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ARAŞTIRMA MAKALESİ / RESEARCH ARTICLE

THE EFFECT OF ASPECT ON GLACIATION: A CASE STUDY OF EASTERN BLACK SEA MOUNTAINS (TURKEY)

Reşat GEÇEN [1]

Hatay Mustafa Kemal Üniversitesi, Fen Edebiyat Fakültesi, Coğrafya Bölümü

rgecen@gmail.com

Vedat TOPRAK

Ortadoğu Teknik Üniversitesi, Mühendislik Fakültesi, Jeoloji Mühendisliği Bölümü

toprak@metu.edu.tr

Saadettin TONBUL

Fırat Üniversitesi, İnsani ve Sosyal Bilimler Fakültesi, Coğrafya Bölümü

stonbul@firat.edu.tr

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Abstract

Glaciation directly depends on climate changing that developed and spread during colder temperature period and shrunk during warmer period. However this changing is not uniform everywhere on earth. Beside climate properties several other conditions have effect on glaciation such as; latitude, elevation, aspect, continentality, slope, humidity etc. Especially throughout mid-latitudes the aspect becomes more important effect on development of glaciation. Because of its location Turkey has been influenced by glaciers in Pleistocene era, and many glacial landscapes have been formed throughout the country during this period.

The aim of this study is to investigate the glaciated area in the Eastern Black Sea Mountain range using Geographic Information System (GIS) technologies in order to map and evaluate several features associated with glaciers. In addition depend on aspect effect the changes on glaciated area, number and distribution of glacial landscapes on different flanks of Eastern Black Sea Mountain Range is examined. Therefore the effect of aspect on glaciation is tried to be explained.

The glacial shapes determined in investigation area show different properties depending on their locations. Generally on northern side the landscapes are more widespread than the southern. 19 of 30 main valleys, 49 of 63 tributary valleys, 820 of 1222 cirques and 431 of 685 glacial lakes are located on northern side of the mountain chain.

Keywords: Glaciation, Eastern Black Sea Mountain, aspect, GIS.

[1] Sorumlu Yazar/ Corresponding author: Reşat GEÇEN / rgecen@gmail.com

BUZULLAŞMA ÜZERİNDE BAKI'NIN ETKİSİ: DOĞU KARADENİZ DAĞLARI (TÜRKİYE) ÖRNEĞİ

Öz

Buzullar doğrudan iklim değişikliğine bağlı olup, soğuk dönemlerde gelişir ve yayılır, sıcak dönemlerde ise çekilir. Ancak bu değişim yeryüzünde her yerde aynı şekilde değildir. İklim özellikleri yanısıra enlem, yükselti, bakı, karasallık, eğim, nemlilik gibi faktörler de etkilidir. Özellikle orta enlemlerde bakı faktörü buzullaşma üzerinde önemli etkiye sahiptir. Türkiye bulunduğu konum itibariyle Pleyistosen'de buzullaşmaya önemli ölçüde maruz kalmış ve bu dönemde ülkenin farklı yerlerinde birçok buzul şekli oluşmuştur.

Bu çalışmanın temel amacı Coğrafi Bilgi Sistemleri (CBS) teknolojisi kullanarak Doğu Karadeniz Dağları'nda buzullaşmaya maruz kalan sahaları incelemek ve oluşmuş buzul şekilleri tespit edip haritalamaktır. Ayrıca bakı etkisine bağlı olarak Doğu Karadeniz Dağları'nın farklı yamaçlarında meydana gelen şekil sayıları ve dağılışlarını incelemektir. Böylece bakının buzullaşma üzerinde etkisini açıklamaya çalışmaktır.

Çalışma sahasında tespit edilen buzul şekilleri konumları itibariyle farklı sayı ve özelliklere sahiptir. Genel anlamda kuzey yamaçta buzul şekilleri güney yamaca göre daha fazla yayılış göstermektedir. 30 ana buzul vadisinin 19'u, 63 tali buzul vadisinin 49'u, 1222 sirkin 820'si ve 685 buzul gölünün 431'i kuzey yamaçta yer almaktadır.

Anahtar Kelimeler: Buzullaşma, Doğu Karadeniz Dağları, bakı, CBS.

