses unliveable (Figure 31).

Initially, many people don't know and pay attention to this problem on the clayey soils. When they start to build their homes, they come face to face with this severe problem. Actually presence of surface cracks is usually an indication of an expansion of clay. However if one building is constructed on this expansive soil, the concentrated weight of the structure inhibit the upward expansion of soil. On the other hand outward expansion may continue and damage to the buildings if essential precautions are not taken.

## 3.7 CONCLUSION

Landslides are very significant problem throughout the coastal zone of the study area, as shown by the extensive damage to the buildings, roads, water pipe lines and sewer systems. As they extend over large areas, the rotational slides are the most damaging landslide type within the study area. In addition, many of them are still active and their movements are still on going. However, the other types of landslide including rock fall, soil flow, and creep can be seen on the west facing slopes of the coast in Gürpınar. Because their small sizes and less common distributions, they have not damaged as much as the rotational slide. Apart from these types of landslide, the expansive clayey soil is also a severe problem in the coastal zone. To build homes without any precautions causes damage on the buildings in these clay-rich soils.

The coastal zone of the study area has a very attractive view over which to build home and villas. Because of that many new homes especially villas have been built on the coastal zone without taking sufficient precautions. If this severe problem continues, there will be most likely much damage on these areas due to landslides in the near future.

# CHAPTER 4

# CAUSATIVE FACTORS OF LANDSLIDE

## 4.1 INTRODUCTION

Every location on a hillslope can be considered as a part of a continuous tug-of-war between the driving force of gravity and resisting forces due to materials that constitute a slope (De Graff, 1987). Both natural processes and human modifications of slopes can change this balance in the favour of gravity. Considering the general characteristics of the affected region, geological, morphological, and hydrological conditions, and human interventions are considered as the major causative factors of landslide in the study area. These factors contribute in different degrees to initiate or to progress a landslide. The specific impacts of these causative factors are very complex and difficult to differentiate, because these factors can sometimes be confounded among themselves. The primary focus of this chapter is to determine the causative factors of landslide in the study area.

## 4.2 GEOLOGICAL FACTORS

Unconsolidated lithology is the main causative factor of landslide in the study area. Clay, silt, marl, sand and pebble units of the formations are particularly susceptible to landslide. In particular, clay layers play important role to determine the susceptibility of the formations to landslide. These layers have a high percentage of clay-sized particles, which include expansive clays. Thus, these layers can become the failure planes of landslides. If the other factors including slope angle and hydrologic conditions are suitable, any disruption of the slope balance causes landslide on these susceptible grounds.

The other geologic factor that facilitates landslides is that all lithologic units were deposited horizontally and they are interbedded with clay layers. In particular, the direction of the clay layers is parallel to the gradient and this situation is very appropriate for materials to easily slide on the clay layer with the addition water.

**TABLE 4: DISTRIBUTION OF LANDSLIDES IN THE SOUTHERN PART OF THE STUDY AREA ACCORDING TO THE FORMATIONS AND THEIR MAIN LITHOLOGIC UNITS ( Yakuplu Belediyesi, 2000).**

<table>
<tr><th colspan="3">FORMATIONS</th><th colspan="2">Gürpınar</th><th colspan="2">Çukurçeşme</th><th colspan="2">Güngören</th></tr>
<tr><td colspan="3">Statistics</td><td>Observation</td><td>%</td><td>Observation</td><td>%</td><td>Observation</td><td>%</td></tr>
<tr><td rowspan="8">Lithologic Units</td><td rowspan="2">Clay</td><td>number</td><td>18</td><td rowspan="8">21<br>%70</td><td>-</td><td rowspan="8">4<br>%13</td><td>4</td><td rowspan="8">5<br>%17</td></tr>
<tr><td>%</td><td>85</td><td>-</td><td>80</td></tr>
<tr><td rowspan="2">Silt</td><td>number</td><td>3</td><td>-</td><td>1</td></tr>
<tr><td>%</td><td>15</td><td>-</td><td>20</td></tr>
<tr><td rowspan="2">Sand</td><td>number</td><td>-</td><td>1</td><td>-</td></tr>
<tr><td>%</td><td>-</td><td>25</td><td>-</td></tr>
<tr><td rowspan="2">Sand-Pebble</td><td>number</td><td>-</td><td>3</td><td>-</td></tr>
<tr><td>%</td><td>-</td><td>75</td><td>-</td></tr>
</table>

Most of the formations (Gürpınar, Çukurçeşme, Güngören) whose porosities are generally high, are characterized by unconsolidated materials including clay, marl, silt, sand and pebble. Although Bakirkoy Formation is regarded as the least susceptible formation to landslides because of the limestone, it is soluble in some places as shown by its many cracks. The geologic formation in the study area with the most landslides per unit area of exposure is the Gürpınar Formation. This finding agrees with the general perception of the Gürpınar Formation as the most landslide-prone lithologic unit in the study area. The Güngören formation composed of marl, clay and silt is the second important formation susceptible to landslide.

#### 4.2.1 Gürpınar Formation

Since it is mostly characterized by clay minerals, Gürpınar formation has the most susceptible litology to landslide. Marl, silt, and sand are the other common materials in this formation. These unconsolidated materials of the formation are particularly low in strength and are more susceptible to landslides than other lithologic units. That is why old and recent landslides took place mostly in the Gürpınar Formation. This situation can be seen in the report that was made for Yakuplu municipality (Table 4). In that report 30 rotational slides were observed on the southern part of the study area near the harbour and 21 of them took place in the Gürpınar Formation. Within this formation, most of these landslides (18) occurred on the clayey layers. The remaining landslides (3) took place on the silt layers. According to the same report, there are only 4 landslides that occurred in the Çukurçeşme Formation. Within the Güngören Formation 5 landslides were observed in the same area (Table 4). It is evident in the report that most of landslides have been taking place on the Gürpınar Formation and clay minerals are the most important material causing these landslides. These conditions are the same for the other parts of the coasts. Nearly all landslides also took place in the Gürpınar formation in the western part of Gürpınar.

**TABLE 5: AVERAGE COHESION VALUES OF THE MAIN LITHOLOGIC UNITS ACCORDING TO THE FORMATIONS (Yakuplu Belediyesi, 2000).**

| Formations | Lithologic Units | Number of Sample | Cohesion c, ($kg/cm^2$) |
|---|---|---|---|
| **Bakırköy** | Marl | 1 | 0,54 |
| **Güngören** | Clay | 14 | 1.50 |
| | Silt | 2 | 1.45 |
| | Sand | 1 | 0.85 |
| | Marl | 1 | 0.80 |
| | Silt-Clay | 1 | 1.70 |
| **Çukurçeşme** | Sand | 2 | 6.13 |
| | Sand-Silt | 6 | 0.76 |
| **Gürpınar** | Clay | 89 | 1.21 |
| | Silt | 12 | 1.12 |
| | Clay-Sand | 3 | 0.95 |
| | Clay-Silt | 5 | 0.61 |
| | Claystone-Siltstone | 1 | 1.40 |

