IJEGEO International Journal of Environment and Geoinformatics 2(2), 1-15 (2015)

Using Digital Elevation Model and Remotely Sensed Data in Determining the Geomorphological and Morphometric Features: Gaziköy-Saros Region, Northwestern Turkey

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Received 24 Feb 2015
Accepted 01 Jul 2015

Abstract

The Gaziköy–Saros region is located in the western part of the North Anatolian Fault Zone (NAFZ), Turkey, which is one of the major active strike-slip faults recognized in the world. The morphological characteristics of this region were shaped by the nature of the fault. By means of combination techniques of remotely sensed and Digital Elevation Model (DEM) data a 3-D (three-dimensional) model can be generated. Afterwards, the produced 3-D model of the study region can be effectively used in examining the aforesaid features and various other associated analyses. In this study, the DEM data is obtained by digitizing 1/25,000 scaled maps and Landsat 5 TM data. A novel method is used to define the region′s geomorphology through merged digital elevation model (DEM) and remotely sensed data. The morphometric analyses of our study identified five erosion surfaces and indicated that the active faults contributed to the morphological development of the study area. Moreover, another hypothesis derived from our study is that the formation of the elevated areas was caused by fault compressional force components and formation′s linear features were produced by the strike-slips.

Keywords: Remote sensing, digital elevation model, erosion surfaces, morphology

Introduction

One of the goals of earth sciences is to understand the factors contributing to the formation of landforms. On the basis of the known factors forming and controlling the landforms for a given study area, an approach can be developed for the unknown ones. For instance, development of different landforms on a rock with same lithology, under the same climatic conditions may be attributed to structural control. Descriptive examples of this subject are the morphotectonic studies. Young or active faults can easily be identified benefiting from their typical signatures on the landforms.

Both remotely sensed data and aerial photographs offer valuable contribution to the morphological studies (Cooke and Doornkamp, 1990). Remote sensing data have advantages such as providing information for large areas, multi-spectral recordability, ability to map inaccessible areas and multi-purpose processing of the obtained data, etc. Especially, the possibility of multi-spectrally recording the remote sensing data gives image-processing the capability of adding considerable dynamism to such studies (Walsh et al., 1998; Brown et al., 1993; Kaya, 1999). Furthermore, remote sensing technology has the advantage of obtaining up to date digital data through cost-effective and rapidtechniques in comparisionto the conventional in-situ methods (Kaya, 2007; Kaya et al., 2006; Seker et al., 2005; Kaya, et al., 2004; Okay et al., 2004).

In this study, the morphology of Saros-Gaziköy (Saros) area located in the northwestern part of Turkey was analysed through integration of DEM and remote sensing data. The obtained results were compared with some of the previous studies in the same area implemented on 1/ 25,000 scaled standard topographic maps (Altın, 1992; Eldeniz, 1996; Erol, 1979, 1983, Erol and Cetin, 1995). In this study, analysis of the geomorphological surfaces (erosional surfaces and terraces) formed in the course of time was based on slope classification between contour lines.

Erosional surfaces age is based on their time of formation. The slope group analysis was performed using raster DEM data. Furthermore, making use of previous studies, consistent with elevations data five geomorphological surfaces were determined. These are named as DI (Level I, Erosion Surface System), DII (Level II, Erosion Surface System), DIII (Level III, Erosion Surface System), SY (High Terrace Systems) , and SA (High Terrace Systems). With the purpose of investigating the parameters controlling the morphology of the area morphometric analyses were performed in some critical areas.

Study Area

The study area is located in a tectonically active region lying in the Marmara region, northwest of Turkey, , where the western tip of the North Anatolian Fault stretches out of Marmara Sea, where it crosses with Gaziköy – Saros segment (Figure 1). The study area covers 15 standard topographic maps with scale of 1 / 25000. Isiklar Mountain (924 m) and Koru Mountain (676 m) are also located in the same area. Kavakderesi stream flows between these two mountains and drains into to the Gulf of Saros (Ertek et al., 2003). The largest flat area in the coverage of the study area is the Evreşe Plain, which is located in the western side of the area, stretching out towards the Gulf of Saros . The southern sections of Işıklar Mountain and parts of upper hills of Koru Mountain have relatively steep slopes (40 % +) (Figure 2, Kaya, 1999). In terms of rock type and climate, there are not major differences in the area. Therefore, we can assume that this active fault is the main controller of the area's morphology. An obvious evidence for faults activity in the area is the earthquake dating 1912 with magnitude of 7,4. Significant signs of tectonics effects on the morphology such as surface ruptures, offsets in the roads and streams, sag ponds and landslides occurred during the earthquake (Tüysüz et al., 1998; Yaltırak, 2002; Rockwell et al., 2002). As the prevalent precipitation of the area is in form of rain showers the earth surface is mainly impermeable, and its erosion is caused by sudden downpour of rain over the slightly sloped hillsides (Dönmez, 1990).

Data Analyses and Method

Overlaid remotely sensed data and digital elevation model

DEM is a representation of the Earth's topographic surface (Summerfield, 2000). In other words, it is the mathematical and numerical description of the surface by means of enough given number of points (X, Y, Z) with known coordinates, defining the appropriate surface fit for the purpose. In the study, the contour lines were digitized with interval of 10 m through standard topographic maps at 1/25000 scale and DEM was formed from these contour lines using the grid method. Bilinear interpolation method was used in Z elevation interpolation.

When used alone DEMs show only the formation of the surface of earth. After DEMs data are combined with remotely sensed data, they reach the capability of representing the formations with real surface characteristics. As the remote sensing data are recorded multi-spectrally, they express features of the earth surface in colours, providing better and detailed visual interpretation facilitiy. At present in a scientific sense, the use of DEM and remote sensing data together contributes, , a great deal to the geological sciences. Moreover, enhanced remote sensing data brought a new contribution to the process of defining the surface features and determining the erosional surfaces when they are used together with digital elevation model (Kaya, 1999). In this study Landsat 5 TM data with spatial resolution of 30 m are used. These data are geometrically rectified by using Ground Control Points (GCP) obtained from standard topographic maps of 1 / 25000 scale and converted into UTM projection system. The two dimensionality nature of remotely sensed data makes it rather difficult to define the boundaries of geomorphological surfaces, and evaluate as well as interpret some of their intrinsic (built-in) characteristics. The 3rd dimension of DEM added new and extremely important information to the science of geomorphology. Moreover, image enhancement techniques of remotely sensed data provide opportunity for higher interpretation and separation of land structures. In this study, as an image enhancement technique principal component analysis (PCA) method was used.