1. Introduction

Glaciation, especially Pleistocene glaciation has important role on formation of earth surface directly or indirectly. During Pleistocene era, 1/3 area of earth has been influenced by glaciation. Glaciers have been covered the 45% of North America, 64% of Europe continent (Erinç, 2001).

Glaciation directly depends on climate changing that developed and spread during colder temperature period and shrunk during warmer period. However this development, spread and shrinkage is not uniform everywhere on earth. Several other conditions also have effect on glaciation such as; latitude, elevation, aspect, continentality, slope, humidity etc. (Erinç, 2001). Especially throughout mid-latitudes the aspect becomes more important effect on development of glaciation. Due to angle of solar radiation, over north hemisphere, the northern parts of mountains are colder and more convenient for developing of glaciation than the southern parts.

Because of its location (between 36º-42º North Latitude), Turkey has been influenced by glaciers in Pleistocene era, and many glacial landscapes have been formed throughout the country during this period. Turkey has a complex topography that has different characteristics in different parts of the country. The altitude can vary from one region to another. Although the country is mostly surrounded by seas, in several regions the elevation is above 3000 m. The altitude, generally, increases from west to east (Kurter, 1991). Due to climatic conditions existing in the region, some parts of Turkey have been influenced by glaciation in Pleistocene era. Although they retreat due to global warming, several actual glaciers exist over high mountains.

In general, very limited data are available on Turkish glaciers. The recent observations indicate a glacier recession at least since the beginning of the 20th century (Çiner, 2003). Present-day glaciers and glacier-related landforms occur in 3 major regions in Turkey: 1) The Taurus Mountains, 2) The Eastern Black Sea Mountains, and 3) Volcanoes and independent mountain chains scattered throughout the Anatolian plateau (Çiner, 2003).

The Taurus Mountain Range (Mediterranean coast and SE Turkey) covers two-third of the present day glaciers which are mostly concentrated in the SE part. Among these, Mount Cilo alone supports more than ten glaciers (Erinç, 1952; Yavaşlı and Ölgen, 2008; Sarıkaya, 2011). Here the actual snowline changes between 3400-3600 m and the Last Glacial snowline is estimated to have been at around 2800 m (Messerli, 1967). In the Central part, Aladağ (3756 m) and Bolkardağ (3524 m) constitute two of the most important mountains where modern glaciers, although very small, are present. Even though there are signs of past glacial activity (Last Glacial snowline is estimated to be around 2200 m), no glaciers are present in the Western Taurus Mountains today (Çiner, 2003).

Eastern Black Sea region (Pontic Mountain Range) has the highest peak 3932 m located on Mount Kaçkar where five glaciers are developed (Erinç, 1945; Erinç, 1949; Doğu et al., 1993). Several other mountains such as Verçenik (Doğu et al., 1996), Bulut (Doğu et al., 1997), Altıparmak (Doğu et al., 1997), Göller (Hunut) (Doğu et al., 1994) and Demirkapı Dağı (Doğu et al., 2000) also support various glaciers. The modern snowline elevation is much lower on the north facing slopes (3100-3200 m) compared to that of south face (3550 m), because of the effect of more humid air masses. The Last Glacial snowline elevation was 2600 m on average (Çiner, 2003).

Volcanoes and independent mountains are scattered in the Anatolian plateau. In the interior of the country, volcanoes such as Mount Ağrı (Ararat), with an ice cap of 10 km^2 (Blumenthal, 1956; 1958); Mount Süphan (Kurter and Sungur, 1980) and Mount Erciyes (Erinç, 1951; Emre and Güner, 1983; Sarıkaya et al., 2003) show signs of glacial activity and active glaciers. On the other hand, Mount Uludağ, Mount Mercan and Mount Mescid (Atalay, 1984) in Central Anatolia also bear traces of past glacial activity (Çiner, 2003).