In particular, clay layers cause many landslides in the Gürpınar formation. Clay minerals become impermeable and create a slip plane when they absorb water. The general characteristics of the clay minerals slightly differ from place to place within the Gürpınar Formation. However, they are characterized by their fissured structure with different colors including green, brown and gray according to samples that were taken from southern part of study area. They are very fine-grained and capable of absorbing much water (Table 8). When water penetrates in this clay minerals they swell and become impermeable. Their permeability is lower than $10^{-6}$ m/day. Their cohesion is between 1.29 and 1.13 $kg/cm^2$ (average: 1.21 $kg/cm^2$) and their water content is between 26.8 % and 26.4 % (Yakuplu Belediyesi, 2000).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Güngören | Silt | 8 | 53.5 | 29 | 8 | 0.05 | 25.5 |
| | Silt, Clay | 2 | 75.8 | 24.5 | 3 | 0.10 | 33.5 |
| | Silt, Sand | 2 | 69 | 29.5 | 2 | 0.15 | 39.5 |
| Çukurçeşme | Silt | 4 | 73.9 | 30 | 4 | 0.04 | 43 |
| | Clay | 6 | 47 | 21.7 | 6 | 0.15 | 29.1 |
| Gürpınar | Clay | 185 | 59.6 | 25.5 | 172 | 0.20 | 36.8 |
| | Silt | 20 | 55.6 | 29.9 | 20 | 0.15 | 24.8 |
| | Clay, Silt | 5 | 44.3 | 28 | 5 | 0.25 | 8.5 |
| | Claystone | 1 | 66 | 32 | 1 | - | 34 |

The fine-grained materials (clay, marl, silt) of the Gürpınar formation are also susceptible to flow especially on the upper layers. Weathering produces a decrease in the strength of these materials by chemically loosening the bonds between the mineral grains, dissolving the minerals and producing, as a result, clay minerals that are inherently low in strength. With water these unconsolidated materials become saturated and turn into the liquid form and flow downward. If the ground include more cohesive clay minerals, the materials move downward more slowly as creep. Liquid and plastic limits of the main lithologic units of the formations have been indicated within table 6.

The sandstone of the Gürpınar Formation that is mostly seen along the coastal zone of the study area is also susceptible to landslide because of its very weak and unconsolidated structure. The weathering processes, especially presence of water, reduce the shear strength of the sandstone by dissolving the cement between the sand particles. As the cohesion of sandstone is very low, the sandstone dissolves easily. The other important feature of the sandstone in the study area is that it has very high porosity. To determine the porosity of sandstone, some samples have been taken from western coast of Gürpınar and subjected to laboratory test (to add water and measure weight). According to the test results, the sandstone has 25 % volume composed of dry pore spaces, which can fill with water and greatly increase the weight. With gravitational forces, these unconsolidated materials crack and easily fall from the cliffs.

In the study area, nearly all landslides have been taking place along the coastal zone mostly characterized by Gürpınar Formation. However it can not be said that there is always landslide on all parts of this formation. Because towards the north, along the valley slopes of Kavaklı and Haramidere streams, there is no important landslide activity despite these places being characterized by Gürpınar Formation. This condition relates to fact that the distribution and structures of the lithologic units differ from place to place in Gürpınar Formation. Because of that in some part of the area the sand and pebble particles within the clay materials can be less susceptible to landslide.

#### 4.2.2 Çukurçeşme Formation

Çukurçeşme Formation commonly composed of sand and pebble is generally regarded resistant to landslide (Figure 33). However, the presence of the susceptible clay and clay-sand layers surrounding and within the Gürpınar formation cause this formation to be susceptible to landslide. Apart from the clay minerals, the size and shape of the pebble particles affect the stability of the slopes in this formation.

For dry, unconsolidated material, the maximum slope angle at which the material is stable is known as the angle of repose. Smooth, rounded particles have a lower angle of repose than rough, angular particles, and coarse fragments can maintain a greater slope than fine fragments. Fine sand has an angle of repose of around 35°, coarse sand about 40° and angular pebbles at around 45° (Rogers, and Feiss, 1988).

In Çukurçeşme Formation, particle size and shape of the pebbles differ from place to place and they exist with sand particles together. The diameter of pebbles varies between 0,5 and 200 mm and they are slightly round. Small pebbles (< 10 mm) are more angular. In this formation, larger particles maintain a steeper slope than smaller ones. Angular particles can interlock along their rough edges and maintain steeper slopes than smooth ones. That is why coarse or rough textured materials have greater shear strength, and so resist movement. Sand particles that have no strong cementing material or interlocking crystal structure are less stable.

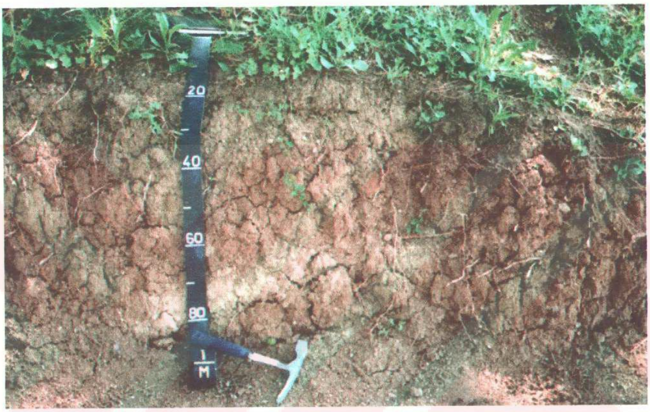


**Figure 32:** The clayey soil causes creep in the western part of Gürpınar.

The sand and pebble deposits of this formation have generally tight structure ($N_{30}$ = 55-61) according to the Standard Penetration Test (Table 7). However in some parts of the study area they have a looser and more unconsolidated structure, which is vulnerable to landslides. On these places when the slope bottom is removed by construction, they fall easily. Although this formation is generally resistant to landslide, many landslides have taken place where the sand and pebble deposits of Çukurçeşme Formation exist on the clay layers of the Gürpınar Formation especially on the steep slopes (15-25 degrees). When the water percolates into the sand and pebble layers, it does not pass the clay layers of Gurpınar Formation and starts to flow downward through the slopes. Because it lubricates the clay layers, water creates a slip plane between two formations. With the weight of additional water, the unconsolidated sand and pebble units of Çukurçeşme Formation start to slide downward by gravitational forces on the clay layer of Gürpınar Formation. Not only the Gürpınar Formation, but also the other formations have clay layers in different thickness, even the Bakırköy Formation. These clay layers cause landslide in all formations, if the other conditions are ready to slide.