PCA method extracts maximum data information by compressing it with the minimum correlation. Through image enhancement the visual interpretability of the satellite images is dramatically increased compared to the ordinary multi-channel data (Curran, 1985; Lillesand and Kiefer, 1987). As a result of PCA image enhancement technique, the erosional surfaces in the Isiklar Mountain area have been clearly determined (Figure 6).

Slope maps

Slope maps are habitually produced using maps contour lines, where each contour line (isoline) joins points of equal elevation, so the slope gradientdepends on the distance between the contour lines, i.e. the closer two isolines, the steeper is the slope of the earth surface. It is fairly time and labour consuming to work out the distance among the elevation isolines for the delineation of the slopes in the entire study area. Therefore, as the slope maps forms the basis of geomorphological studies, are carried out by working on small areas (Erol, 1993). This poses itself to be an important disadvantage in evaluating and interpreting the entire region. At present, possibility of making such studies through digital data and capability of studying on wider areas with the algorithms set in computer media gained a new dimension to geomorphology. In this study, firstly DEM datum was produced from digitized topographic maps. Next, slope map was then produced for the study area by using DEM. The purpose of all this is to find the slope groups on the entire surface to determine the erosional surfaces and the terraces (plains formed erosionally). In this study, areas with 0 – 5 % slopes were considered to be flat terrains. Slope map was classified and separated into 5 groups (Figure 2) (Erol, 1993).

- 0-5 % Flat terrains (yellow)
- 5-10 % Low slopes (orange)
- 10- 20 % Medial slopes (green)
- 20-40 % Steep terrains (red)
- 40 + % Very steep terrains (cyan)

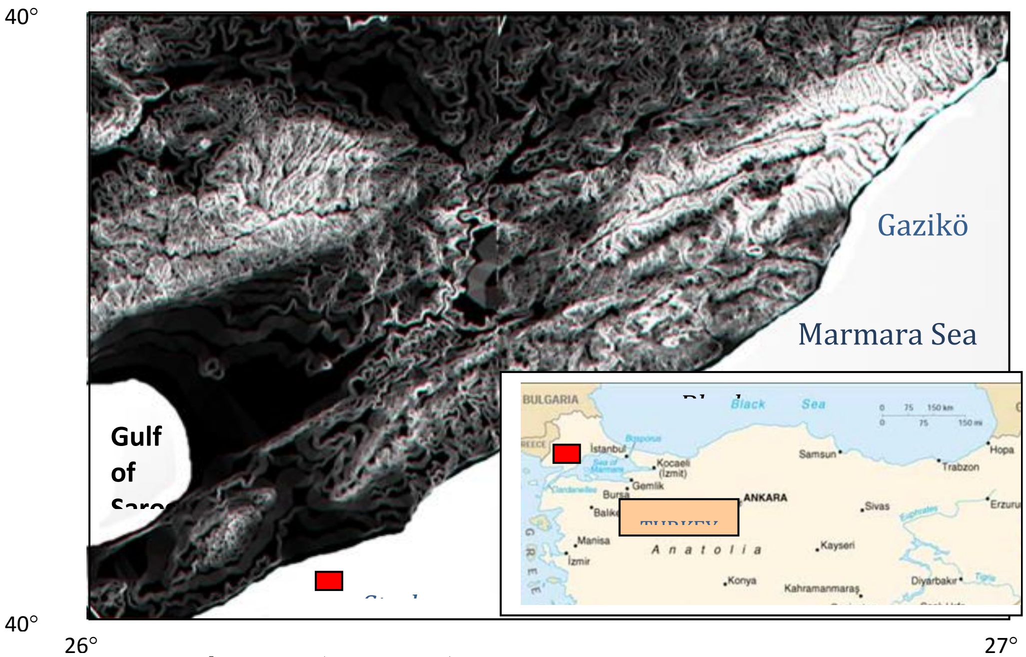


Figure 1: Slope Map (Kaya, 1999).

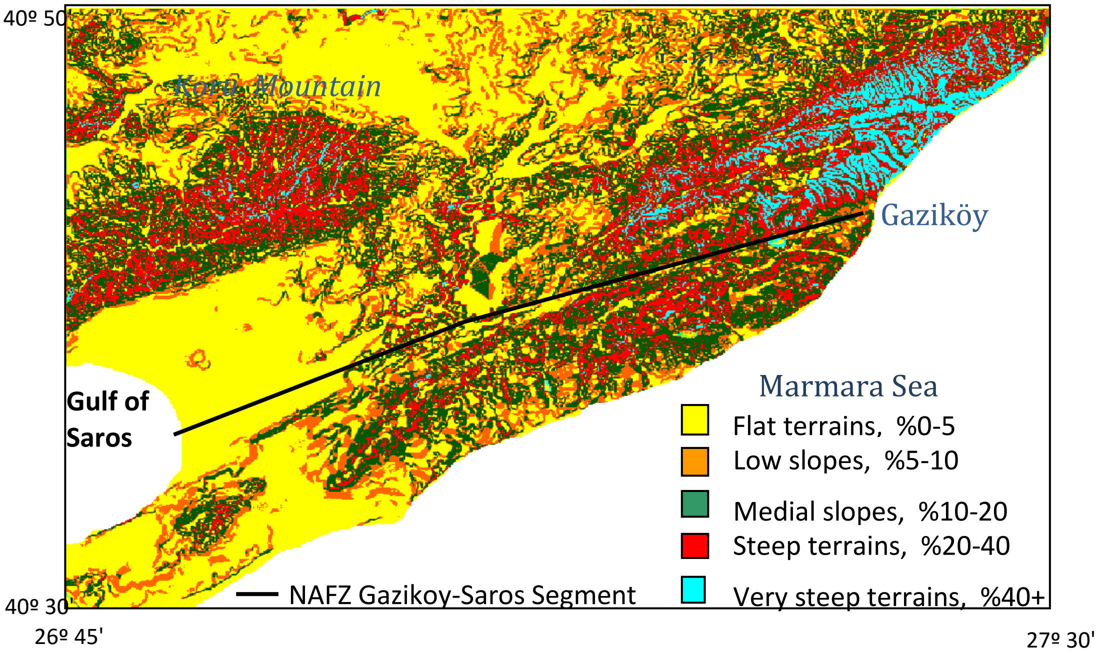


Figure 2: Classified slope map (Kaya, 1999).