Glacial geomorphology is an important aspect of geomorphology that investigates the actual glaciers, the history of glaciation, and landscapes formed by glaciers. Recently, the study of glacial geomorphology becomes more attractive because of direct effect on life and human due to global warming theories. However, the studies carried out on glacial geomorphology have several difficulties mostly because the glaciers and glacial landscapes are located at high altitudes. Exploring, mapping and surveying through such regions is not easy. In some case, it is impossible to carry out field surveys depending on the morphology and climatic conditions of the area. On the other hand, recent developments in the field of glacial geomorphology have dramatically increased the need to acquire, maintain, manipulate, and analyze large amounts of landform, landscape and sediment data. At this point, remote sensing (RS) and geographic information systems (GIS) seems to complete these requirements and can contribute a lot to the study of glacial geomorphology.

1.1. Study Area

The study area is located in the northeastern part of Turkey located between the provinces of Trabzon, Rize, Artvin and Bayburt (Figure 1). The mountainous area between these settlements known as the Eastern Black Sea Mountains is the main focus of this study.

The area covers approximately 6.000 km2 of rugged terrain including the highest mountains of the region. The highest peak is the summit of Mount Kaçkar with an elevation of 3932 m elevation. Three highest peaks to the west of Kaçkar Mountain are Dilek, Cimil and Kırklar mountains with elevations of 3550, 3331 and 3354 m, respectively. To the west of Kaçkar Mountain the highest peak is the top of Gül Mountain with an elevation of 3348 m.

Depending on results and taking into account the previous studies, the 1500 meters elevation contour is accepted as the boundary between glaciated and unglaciated area. Thus this elevation is taken as the boundary of the study area and after this point this area is investigated in detail.

1.2. Aim of the study

Although there is little area of actual glaciers over Turkey, in Pleistocene era many regions had been occupied by glaciers. The movement of the glaciers modified the earth’s surface which in turn developed a glacial landform characterized by various glacial features such as valleys, cirques and lakes. EasternBlack SeaMountain Range is a typical region holding actual glaciers with many landscapes formed by glaciers in Pleistocene era. Due to the aspect effect, existence and distribution of both active glaciers and glacial landscapes are differed on South and North side of Eastern Black Sea Mountain Range.