**Figure 33:** Unconsolidated sand unit of the Çukurçeşme formation is susceptible to weathering process.

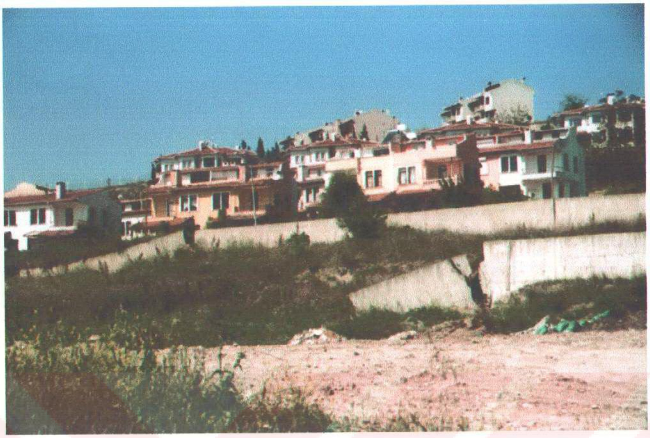

**Figure 34:** Damaged retaining walls in the western part of Gürpınar.

**Figure 35:** Building on the landslide area in the southern part of Gürpınar.

**TABLE 7: THE RESULTS OF THE STANDARD PENETRATION TEST ACCORDING TO THE MAIN LITHOLOGIC UNITS OF THE FORMATIONS (Yakuplu Belediyesi, 2000).**

| Formations | Lithologic Units | Number of Sample | Limit Values ($N_{30}$) | Statistical Average ($N_{30}$) | % 95 reliable values ($N_{30}$) |
|---|---|---|---|---|---|
| Bakırköy | Limestone | 30 | 17 - 105 | 65.5 | 63 – 68 |
| | Clay | 12 | 6 - 46 | 25 | 23 – 27 |
| | Marl | 65 | 8 - 95 | 46.5 | 44 – 49 |
| | Marl-Clay | 74 | 6 - 80 | 38.5 | 37 – 40 |
| Güngören | Clay | 148 | 5 - 88 | 30 | 29 – 31 |
| | Silt | 19 | 7 - 50 | 26.5 | 24 – 29 |
| | Sand | 16 | 16 - 60 | 40 | 36 – 44 |
| | Marl | 4 | 37 - 48 | 43 | 39 – 47 |
| Çukurçeşme | Sand | 209 | 4 - 105 | 34.5 | 34 – 35 |
| | Pebble-Sand | 19 | 8 - 80 | 58 | 55 – 61 |
| | Pebble | 25 | 18 - 105 | 71.5 | 68 – 75 |
| | Silt | 9 | 8 - 80 | 26 | 13 – 39 |
| Gürpınar | Clay | 642 | 5 - 105 | 40.5 | 40 – 41 |
| | Silt | 75 | 5 - 105 | 30.5 | 29 – 32 |
| | Sand | 14 | 9 - 105 | 46 | 38 – 54 |

### 4.2.3 Güngören Formation

In particular, the Güngören Formation composed of clay, marl, silt is the second most important unit that landslide can be seen on. In this formation clay and marl layers cause landslides. Because it has very small distribution area, only a few landslides can be seen in this formation.

### 4.2.4 Bakırköy Formation

The Bakırköy Formation characterized by limestone and marl has the most resistant lithology to landslides in the study area. However, this formation also includes thin clay layers within its limestone and marl units.

Although no landslide was observed on this formation, these clay layers might cause the landslide especially on the steep slopes. Because the limestone and marl have fissured structure, they can dissolve and slide on the slippery clay surfaces by water especially where the clay layers of Güngören formation extend beneath.

**TABLE 8: GRANULOMETRIC ANALYSIS OF THE MAIN LITHOLOGIC UNITS OF THE FORMATIONS (Yakuplu Belediyesi, 2000).**

| Formations | Lithology | Number of sample | > 2 mm % | 2 - 0.075 mm (%) | < 0.075 mm (%) |
|---|---|---|---|---|---|
| Bakırköy | Clay | 38 | 98.5 | 93 | 80 |
| | Marl | 5 | 96 | 80.5 | 63.5 |
| | Marl - Clay | 2 | 96 | 76 | 65.5 |
| | Silt - Clay | 1 | 75 | 49 | 42 |
| | Silt-Sand | 1 | 96 | 56 | 39 |
| | Sand | 2 | 64.5 | 39.5 | 28.5 |
| Güngören | Clay | 29 | 97 | 95 | 87 |
| | Silt | 1 | 99 | 84.5 | 31 |
| | Sand | 8 | 99 | 84.5 | 31 |
| | Silt - Clay | 1 | 79 | 87 | 56.5 |
| | Silt - Sand | 1 | 73 | 56 | 45 |
| Çukurçeşme | Sand | 4 | 57 | 45.5 | 13.5 |
| | Pebble-Sand | 5 | 42 | 32 | 17 |
| | Pebble | 1 | 35 | 10 | 4 |
| | Sand - Silt | 1 | 100 | 100 | 50 |
| | Clay | 11 | 99 | 94 | 78.5 |
| | Sand - Clay | 1 | 81 | 73 | 54 |
| Gürpınar | Clay | 29 | 98.5 | 97 | 89 |
| | Sand | 2 | 94.5 | 54.5 | 13 |
| | Clay - Sand | 1 | 86 | 80 | 40 |
| | Silt - Sand | 1 | 56 | 36 | 24 |

## 4.3 GEOMORPHOLOGICAL FACTORS

Geomorphological processes have affected the landslide by creating the slope conditions of the area. When the land rose up, the weathering process started to shape the ground. While streams were cutting and deepening their valleys, the waves were eroding the cliff bases along the coast. In particular the wave erosion have played a key role in creating landslides along the coastal zone of the study area. The last sea level rise was an especially important factor affecting the slope stability of the coastal zone. When the sea level rose up, the wave erosion started to erode cliff bases and removed supporting material from the slopes. The slopes composed of unconsolidated material lost their equilibrium easily and started to move downward in a large spoon-shape as rotational slide. The impacts of this condition can be mostly seen on the western and southern coast of the Gürpınar. Long curved scarps at the top of the slopes can be identified by looking at the topographic map of the study area (Figure 9). Although the waves have mostly lost their impact on the coast due to human impact, new landslides have been taking place on the area that had slid in the past. The field investigations indicated the fact that most of the current landslides have been occurring on collapsed parts of older landslide especially in the western and southern coast of Gürpınar.

Within the geomorphologic factors, slope steepness is a major contributing factor to the occurrence of landslides. It is closely related to many other factors including the lithology, hydrology and climatic conditions of the study area. All landslides move downslope under the influence of gravity. Therefore, slopes are required for development of a landslide.

The distribution of slope angles within a geologic unit's outcrop area affects the susceptibility ranking of each unit. The Bakırkoy formation, the most resistant unit to landslide, is located at the top and in the northern portion of the study area where gentle slopes dominate. The slope angle is generally between 0-5 degrees on these places. However the Gürpınar formation, the most susceptible, is located along the coast and valley slopes where steep slopes dominate. Although the average slope angle is between 5 and 25 degrees, the steepest slopes are in limited areas along the coast and streams with the angle of greater than 25°. The steepest slopes are situated on the western coast in this formation. Thus, the Gürpınar formation is in an area that is more prone to landslides because of slope angle (Figure 36).

There is not enough data about the angles of individual landslides in the study area. However the distributio of landslides has been taken into account and the Digital Elevation Model has been used to determine the susceptible slope angles in the study area. By using this kind of data, three slope classes (0 - 5°; 5 - 25°; and > 25°) have been analyzed according to their susceptibilities to landslide (Figure 36).

The average slope angle for landslides is between 5 and 25°. Recent landslides occurred on moderate to steep slopes (15 - 25°), but some are found on gentle slopes at an angle of between 5 and 10°. However the greater slope angles are mostly related to the old landslides. The old landslides have created steep scarps that are greater than 25° on the upper parts of the slopes. The 5° is the minimum slope angle for landslide, so that there is no landslide activity on places where slope angle lower than 5°.