Interpretation of Slope Maps

Analysing Erosion Surfaces and Terraces

As mentioned above, the factors controlling the morphology are various. When the study area was analyzed geologically, it was given that that Gaziköy segment of the North Anatolian Fault was located between Gaziköy and Saros Gulf. At the north of Gazikoy segment, Eocene - Oligocene age flysch type sandstone–claystone alternation can be observed, which type of sandstone is prevalent in the Thracian peninsula. In addition, to the south of the faultUpper Miocene age deposits also exist. These are represented by Gazhandere Formation consisting of mudstones, Kirazlı Formation consisting of sandstones, and Alçıtepe Formation consisting of bioclastic limestones (Figure 7, Yaltırak and Alpar, 2002). As it is known, flysch type deposits form rough and irregular land topography due to their impermeable and easily erodible nature. This kind of morphology was not observed in the deposits of Eocene – Oligocene, which is situated in the north of our study area. The dominating steep slope and the presence of thick, solid sandstone stratas (layers) of the unit are possibly the basis for this. Alternatively, the other units, exhibit characteristics of softer and easily erodible topography. The most resistant (sturdy) lithologies of the Miocene units are the limestones of the Alçıtepe Formation (Yaltırak and Alpar, 2002).

In our study area, it is obvious that the structural control of its morphology belongs to the Ganos and its associated faults. By both of the approaches used the field and position data of GPS vectors was found that, this fault was shaped under a compressional regime (Yaltırak, 1996; Tuysuz et al., 1998 ; Yaltırak and Alpar , 2002). When both of the slope map and the digital elevation model are analyzed in the zones surrounded by faults, areas with highly and deeply eroded, demonstrating high slope values are observed. This clearly verifies that these areas were elevated at nearly same geological time as this of the faults. On the other hand, it is essential to emphasize that North Anatolian Fault has been active for the past 3 million years.

The erosional surfaces of the area were determined with analysing the slope map. Developed by Erol the key methodology used in this study, made possible to differentiate the landform generations formed under same morphoclimatic conditions as a result of joint evaluation of the denudational surfaces and their correlating deposits. (Erol, 1979, 1983).

In this method, landform generations were listed and named in a chronological order starting from the oldest to the newest, and from the highest to the lowest (Erol, 1991). The geomorphological researches made on the denudational surfaces on higher places around the study area ascertained that there is full compatibility between the erosional phases and the existing sediments, which are the correlates of these surfaces in the basins (Siyako et al., 1989; Wong et al., 1995).

In the previous geomorphological studies done on the stduy area, the denudational surfaces and their related the terraces, had been grouped according to their time of formation and 7 elevation values, in an order starting from the oldest to the newest one (Table 1). As a reference the flat portions given on the slope map were obtained and used as they were given in the above mentioned previous studies. The remaining landform formations were found separately from the elevation values of the contour lines of the topographic map. For example, for DI erosion surface system, contour lines with corresponding values higher than 460 m were merged with the flat portions ranging with slope values from 0 % to 5 % (Figure 3, Figure 4a). As a result, the remaining components of DI erosion surface were easily identified. The accuracy of the system used was tested benefiting from previously produced geomorphological maps using standard methods (Altın, 1992; Figure 4b). This classical study the refered method was done on a study area from Isıklar Mountain region by using only 2 maps of 1/ 25 000 scale.

Table 1. Landform Generations of Study Area. (Altin, 1992; Erol and Cetin, 1995; Eldeniz, 1996).

LANDFORM GENERATIONS	
SYMBOL	MORPHOCLIMATIC CHARACTERISTICS
DI Erosion Surface System	Lower-Middle Miocene Period Hot-Humid Conditions, Between 460-924 m.
DII Erosion Surface System	Upper Miocene Period Dry-Semi Dry Conditions, Between 260-460 m.
DIII Erosion Surface System	Upper Pliocene Period Subtropical-Humid Conditions, Between140-260 m.
SY High Terrace Systems	Lowest-Middle Pleistocene Period Subtropical-Humid Conditions, Between 60-140 m.
SA Low Terrace Systems	Upper Pleistocene Period Cool-Humid Conditions, Between 0-60 m.

In geological sciences, it is important to evaluate and interpret all accessible aspects of a given formation. Therefore, conventionally produced geomorphological data and digitally produced contour maps are required in analysis over large areas. With the availability of this kind of data, any type of formations representing a given area could be analyzed in a short period of time. In our study the slope map of raster type, and the topographic map of vector type with its contour lines were produced using ArcView commercial software programme. For that, firstly the denudational surfaces were located through the use of the topographic map based on their minimum elevation values and subsequently merged with the slope map. The flat terrains lying among these elevations were given with the same colors of the denudational surfaces defined by Erol. The area given in white color indicate the areas with slopes higher than 5 %. The areas in blue were defined as DI surfaces with elevations varying between 460 m and 920 m. (Figure 3). In Figure 5, the erosional surfaces and terraces were placed according to data given in table 1, and through analysis of the entire study area. In relation to Figure 5, the areas in blue designate the DI erosional surfaces (Lower-Middle Miocene), the areas in red point out DII Erosional surfaces (Upper Miocene), the areas in yellow show DIII Erosional surfaces (Upper Pliocene), the areas in dark green color indicate SY High terraces (Lowest – Middle Pleistocene), and finally the areas in green show SA Low Terraces (Upper Pleistocene).