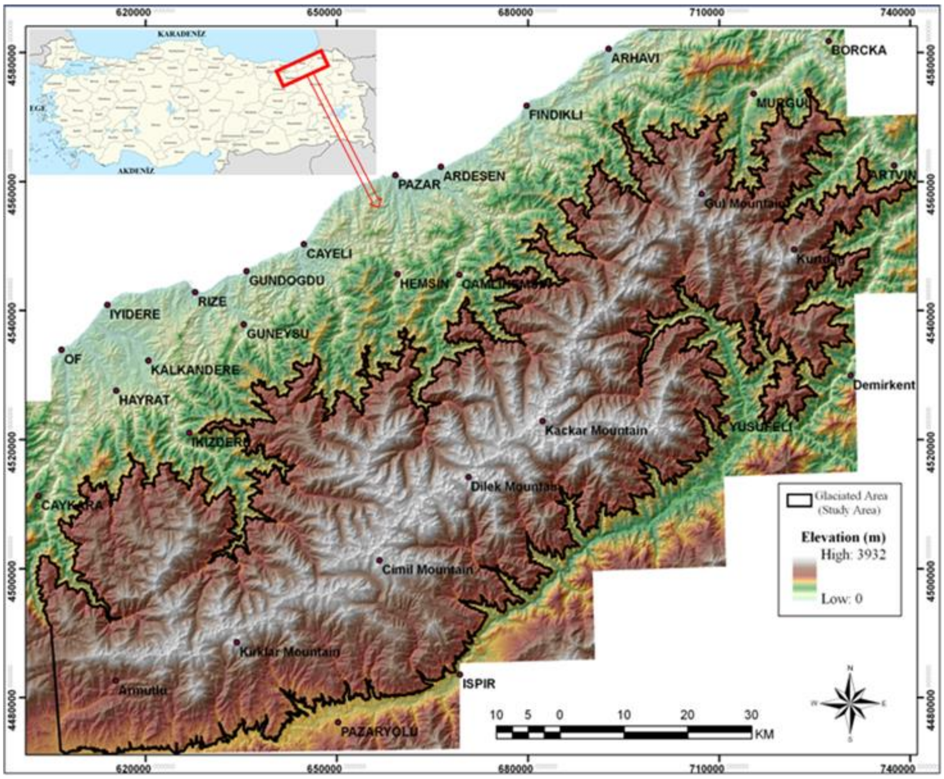


Figure 1- Location map of study area

The aim of this study is to investigate the glaciated area in the Eastern Black Sea Mountain range using Geographic Information System technologies in order to map and evaluate several features associated with glaciers. In addition depend on aspect effect the changes on glaciated area, number and distribution of glacial landscapes on different flanks of Eastern Black Sea Mountain Range is examined. Therefore the effect of aspect on glaciation is tried to be explained.

This study is carried out by comparing the North side and South side of Eastern Black Sea Mountain Range in context of existing numbers, conditions and distribution of main glacial landscapes including glacial valleys, cirques, and glacial lakes.

1.3. Data and Methodology

1.3.1. Data

This study is carried out via Geographic Information Systems, the input data should be in a suitable format. In this context three datasets are identified and obtained which include 1) Digital Topographic maps with scale of 1/25.000, 2) Analogue Topographic maps with scale of 1/25.000, 3) Digital hydrologic maps with scale of 1/25.000,

Digital Topographic Maps

As the main input data of this study, the digital topographic maps of the area are taken from General Command of Mapping of Turkey (Harita Genel Komutanlığı (HGK)) with scale of 1/25.000. Each sheet of this dataset contains contour lines with 10 m interval, points of summits with their elevation values, shore lines of Black Sea, and lakes located in this area. This raw dataset is in Arc Coverage format, with Universal Transverse Mercator (UTM) coordinate systems (Zone 37), and World Geodetic Systems 1984 (WGS 84) datum.

In the first step, these maps were merged into one single layer in order to use in GIS . Then the lines and points within this layer were separated into two different layers. These layers are later converted into several different formats for analyses and processing such as rvc (TNTmips), tab (MapInfo), shp (ArcGIS) etc.

Analogue Topographic Maps

Analogue Topographic Maps with scale of 1/25000 are also obtained from HGK as 80 sheets. These sheets, are scanned, georeferenced, and mosaicked. The resultant map contains contour lines, summit point elevations, locations of settlement, hydrologic elements (such as lakes, temporary and permanent rivers, water resources etc) and roads. This map is used as ancillary data for verification and complementing the missing data.

Digital Hydrologic Maps

This data is also taken from HGK at 1/25000 scale. They have the same format and coordinate system. The main reason for acquiring this data is the presence of glacial lakes in the region. Since there is not any complete inventory of the lakes in the area, the identification of the lakes might be problematic. In order not to miss any lake that may exist in the region, it is believed that this data should be used because it will contribute to a more accurate determination of the glacial lakes. A lake could be missed easily in digital and/or analog topographic map.

A single layer of hydrologic map is generated by merging all the sheets. This layer contains rivers represented by polygons and lines, the lakes by polygons, and water resources (mostly springs) as points. The required objects from this layer are extracted and saved as separate GIS files to be used in the later sections of the study.

1.3.2. Methodology

The methodology of study consists of three main stages: 1) Data input and pre processing, 2) Data management and processing, and 3) Integration and evaluation.

Data input and pre-processing: This stage includes data input that are provided from related institutions, and preprocessing of these raw data. Three data sets used in the study are digital topographic maps, analogue topographic maps, digital hydrographic maps. Preprocessing of these input data vary depending on the properties of individual data. Digital maps (topographic and hydrographic) are merged and converted into applicable formats. Analogue topographic maps are scanned, georeferenced and mosaicked in raster format. It is digitized and converted into vector format followed by reclassification in accordance with the purpose of the study.

Data management and processing: The second part of methodology consists of management, processing and analyses. After preprocessing of datasets, all layers are processed and analyzed individually.