The types of landslide change according to the slope angle and lithologic structures in the study area. Rock falls can only be seen on the steep cliffs in the western coast of the Gürpınar. Soil flow, creep and mostly rotational slides can be seen where slope angles are between 5 – 25°.

All coastal zone and valley slopes are susceptible to landslide according to the slope angles. In particular, the valley slopes of the Kavaklı stream are steep as much as slopes of coastal zone. However there is no important landslide activity on these valley slopes. This result show that for entire study area the steepest slopes are not necessarily the most prone to landsliding and suggest other factors influence slope stability.

## 4.4 HYDROLOGICAL FACTORS

Ground-water conditions, soil moisture, the permeabilities of the formations, and drainage characteristics play a key role in affecting slope failure. Although these factors are under the control of the climatic, geologic and geomorphologic conditions, the effects of water on landslides are taken into account in this part of the chapter.

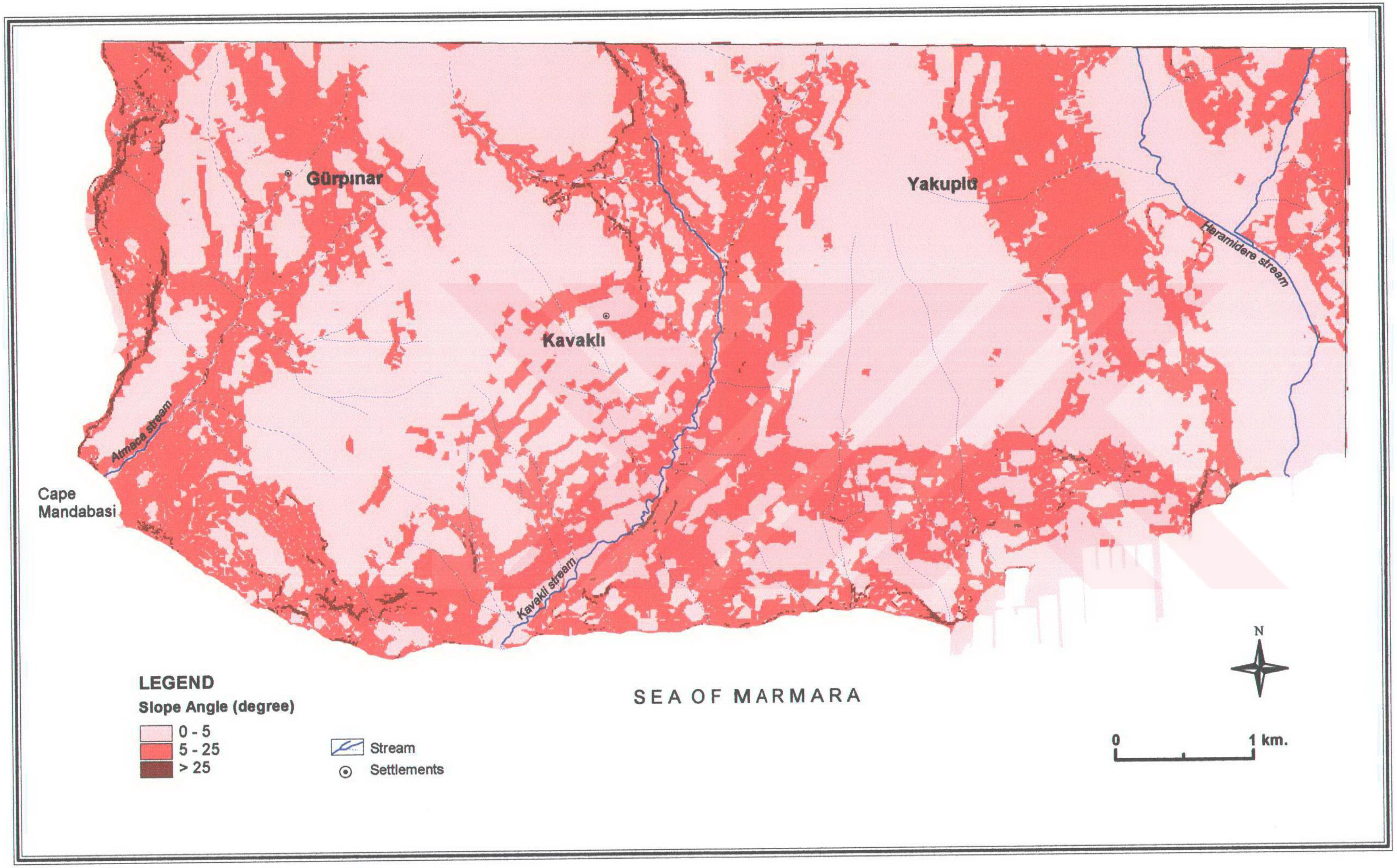


Figure 36: Slope ranges according to their susceptibilities to landslide.

Groundwater is the major hydrologic agent of landslides, although other hydrologic agents are occasionally important. The groundwater level changes not only from formation to formation but also from season to season in the study area. It increases in the rainy season from October to April, causing landslides especially on slopes characterized by unconsolidated clay, marl, sand and silt units. As rain continues to fall, the water table, the point at which the ground below is completely saturated with water, moves toward the soil surface. While water fills previously empty pore spaces and fractures, it reduces the shear strength of the materials by loading, adding to the total mass that is subjected to the force of gravity. On the other hand water also weakens slope materials by chemical weathering. When the unconsolidated materials are completely saturated they become very susceptible to landslide and move downward. These conditions caused many landslides on the coastal zone of the area especially in the Gürpınar Formation.

Excess ground water in the area of contact between susceptible units and underlying materials can lubricate this contact and thus promote failure by creating a slip plane. This condition has caused landslide on the slopes where the permeable sand and pebble units of the Çukurçeşme formation exist on the impermeable clay layers of the Gürpınar Formation.

The amount of soil moisture is very important for the stability of the unconsolidated materials. In small amounts, water content between the grains of sand or silt can actually increase the strength of those materials.

Because in pore spaces that are not completely filled with water, the thin water film actually makes the particles cohesive. However as the ground is saturated during the heavy rain, the large amount of water keeps particles apart from each other and reduces the shear strength of the unconsolidated materials. This condition of the ground is very susceptible to landslide on the slopes in the coastal zone of the study area.

**Figure 37:** Damaged buildings on the collapsed parts of the landslide in the western coast of the study area.

The permeability of the formations is also affected on the landslide. Gürpınar and Güngören formations are generally impermeable due to their clay minerals. However the sand and pebble units of the Çukurçeşme Formation and the limestone of the Bakırköy formation are generally regarded as permeable.

The drainage characteristics of the ground play a very important in the susceptibility of the slopes. Nearly all landslides have taken place where there is no proper drainage. That is why the water remains on the soil and causes the landslide. The importance of the proper drainage can be easily understood by looking at the valley slopes of the streams. The slope angle and geologic structure of the valley slopes of the Atmaca and Kavaklı rivers are slightly the same as the slopes in the coastal zone. However proper drainage conditions do not allow water to remain in the soil in these slopes and this is an advantage of valley slopes to landslide if they compare with the slope of coastal zone.