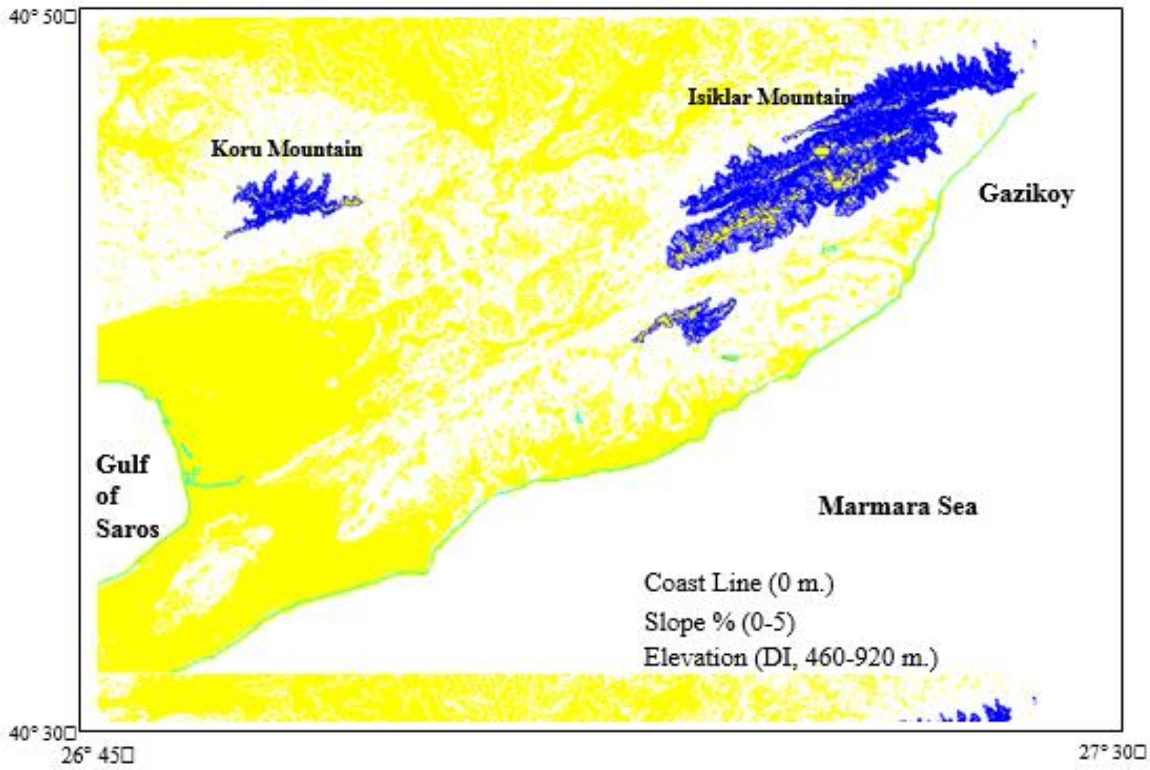


Figure 3: Image queried according to slope and elevation (DI erosional surface, slope 5 %, elevation 460-920 m).

Morphometric Analysis

As mentioned above, our study area is located on the North Anatolian Fault Zone. Part of the fault is lying within the study area, also known as the Ganos fault. As the Ganos fault has a compressional structure it caused the formation of elevated zones in the area. While the main branch of the fault extends between Gaziköy and Saros Gulf, the secondary branches in the north and the south make an angle with the main fault and extend in NW – SE direction. This structure can be observed on the geology map given in Figure 7. In the same Figure 7 the secondary branches are observed to exhibit a thrust nature. When the geology map is compared with the 3D digital elevation model of the study area, it can be observed that these thrusts corresponds to the uplifts in the morphology.

As it is well known, elevations in an area involve deformations of the base level (layer, strata) and accelerated erosion. In that case, erosion surfaces are quickly eroded by the streams, which eventually disintegrate. In mature areas, the uplifted areas are eroded, therefore, in the course of time the area was brought down to the base level; while in young elevations the highly/deeply eroded valleys still continue to disintegrate the erosion surfaces. The most common and useful method in analysing this kind of development is the use of hypsometric curves.