For the digital topographic map a Digital Elevation Model (DEM) and its derivatives (aspect and slope maps) are generated. For this, the contours lines are converted into point data. Applying Triangulation Irregular Network (TIN) model a surface model of study area is obtained. Finally this surface model is interpolated into raster format with pixel size of ten meters. Aspect and slope maps are derived from DEM, 360° for aspect and 90° for slope. At this point a general geomorphologic characterization of area is investigated. Depending on results and taking into account the previous studies, the 1500 meters elevation contour is accepted as the boundary between glaciated and unglaciated area. Thus this elevation is taken as the boundary of the study area and after this point this area is investigated in detail. The study area above 1500 m is analyzed in two parts as northern and southern separated by the drainage divide (Figure 2).

Integration and evaluation: In the last stage of methodology, individual products generated for north and south sides are compared and evaluated. Therefore the effect of aspect on glaciations is explained.

2. Results and Discussion

2.1. Comparison of General Topographic Properties on Northern and Southern Sides

Elevation and Slopes

As indicated above, the study area is considered to cover the region above 1500 m. Aerial extent of this area as shown in Figure 2 forms a belt in NE-SW direction. The drainage divide in the area passes almost in the middle of this belt dividing the area into two parts. These parts will be referred to as “northern side” and “southern side” from this point on. The whole study area covers approximately 5375 km^2. South side has approximately 2879 km^2 area, and North side has approximately 2496 km^2 area.

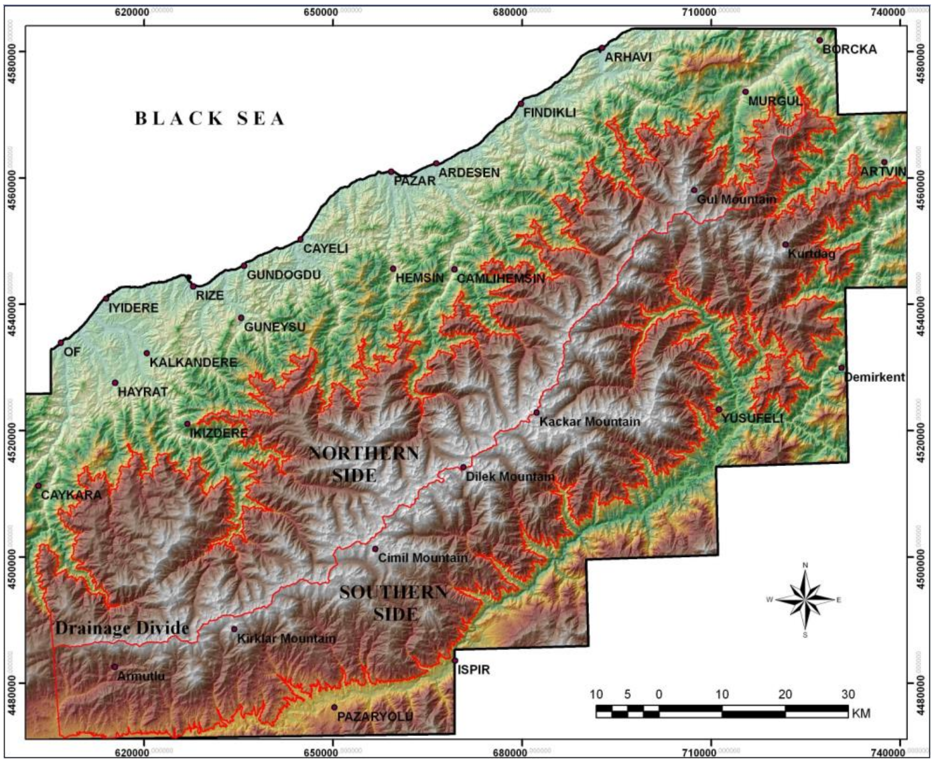


Figure 2- North and south side of study area.

Main statistics of topographic properties for the study area are illustrated in Table 1. Minimum, maximum, mean, mode, median, and standard deviation values of elevation and slope for the whole area, for the northern part and for the southern part are illustrated separately. Because the statistic values are not applicable to aspect value, this property is not included in the computations.