**Figure 38:** Tilted buildings in the southern part of Gürpınar.

## 4.5 CLIMATIC FACTORS

The amount of rainfall, its duration and the temperature are the main climatic factors that affects the timing of landslide in the study area. The time between October and March is the rainy season. The temperature is also low during these months. Because of the rainfall and low evapotranspiration rate, the ground is always saturated with water and vulnerable to landslide on slopes composed of unconsolidated materials. That is why almost all landslides take place during rainy month especially from December to March. Within these months, landslides are often associated with heavy or persistant rain that saturated the ground. No landslide was observed during the summer.

## 4.6 SEISMIC FACTORS

Tectonic activities affected old landslide in the study area. Some fault lines that are not active at present were thought to have triggered the landslide on the upper part of the slopes. Although it requires detailed investigation to find out the existence of these fault lines, some close counter lines in the topographic map can be regard as fault lines. However it is not clear and requires detailed study.

One of the major hazards of earthquakes is the threat of landslides. Vibrations from earthquakes can trigger landslides as friction is reduced in unconsolidated materials when seismic waves passing through in. However no landslide has been documented due to earthquake in the study area.

## 4.7 ANTHROPOGENIC FACTORS

Apart from the physical characteristics of the study area, some human activities can either be triggering mechanisms or causal factors depending on the other slope conditions. The most important human activities that increase the risk of landslide are;

1- Removal of vegetation

2- Oversteepening of slope for buildings and roads

3- Adding weight to slope by buildings

4- Adding water through pipe leakage and irrigation

**Figure 39:** New villas have been building on the susceptible slopes in the southern part of the study area.

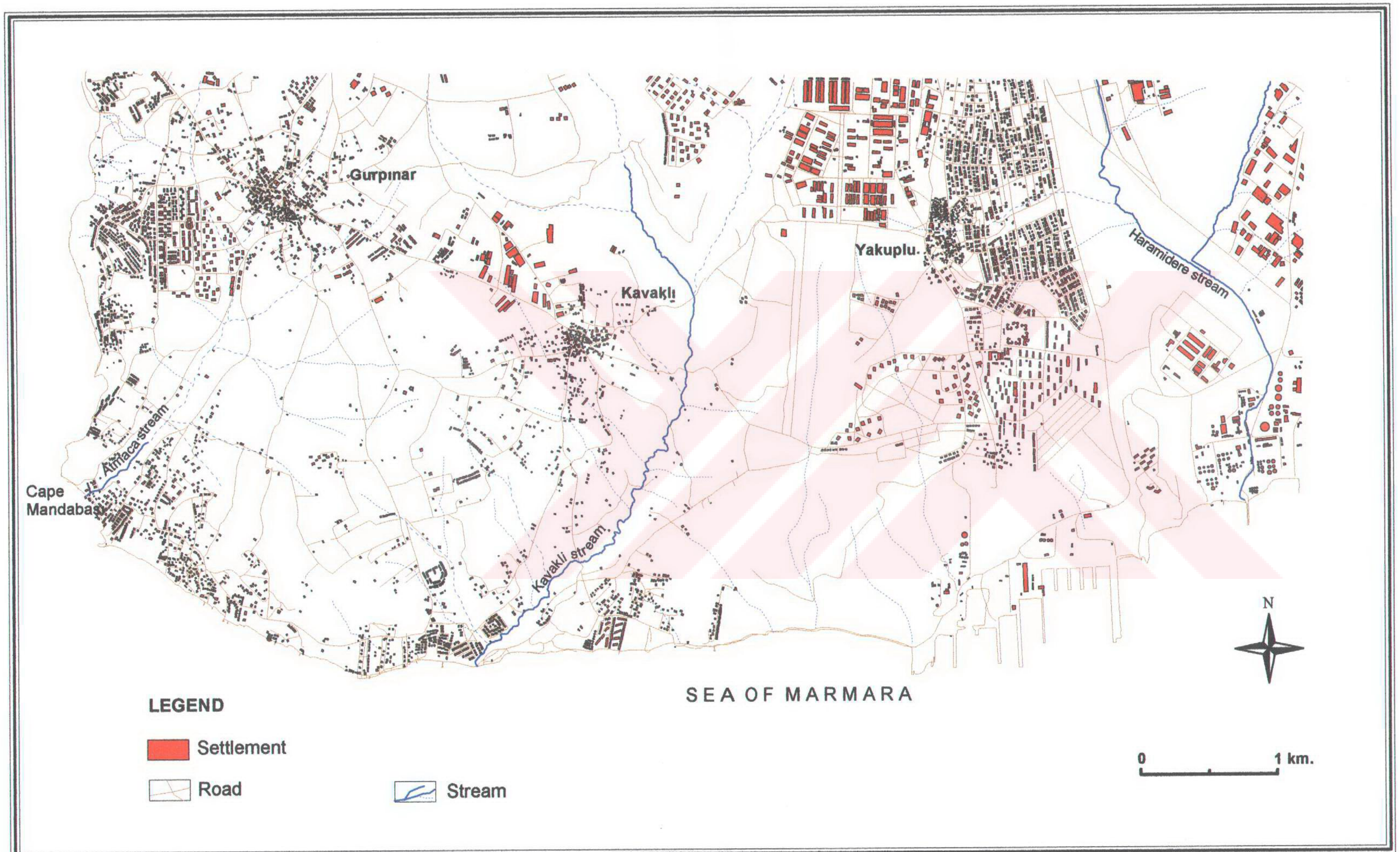


Figure 40: Expansion areas of the settlements in the study area. (1996)

Decrease in vegetation reduces resisting forces and increases pore water pressure. Plant roots can provide a strong interlocking network to hold unconsolidated materials together and prevent flow. Furthermore, plants are very effective at removing water from the soil by evapotranspiration. However the vegetation cover of the study area has been totally cleared by prolonged human impact due to gaining land for agriculture and constructions. That is why the ground of the study area was deprived of these supporting impacts of vegetation cover against landslide.

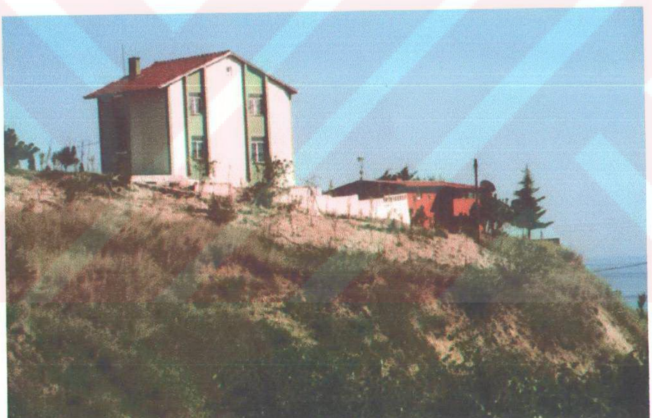

**Figure 41:** Watering tree may increases the landslide risk of the slope.

Urbanization also has an effect on slope stability as the study area is under very dense constructions (Figure 40). Many homes and villas have been built even on the slopes that are susceptible to landslide (Figure 42, 44). Undercutting of the slope by human construction activities disturbs the equilibrium of stable slopes and causes them to fail. The addition of large amounts of fill, the construction of a building or other structure, or an unusual increase in water from artificial alteration of drainage patterns trigger a landslide in the study area (Figure 39). Even some wrong preventive precautions facilitate landslides (Figure 41). People generally prefer to build retaining wall and plant some trees on the slopes. But most of them do not work because they are not done properly (Figure 34, 45). In particular, when people plant trees they always water the ground to help the trees grow fast. However this wrong method also facilitates landslide, as it overburdens the slope.