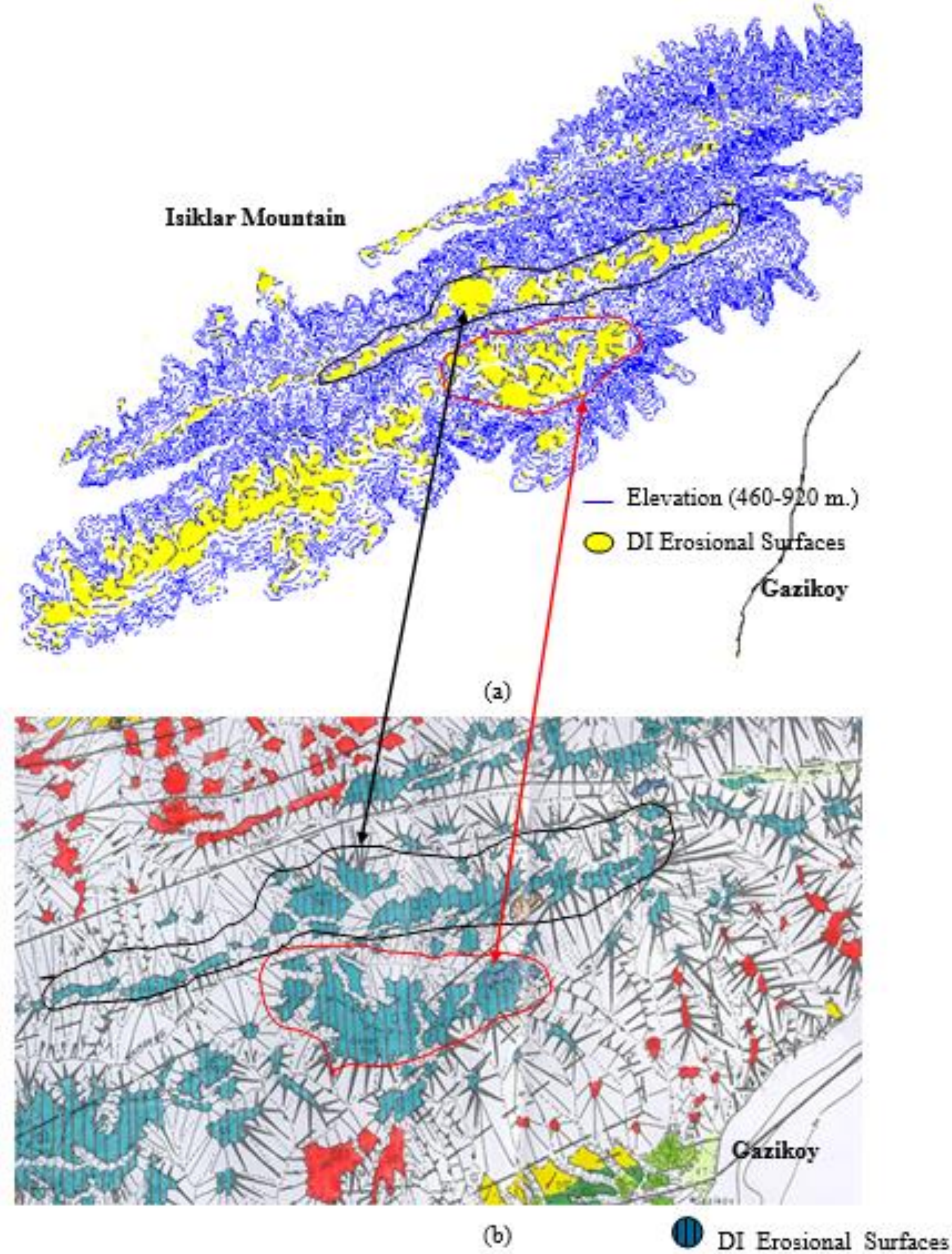


Figure 4: Testing the queried DI surface a) DI erosional surfaces queried according to elevation and slope in Isiklar Mountain region b) DI erosional surface produced by classical method (Altın, 1992).

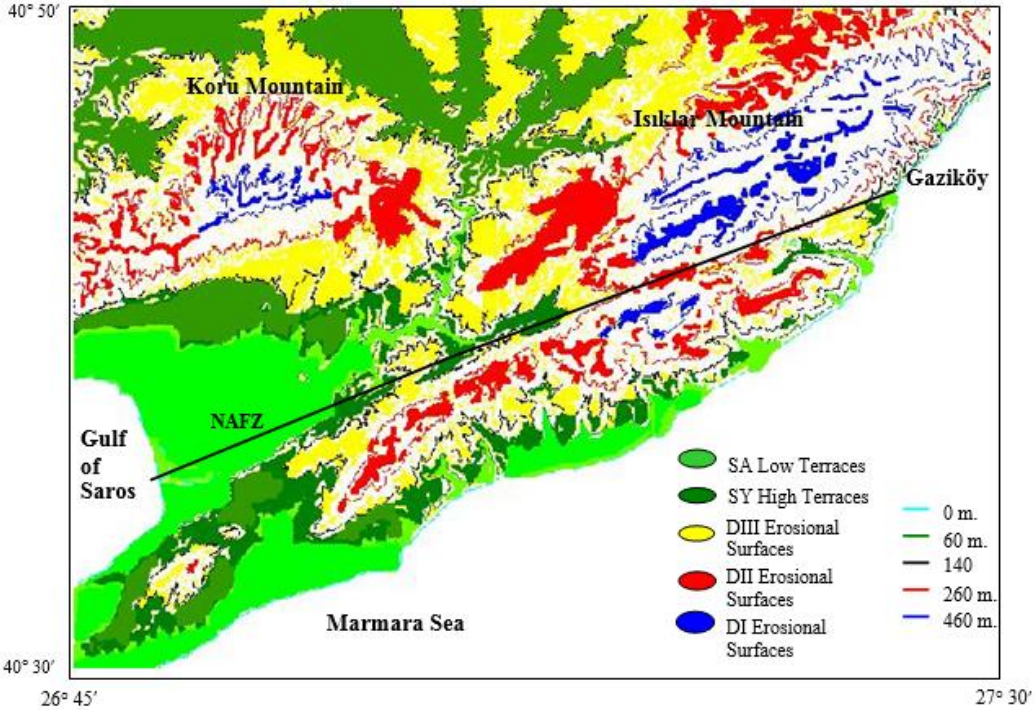


Figure 5: Erosional surfaces and terraces identified in the Study Area.