Elevation starts from 1500 m and rises to 3932 m at the summit. Mean elevations are 2317.7 m and 2247.6 m for the north and south, respectively. The variation is obtained by subtracting south side elevation values from north side values. The result is shown in Figure 3 at 50 m interval. The difference between north and south ranges from -1 to 1 indicating that the elevation for both sections is almost similar. However, there is a clear pattern in the diagram suggesting that in two intervals (1500 to 2150 m and 3050 to summit) southern part is dominating whereas between 2200 and 3000 m the northern part does. The positive zone suggests the glacial activity (such as truncation) and therefore contains the glacial features namely, the cirques and the glacial valleys.

Table 1- Main statistics of topographic properties of the study area.

		MIN	MAX	MEAN	MODE	MEDIAN	STDDEV
Elevation	Whole Area	1500.0	3932.0	2280.0	1652.0	2257.0	475.5
	North Side	1500.0	3932.0	2317.7	2397.0	2335.0	460.3
	South Side	1500.0	3932.0	2247.6	1652.0	2195.0	486.1
Slope	Whole Area	0.0	77.0	27.7	27.0	28.0	10.1
	North Side	0.0	77.0	27.8	27.0	28.0	10.1
	South Side	0.0	76.0	27.7	27.0	28.0	10.0

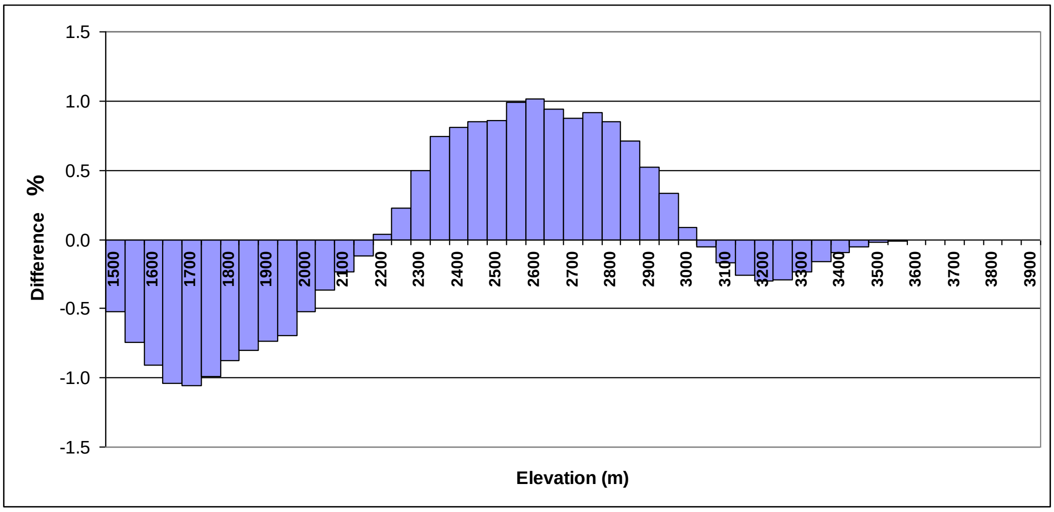


Figure 3- Difference of elevation between north and south side.

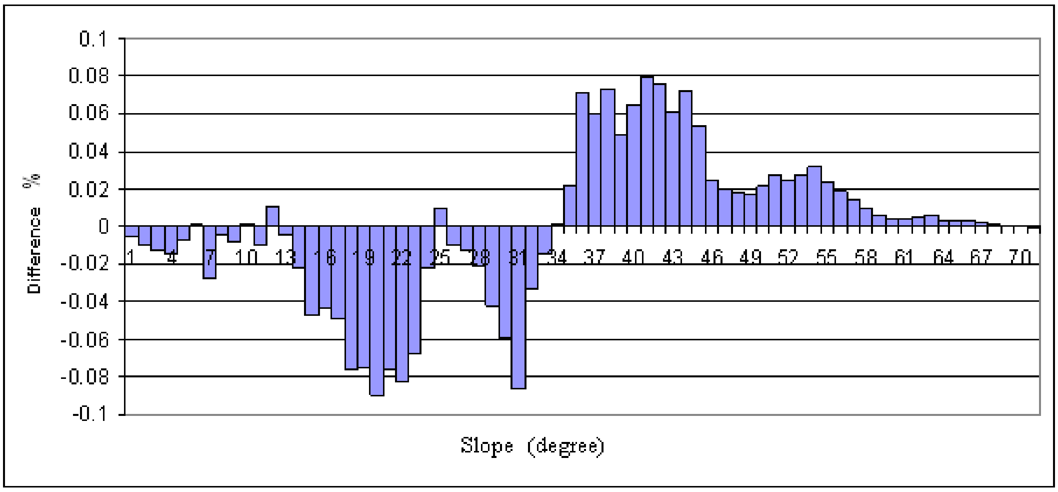


Figure 4- Difference of slope distribution between north and south side.