## 4.8 CONCLUSION

Due to the geological and geomorphological features, landslides are common in the study area (Figure 34, 35). All landslides are caused by a number of factors based on the interaction of geology, geomorphology, hydrology, climate, and anthropogenic activities. Of these causative factors, the most important one is the presence of a thick unconsolidated deposit consisting of sand, pebbles, clay, silt and marl. Slope angle is the second important causative factor. The unconsolidated materials tend to slide where slope angle and hydrologic conditions are susceptible to landslide. Bad drainage characteristics determine the susceptibility of the slopes that have similar geologic and geomorphologic features. Climatic conditions play an important role in the timing and intensity of landslides in the study area. As rainfall is an important trigger for landslides, the highest number of landslide events occurs during the rainy months between October and March. With all these causative factors some anthropogenic activities such as oversteepening of slope and adding weight to slope for building, also affect the slope stability by disturbing the equilibrium of stable slopes. Even some wrong precautionary measures can also cause the landslide in the study area.

# CHAPTER 5

# LANDSLIDE HAZARD ZONATION

## 5.1 INTRODUCTION

Landslide hazard means the probability of occurrence within a specified period of time and within a given area (Carrara at al.,1995). Hazard is a process and it is very difficult to map a process which has not yet occurred. However, landslide hazard map may be defined as a technique of classifying an area into zones of relative degrees of potential hazards by ranking of various causative factors operative in a given area, based on their influence in initiation of landslides. Landslide Hazard Mapping is stated to be undertaken with respect to 4 key properties, magnitude, location, frequency and time. Under the present study the main emphasis was given on the location of landslides and an attempt has been made to prepare a landslide hazard zonation map based on the synthesization of data acquired from various geo-environmental thematic maps. By extending the combinations of factors including distribution of past landslide, susceptible geologic units, slope steepness, and bad drainage characteristics landslide hazard map was produced over the entire study area (Figure 43). The map classified into three zones icluding low, medium, and high hazardous zones.

In this map the Gürpınar formation, most susceptible to landslide, have been mostly indicated as high hazardous zone on the slopes whose angle is greater than 5°. However, the boundaries between Çukurçeşme and Gürpınar formations have also shown within the high hazardous zone on the slopes greater than 5°. Because many landslides have been taking place on these boundaries where the sand and pebble deposits of the Çukurçeşme formation exist on the clayey layers of the Gürpınar formations.

The remaining areas whose slope angle is lower than 5° within the Gürpınar formation and the areas whose slope angle greater than 5° in the Çukurçeşme and Güngören formations have been indicated into the moderate hazard zone. The low hazard zone corresponds with Bakırköy formation that is characterized by limestone. Bakırköy formation extends on top of the study area whose slope angle is generally lower than 5°. Apart from this formation, the alluvion valley floors of the Haramidere, Kavaklı, and Atmaca streams have also been shown within the low hazard zone as their valley floors have the lowest slope angle within the entire study area. Although it is impossible to see a landslide on, these areas are not suitable places for constructions due to liquefaction and flood risks.

## 5.2 LOW HAZARD ZONE

The areas where Bakırköy formation and alluvium extend on with low slope steepness (slope angle less than 5) have been indicated as low hazard zones. In these areas no destructive phenomena are expected to occur within the coming years, given that the land use situation remains the same.

Inadequate construction of infrastructure or buildings may lead to problems, however.

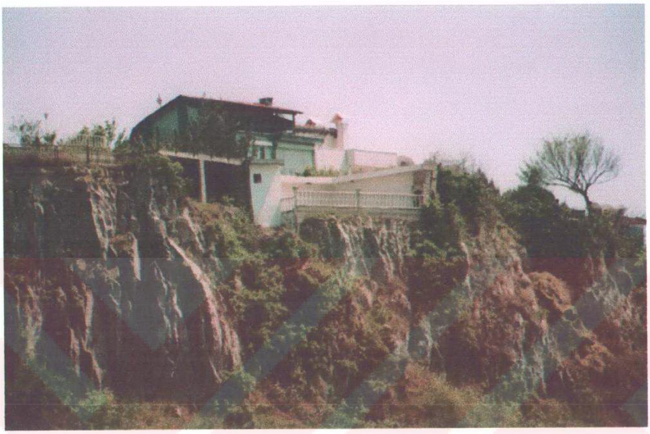

**Figure 42:** Building was built on the high hazardous area.

Because of the limestone and less slope steepness Bakırköy formation is the less susceptible to landslide. Apart from the Bakırköy formaation, alluvion areas also were showed as low hazardous zone because the slope angle is very low between 1 and 2°. However alluvion valley floors are not good places to construction because of the some other problems such as liquefaction and flood.

## 5.3 MODERATE HAZARD ZONE

In Gürpınar formation, the areas where slope angle is higher than 5° and the areas where Çukurçeşme and Güngören formations extend on, have been indicated as moderate hazard zone in the map. In these areas there is no landslide but there is a moderate probability that destructive phenomens will ocur within the coming years, that may damage infrastructure or buildings. Any changes on slope steepness, precipitation, drainage characteristics and landuse because of both human intervention and natural phenomenon increase the probability of landslide in that zones.

## 5.4 HIGH HAZARD ZONE

The area where slope angle is greater than 5° in Gürpınar formation and the boundaries betwenn Gürpınar and Çukurçeşme formations have been indicated as high hazardous zone. In these areas many landslides took place and there is a high probability that destructive phenomena will also occur within the coming years. These are expected to damage infracture or buildings considerably. Because there are already many damage on the buildings and roads, the area needs urgent attention in the form of mitigatory measures. It is advised not to construct new infrastructure or buildings, or at least only after detailed study in this high hazardous zone.

## 5.5 CONCLUSION

The landslide hazard zonation map for the study area covering 42 square kilometers. In terms of aerial distribution, the high hazardous areas are only 11 square kilometers making 27 % of the total area. The moderate hazardous zone covers 16 sq. km forming 38 % of the study area. The low hazardous zone is also covering 15 sq. km making 35 % of the study area.