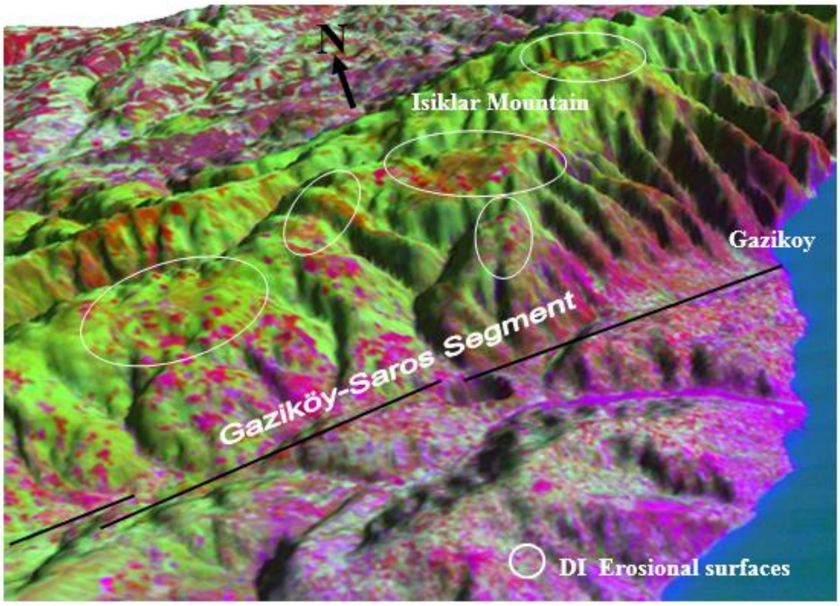


Figure 6: View of Isiklar Mountain Erosional Surfaces with

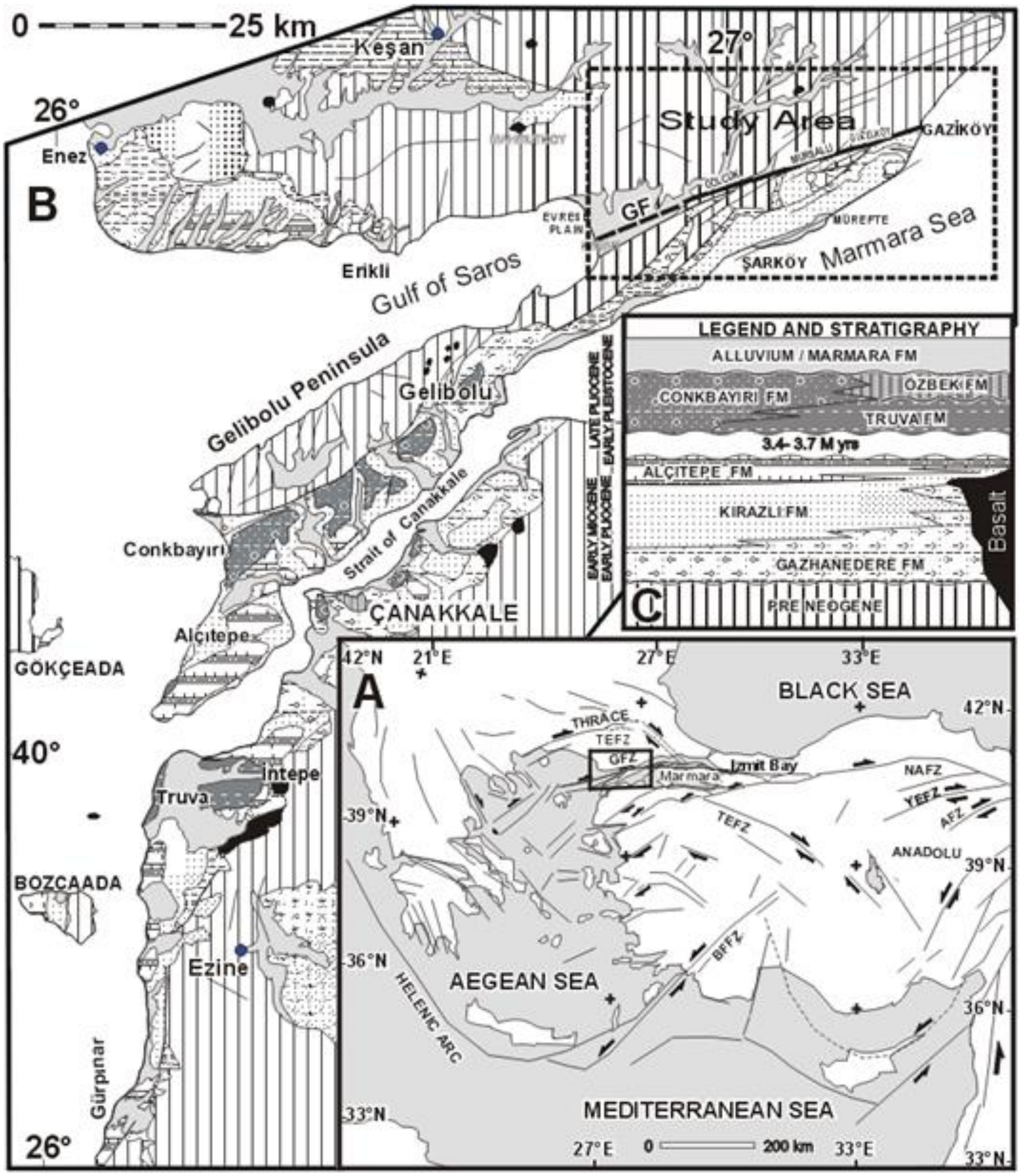


Figure 7: Tectonic setting of the Gaziköy-Saros segment (Yaltırak and Apar 2002).

Table 2. Average Height and Slope of Geological Formation.

Period of Time	Formations	Average Height (m.)	Average Slope
Before Neocene		305	%19.8
Neocene	Gazhanedere FM.	282	%23.8
	Kirazli FM	310	%29.6
	Alcitepe FM.	134	%26.2
Quaternary		34	%8.7
Average		213	%21.62

Hypsometric curve method can be used on different scales from a drainage basin to continental scale. In this study, drainage basins of different sizes located in different areas were used. The selected basins are located almost on the same type of rock. Here the purpose was to remove the differences in the climate and the lithology, and to investigate the tectonic control, which is effective on the morphology of the area. Nonetheless, when the distributions of the elevations in the study area according to the types of rocks were examined, it was observed that the lithology does not have an important effect on the elevation variations. An exception to that is naturally, the alluvium. While the average height of the area is 213 meters, the pre-Neogene units and the Neogene units have similar height of an average of about 300 meters. As Alçıtepe formation, which has about 134 meters of elevation, is seen in small samples with little surface area and this is the reason of its low level of height average (Table 2). Hypsometric curves are as the proportion of an area of the surfaces above and below a certain elevation inside a drainage basin to the total basin area. It follows that, the areas above the obtained hypsometric curve point are the eroded areas while the areas below it indicate the potentially erodable ones. The directional tendency of the curve towards the lower axis is considered to be the indicator of the morphological maturity of the studied area. To reveal the morphological evolution of the study area, hypsometric curves were created in 4 regions (Figure 8). The areas were selected from a single drainage area located on the same-type or similar rock components. The location selection of each area was according to the faults.

The first selected region is lying on the North Anatolian Fault conjunction point of Marmara Sea and main land. . In Gaziköy, where the Koca stream flows into the Marmara Sea and has one main tributary in a generally west direction and many other secondary tributaries merging with the main one, which are stretched out in southeast direction. The main tributary (river/stream bed) extends along the fault line. One of the particular features of this stream is that there are no any tributaries present along south side, which is located in the other block of the fault. As a result, the drainage area exhibits a very high asymmetry as of 13,5 %. While this fact is not geometrically compatible with the turning directions of the stream and its tributaries, it suggests that the present drainage area lying in the south of the fault had occurred in very recent times. Compared with the right lateral movement of the fault, it can be concluded that the southern block clogs the flow of the stream's estuaries, which are prevalent in the northern block. The hypsometric curve in the first area points out a very young structure, which means that the morphology of the area is still developing and the existence of tectonic activities.

The second region was selected resting exactly on the fault, about 10.2 km in west direction from the seashore (Figure 9). In this region the drainage area is almost symmetrical. When the direction of the streams is considered, it is observed that they display turns in both of the blocks in a way so to support the right lateral movement of the fault. The shape of the hypsometric curve reflects a very young morphology. As the fault is of right lateral, there is no obvious asymmetry of the drainage area.