The statistics of slope indicate that the north and south sides of the study area have close slope values (Table 1). Mean slope values are around 28° for both parts. The difference slope values (north minus south), however, suggest that the area is not perfectly symmetric (Figure 4). At lower slope values (0 to 33 degrees) the southern and at the larger slope values (35 to 77 degrees) the northern parts are dominating with 0.08 percentages. Therefore, the northern part of the area is slightly steeper than the southern part.

Hypsometry Analyses

Hypsometry analyses are conducted for the whole study area, the northern side, and the southern side separately. The result is shown in Figure 5 for 50 m intervals for the whole area. The effect of glaciation is very obvious in this graph as indicated by its pattern. Under normal conditions the hypsometry line should be linear so that as the elevation increases the area should decrease linearly.

Hypsometric curve prepared for the area does not display a linear pattern and is composed four distinct shapes. The first section of the line is between 1500 and 2750 m characterized by a relatively gently slope. The second part is between 2750 and 2950 m with a steep slope. The third part is between 2950 and 3300 m having the steepest slope of the whole area. The last section is between

3300 and 3900 with a gentle slope. According to graph, the first three sections show the maximum deviation from the ideal trend, therefore an intense flattening and truncation is observed in this part. The first region most probably correspond to glacial valleys are surrounding regions. The second and the third region should represent the basal parts and the slopes of the cirques, respectively. The last region, on the other hand, indicates the summits of the area.

Hypsometric curves of northern and southern sections are computed separately to see a probable difference between two parts of the area (Figure 6).

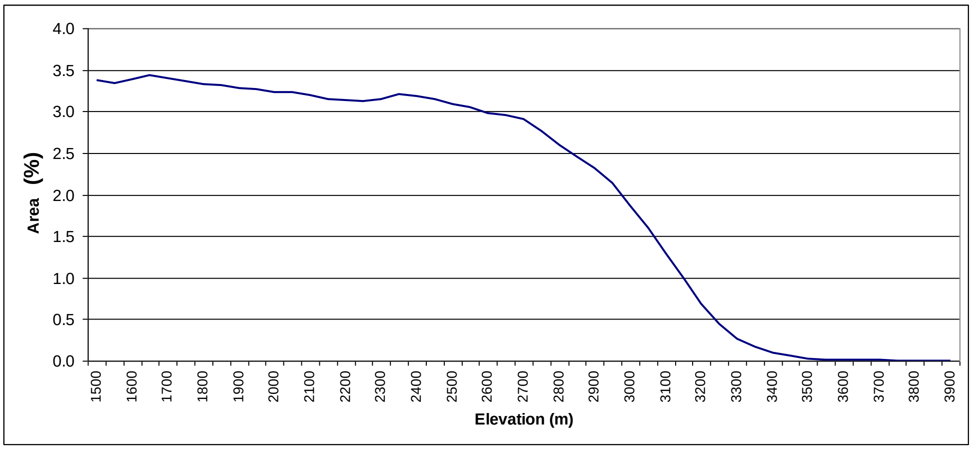


Figure 5- Hypsometry line of study area.