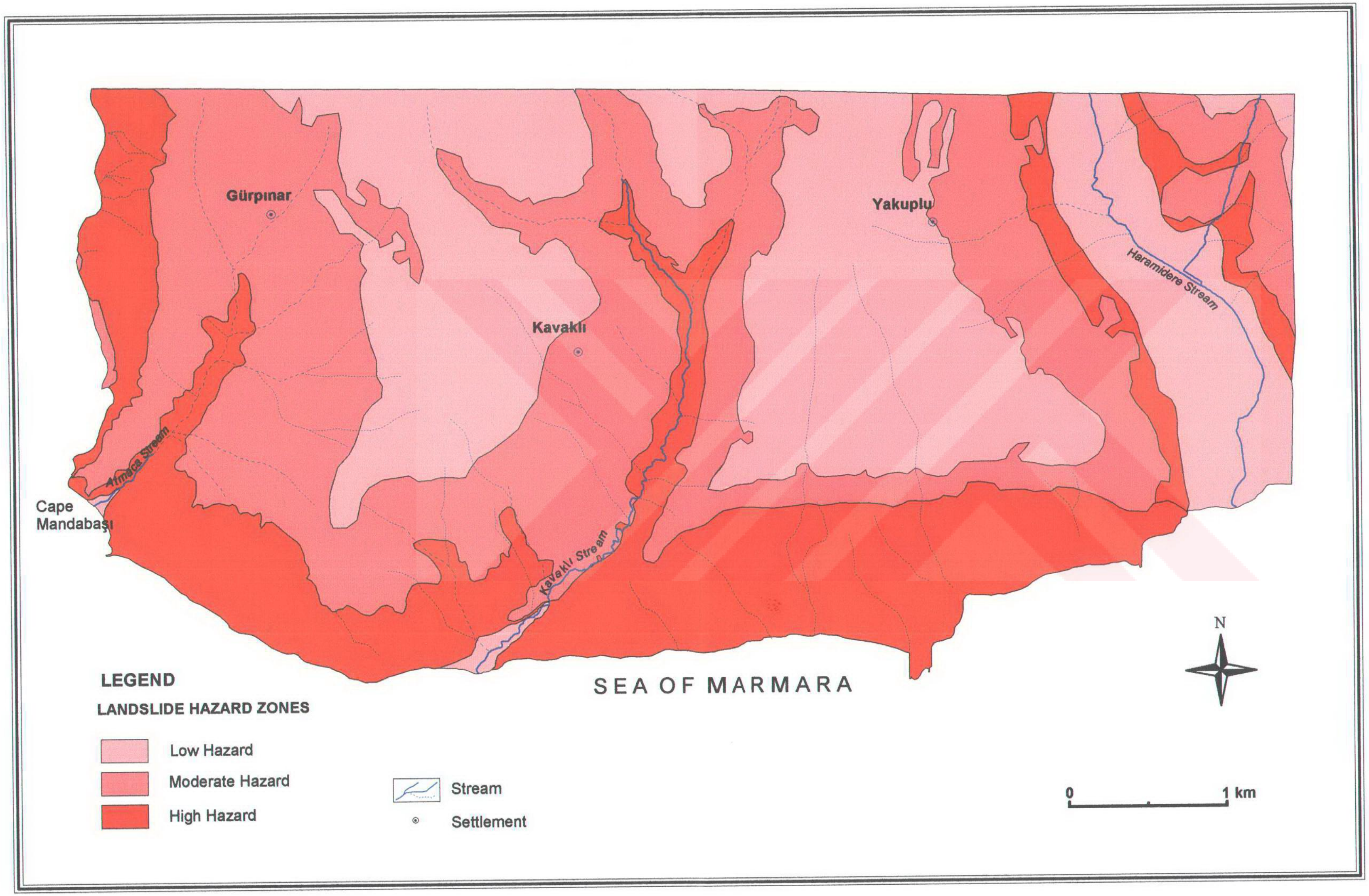


Figure 43: Landslide hazard map of the study area

**Figure 44:** New villas have been constructed on the susceptible slopes in the western coast of Gürpınar.

**Figure 45:** Retaining walls were built uncorrectly

The hazard zonation map of the study area indicates that the most susceptible areas are confined mainly to the coastal zone and valley slopes are characterized by Gürpınar formation where slope angle is higher than 5 degrees. Although the Gürpınar formation regarded susceptible, the lithologic units and also their susceptibilities change from place to place in this formation. For example on the slopes of the Kavaklı and Atmaca streams there is no landslide activity even they also characterized by Gürpınar formation and their slope angle is higher than 5 degrees. This condition is the same for the other geologic formations. Their lithologic units also change from place to place. Because of that, prior to any construction or plannig, a detailed geologic investigations must be done in the all hazardous zones.

# CHAPTER 6

# CONCLUSION

Landslides are a very severe problem in the eastern part of the Buyukçekmece lake along the coast due to geological and geomorphological features. Especially the geological characteristics of the area are very susceptible to landslides. The area is generally characterized by thick unconsolidated deposit consisting of sand, pebbles, clay, silt and marl. All these materials have deposited by marine, lake and fluvial environments, they were divided into groups of formations according to their ages and main lithologic units. As it is mostly characterized by clay, silt deposits, Gürpınar formation is the most susceptible formation to landslides. That is why landslides have been taking place mostly on this formation which is situated along the coast. Clay layers are a very important factor causing landslides not only in the Gürpınar formation but also in other formations.

Apart from the geologic factors, some geomorphologic features of the area are also important for landslides. In particular wave erosion plays a very important role in disrupting the balance of the slopes. Because the slope materials are less cohesive and unconsolidated (sand, sandstone, clay, marl), they lose their balance easily and slide down. Slope angle is the other geomorphologic factor that determines where landslides occur. Landslides generally occur on slopes with an angle between 5 and 25°. There are no any landslides on the ground where slope angle is lower than 5°.

Within hydrologic conditions, soil moisture and bad drainage are important factors affecting landslides. One of the general characteristics of the landslide areas is that they have bad drainage. However, climatic conditions generally affect the timing and intensity of landslide in the study area. Because of the increase of winter precipitation, all landslides take place in the rainy season between October and March.

In the study area, the most common type of landslide is the rotational slide. They can be seen on the both western and southern coast of the study area. The other types of landslide including soil flow, rock fall and creep can only be seen along the coast in the western Gürpınar. The most important striking point of the distribution of the landslide is that all landslides have taken place on the coastal zone. This condition is mostly related to geomorphologic evolution of the coastal zone and lithologic differences even within the same formation. The general characteristic of the lithologic units and their susceptibilities differ from place to place in the same formations.

The occurrence of the landslide has also been affected by human activities in the study area. The landuse is changing rapidly and many new homes and factories are being built. Until 10-15 years ago, the land was mostly used for agricultural puproses. After that time factories, buildings, and villas have started to be built and have increased rapidly. The upper part of the study area, characterized by limestone, has been used to build long buildings. Although it is most susceptible to landslide, the coastal zone has been chosen for building villas because of its attractive views. However, many villas and roads have been damaged by landslide especially in the western and southern coast of Gürpınar. As most of them were built on the collapsed part of old landslides. The most susceptible landslide areas are still used as residential areas and new villas continue to be built on these coastol zones.

To prevent landslides, some precautions have been taken along the coastal zone such as building retaining wall and planting trees. However many of them are not enough to prevent landslide because they are not done properly. Building homes and roads cause landslides by disrupting the slope balance. Oversteepening the slope and adding weight to slope for buildings and roads are additional reasons that trigger landslides.

The study area has been divided into three hazardous zones including high, moderate and low hazard zones, according to the distribution of past landslide, susceptible geologic units, slope steepness, and bad drainage conditions. The high hazard area covers 11 square kilometers making 27 % of the total area. The moderate is 16 and low hazardous zone is 15 square kilometers. The high hazardous zone extend along the coastal zone and there are many buildings and villas have been damaged in that zones.