The third region was chosen from the stream basin area falling on the southern slope of the Koru Mountain, which front part is sharply blocked as a result of the vertical layering. In this area the stream originates from the Eocene-Oligocene flysch flows on the alluvium in the Evreşe Plain. In the hypsometric curve, only the section of the stream on the flysch was considered. This curve indicates the presence of a very young morphology. When the hypsometric curve was structured in a way by taking into account the drainage area (Figure 9), the young morhology was observed in the upstream areas, while the mature morphology due to alluvium was noticed in the downstream areas. When all the above mentioned 3 different selected regions were assessed together, it can be said that the location of the area is still young and in a tendency of active uplifting movements. The area is crossed along by a right lateral fault system. However, when the geometry of the fault branches are compared with the GPS vectors (Strauss and Kahle 1997, Mc Clusky et al. 2001), it is seen that GPS vectors make an angle of 13.0˚ with the fault direction. This detail is considered to be the main reason for the uplifting motions of the Işıklar Mountain as also found by Tüysüz et al. (1998). Furthermore, in the maps produced by Yaltırak and Alpar 2002 also the existence of reverse fault and thrusts in the study region were given, too.

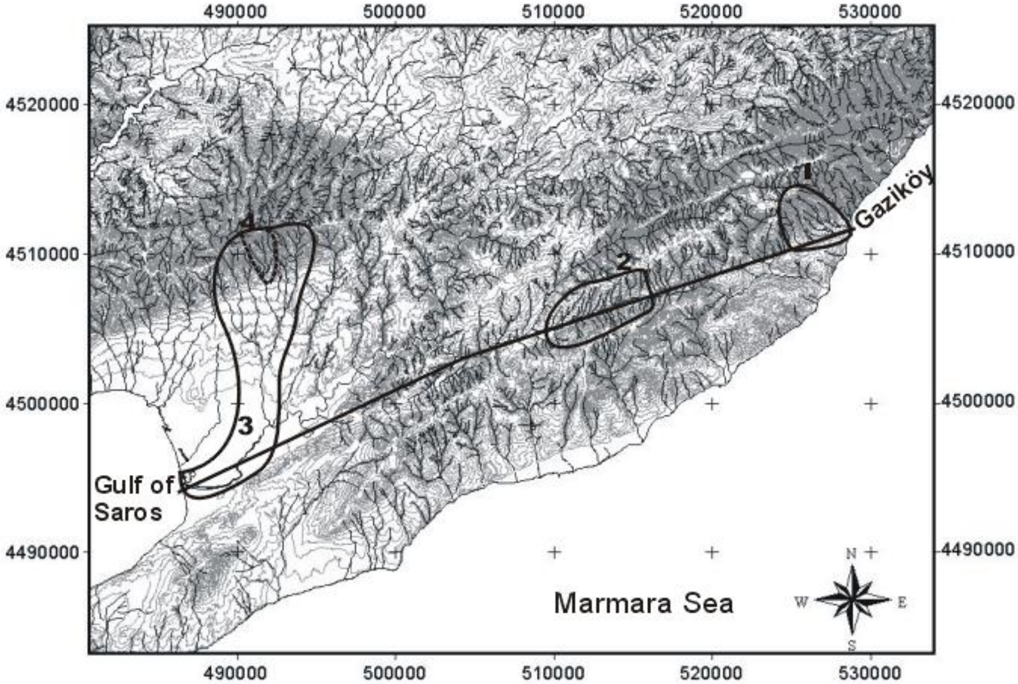
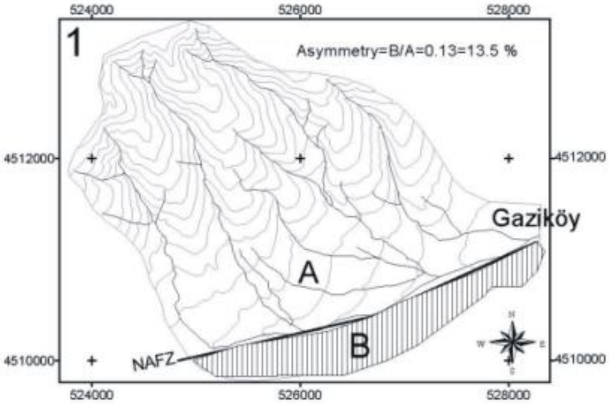
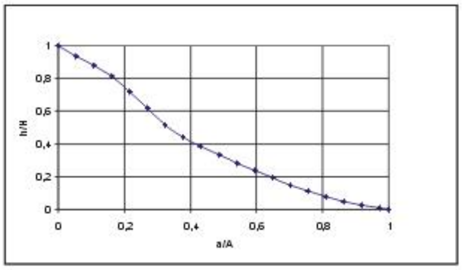
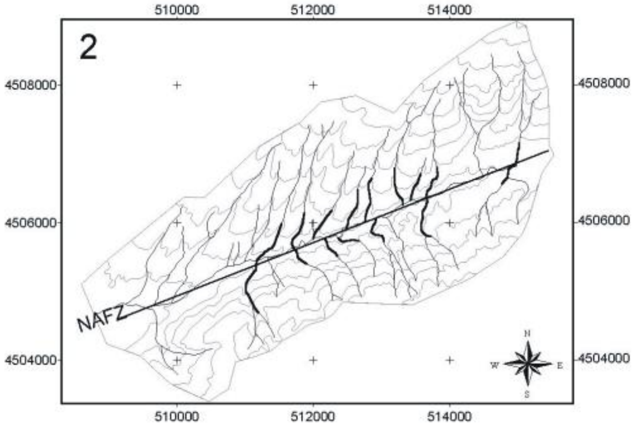


Figure 8: General View of Hypsometric curve.



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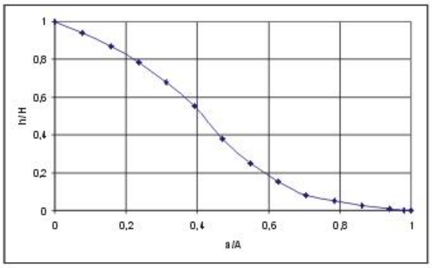
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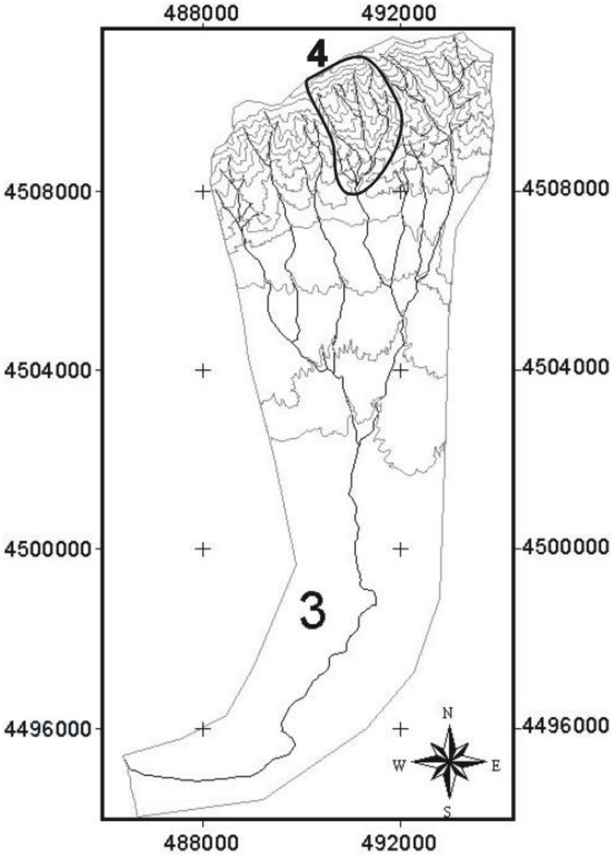
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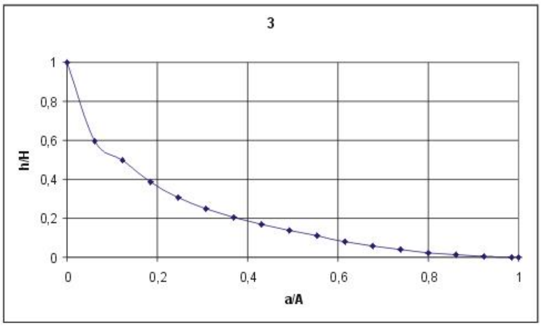
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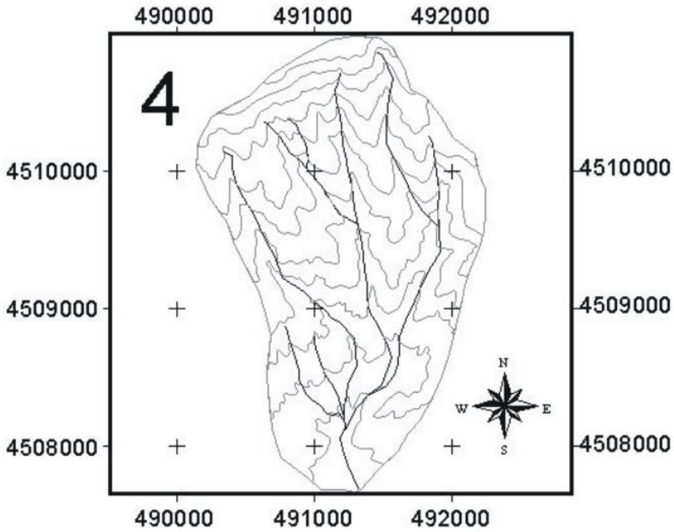

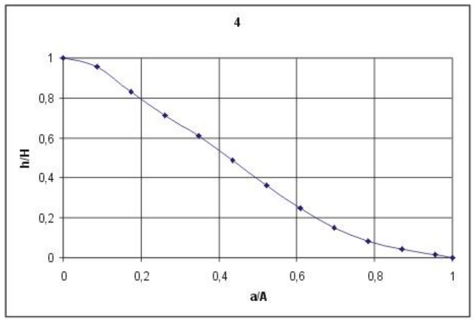

Figure 9: Selected drainage areas and hypsometric curves.

Conclusions

The geomorphological surfaces of our study area were determined using 15 standard maps of 1/25,000 scale through an implementation of a novel method. . Using digital elevation model the traditional methods for geomorphological studies were applied just to limited regions from the study area. Computer aieded anlysis programs made possible the digital data to be applied on large areas. In this study, the slope map was prepared/produced using raster type of DEM. The flat terrains (with slope < 5 %) and hillsides (with slope>5 %) were effortlessly distinguished in contrasts to the groups with sloped surface. The hillsides were grouped according to their slope values groups. There were mainly four groups as slightly sloped (slope 5 - 10 %), sloped (slope 10 - 20 %), steep (slope 20- 40 %) and very steep (slope 40 % +).

By determining the relations between the surface and the hillside through DEM data, similarly to the former studies done in the study area, 5 erosional surfaces were observed. These are the surfaces of DI (lower – middle Miocene), DII (upper Miocene), DIII (upper Pleistocene), SY (the lowest – middle Pleistocene), SA (upper Pleistocene). Compared with the classical geomorphological methods even for a large segments throughout the entire formations of the study area the erosional surfaces were obtained easily and precisely.

The multi-spectral data character of remote sensing data offer significant information about the morphologic structure of the earth surface. Utilizing this feature, the characteristic structure of the earth surface can be analysed based on the colours derived from the remote sensing data. Landsat 5 TM satellite image used in this study was obtained using different band combinations and later enhanced with aim to reveal the geomorphological surfacesdistinctly. Merginig enhanced remote sensing data with DEM provided better visualization of the geomorphological surfaces of the earth. Furthermore, this data fusion made possible the availability of different aspects and scales of visual observation and interpretation. The 3D analyis simplified a great deal in formations evaluation over very large areas and doing it from different aspects. The proposed method presents an important advantage in resolving the characteristic formations of the earth surfaces. It has been proved that geomorphological surfaces could be easily and accurately identified through these data. Other than these methods, effects of the faults on the morphology of the area were researched as well using morphometric applications. Results obtained from these studies revealed that the area in question is an actively elevating one. Main reason of this rapid elevation is the compressional structure of North Anatolian Fault present in the study area.

Acknowledgement:

The Authors cordially thank Prof. Dr. Oğuz EROL for his contribution to the study.

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