The social and economic life is being affected by landslide especially in the coastal zone of the study area on a large scale (Figure 37, 38). The most important reason of damaged buildings and roads is that wrong places have been chosen to build homes and villas. In order to stop or reduce the loss of property, first of all detailed geologic, geomorphologic and hydrologic investigations must be done properly before any constructions as susceptibilities of the ground can change even over short distances. According to this study, the following recommendations are submitted for preventing landslides and reducing the losses:

1- The wave erosion must be stopped by building breakwater and filling the sea water in front of the western and southern coasts of Gürpınar. Nobody should be allowed to take sand from the sea near the coast because they reactivate slope movement.

2- No buildings or infrastructures should be built on the landslide areas especially on the collapsed masses of old landslide. Because these areas will most likely move again and create damage for buildings and roads.

3- Surface water should be deviated and not be allowed to infiltrate in to the ground on the slopes in the coastal zone of the study area. Horizontal drains and drainage galleries can be made for the purpose. The groundwater level must be controlled by being decreased its level.

4- Slope balance should not be disrupted by excavation and building home especially on where slope angle is greater than 5 degrees. If it is necessery to build a home, essential precautions must be taken such as retaining walls.

5- Active landslide areas must be afforested by a kind of trees that have long root systems. However, irrigation should be done carefully otherwise irrigation facilitates landslides on susceptible slopes.

# BIBLIOGRAPHY


Akartuna, M., (1953), "Çatalca Karacaköy Bölgesinin Jeolojisi", *İstanbul Üniv. Fen Fak. Monografileri*, 13: 88.

Ardos, Mehmet, (1994), *Jemorfoloji Sözlüğü*, İst. Ünv. Ed. Fak. Yayınları, İstanbul.

Arıç, C., (1955), Haliç-Küçükçekmece Gölü Bölgesinin Jeolojisi (Doktora Tezi, İ.T.Ü Maden Fak., 1955) *İ.T.Ü Maden Fak Yay.*

Atakan, M., E., (1996), *Küçükçekmece ve Dolayının Çevre Jeolojisi*, Basılmamış Yüksek Lisans Tezi, İst. Ünv. Fen Bil. Enst. Jeoloji Müh. A. D. Genel Jeoloji Programı.

Carrara A., Cardinali M., Guzzetti F., Reichenback P., (1995), "GIS Technology in Mapping Landside Hazard", *Geographical Information Systems in Assessing. Natural Hazards*, p. 135-176, Kluwer Acad. Publ., Dordrecht, The Netherlands.

Çapkın, D., C., (1993), *Avcılar Kavşağı-Haramidere Kavşağı (E5) Bağlantı Yolu Heyelan İncelemesi*, Basılmamış Yüksek Lisans Tezi, İst. Ünv. Fen Bil. Enst. Jeoloji Müh. A. D. Uygulamalı Jeoloji Programı,

Dalgıç, S., (1988), *İstanbul Batısının Yapı Malzemesi Ocaklarının Jeoteknik İncelemesi*, Basılmamış Yüksek Lisans Tezi, İ.Ü. Fen Bil. Enstitüsü.

DeGraff, J.V., (1987), *Landslide Hazard on Dominica, West Indies*. Final Report submitted to the Commonwealth of Dominica, W.I. and department of Regional Development, Organization of American States, Washington, D.C., 25pp.

Efe, Recep, (2001), *Gölcük ve Düzce Depremleri*, Fatih Üniversitesi Yay., İstanbul.

Ercan, A., (1990), "Gürpınar Beldesi Yermühendislik Projesi", Yeraltı Aramacılık Billimsel Araştırma Kuruluşu, cilt 1, 2, Istanbul.

Erinç, S., (1980), "Jeoekoloji Açısından İstanbul Yöresi", *İst. Ünv. Coğrafya Enst. Dergisi*, sayı 23, İstanbul.

Ergin, K., Güçlü, U., Uz, Z., (1967), *Türkiye ve Civarının Deprem Kataloğu (M.S. 11-1964)*, İ.T.Ü. Maden Fak. Arz Fiziği Enstitüsü yayını, No:24, İstanbul.

Erol, O., Altın, B. N., (1991), "Binkılıç-Karacaköy Dolayının Jeomorfolojisi, Istranca Dağları Güneydoğusu, Trakya", *Atatürk Kültür, Dil ve Tarih Yüksek Kurumu Coğrafya Araştırmaları*, sayı 3.

Gürpınar Belediyesi, (2000), "İmar Planı Revizyonuna Esas Jeolojik ve Jeoteknik Etüt Raporu", TEM Jeoteknik Mühendislik ltd. şti, Ankara.

Neslioğlu, M., (1996), *Küçükçekmece Gölü Havzası Heyelanları*, Basılmamış Yüksek Lisans Tezi, İst. Ünv. Sos. Bil. Enst. Türkiye Coğrafyası A. D.

Rogers, J.J.W., Feiss, P.G., (1998), *People and the Earth*, Cambridge University Press, 350 p.

Sayar, C., (1977), "İstanbul Yeni İskan Yöreleri Geoteknik ve Sismik Etüdü", Cilt I, Büyükçekmece-Küçükçekmece Göller Arası Yöre, B.Ü. Deprem Mühendisliği Araştırma Enstitüsü raporu, 14-27.

Sönmez, N., (1964), "Çatalca (Trakya) Civarı Neojen'inden Congeria'lı Serinin Ostracod'larla bulunan yeni yaşı hakkında", *M.T.A. Der.*, 63, s. 43-53.

Şen, Ş., (1994), *Çekmece Gölleri Arasındaki Bölgenin Jeoloji ve Sedimanter Özellikleri*, Basılmamış Yüksek Lisans Tezi, İst. Ünv. Fen Bil. Enst. Jeoloji Müh. A. D. Genel Jeoloji Programı.

Tezcan, S., (1977), "İstanbul Yeni İskan Yöreleri Geoteknik ve Geodinamik Etüdü", Boğaziçi Üniv., İstanbul Belediyesi.

Ülkümen, N., (1960), "Trakya ve Çanakkale Mıntıkalarında Bulunan Neojen Balıklı Formasyonları Hakkında", *İst. Ünv. Fen Fak. Monografileri*, Sayı 16.

Vardar, A. T., (1978), *Long-Term Stability Analysis of Natural Slopes in Cekmece Region*, Unpublished M. Sc. Thesis, Bogazici University, Civil Engineering Department.

Varnes, D.J., (1978), *Slope movement and types and process. In Landslides: Analysis and Control*, Edited by R. L. Schuster and R. J. Krizek. Transportation Research Board, National Academy of Science, Washington, Special Report 176: 11-33

Yakuplu Belediyesi, (2000),"İstanbul-Büyükçekmece Yakuplu Belediye Alanının Yerleşim (kent) Jeoljisi Açısından Yerleşime Uygunluk Amaçlı Mühendislik Jeolojisi ve Jeoteknik Araştırma Projesi", Çağıl Mühendislik Müşavirlik San. ve Tic. Ltd. Şti., İstanbul.

Zarif, İ. H., (1996), *Küçükçekmece-Büyükçekmece Gölleri Arasındaki Alanın Yamaç Stabilitesi*, Basılmamış Doktora Tezi, İst. Ünv. Fen Bil. Enst. Jeoloji Müh. A. D. Uygulamalı Jeoloji Programı.