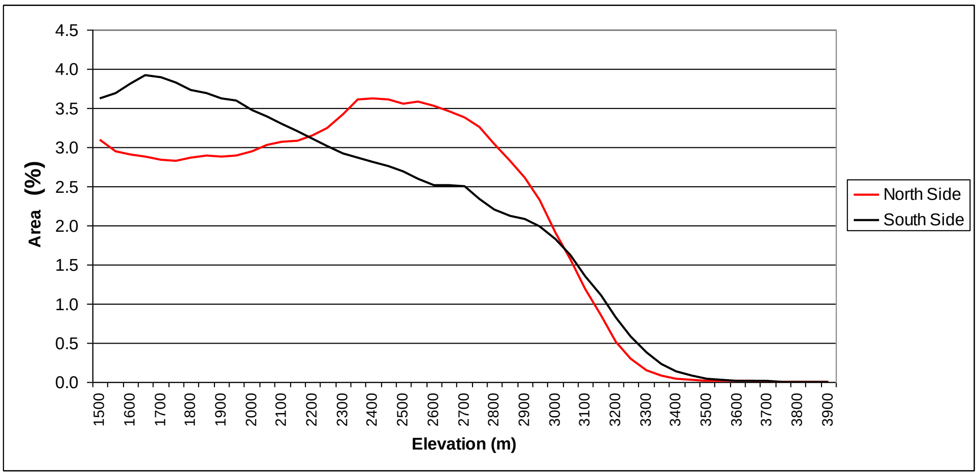


Figure 6- Comparison of North Side and South Side in respect of hypsometry.

The hypsometric curve of the northern part is composed of five sections. Between 1500 and 2200 m, the area is represented by a gentle slope followed by a sudden change between 2200 and 2400 m. After this point the slope is decreasing rapidly as indicated by two sections from 2400 to 2800 and from 2800 to 3250 the latter one being steeper than the former one. The last section is the tail of the line between 3250 and 3900 m elevation. Accordingly, the first two sections represent the glacial valleys which are overemphasized in the second one. The third and the fourth sections, corresponds mainly to cirques most probably including the starting parts of the valleys. The last section stands for the summits at higher elevations.

The hypsometric curve of the southern part of the area is much simpler and resembles an ideal curve with some major deviations. The curve can be divided into three sections with certain generalizations. The first section shows a gradual decrease in slope from 1500 to 2950 m. From this point to 3300 m the curve is steep followed by a gentle slope to the end of the curve. These three parts represent the glacial valleys, the cirques and the summits, respectively.

The difference between the northern and southern parts is clear in the diagrams. Particularly, the maximum difference between 2200 m and 3050 m is noteworthy. In this section, the influence of the glaciers has been much more in the northern part of the area and truncated the surface.

2.2. Comparison of Glacial Valleys on Northern and Southern Sides

Glacial valleys located within the study area are digitized manually over the DEM. Digital topographic contour are displayed over the DEM in order to recognize the landscape. The main criterion in the identification of the glacial valley is the determination of the point where the glacial valley changes into a fluvial valley. This point, on the map, corresponds to the point that defines a difference between U-shape and V-shape valleys. Then from this point for each glacial valley the floor of valley has been traced backward up to start point of each valley where the valley joins a cirque. Therefore a glacial valley is confined to the section of a valley between a cirque and a fluvial valley. The valley floor is represented as line in order to use in GIS.

An example of valley determination is illustrated in Figure 7. The points A and B in the upper figure corresponds the start and the end of glacial valleys, respectively. The blue lines in the lower figure are the “main glacial valleys” with some “tributary glacial valleys” indicated by red color. A total of 93 glacial valleys are detected and mapped in accordance with the criteria mentioned above (Figure 8). Among these, 30 valleys are classified as the “main” and remaining 63 as “tributary”. Considering total number of the valleys which is not suitable for GIS analyses, it is decided to concentrate only on the main valleys. Accordingly, 30 valleys are considered and investigated (Figure 9).

Location of the glacial valley in relation of the drainage divide in the area is believed to be an important feature because the divide passes almost in E-W direction which affects the direction of illumination in the area. This, in turn, controls the climatic properties such as temperature, precipitation etc.

Study area is composed of two belts located to the north and south of the drainage divide. Under normal conditions a similar number of glacial valleys are expected to exist on the both sides because the length of the two belts is the same. However, the number of the identified valleys shows great variation on different sides (Table 2). There are 19 main glacial valleys out of 30 in the northern part whereas only 11 on the southern part. The difference in the spatial distribution of the tributary valleys, on the other hand, is much distinct as indicated by 49 and 14 for the northern and southern parts, respectively.

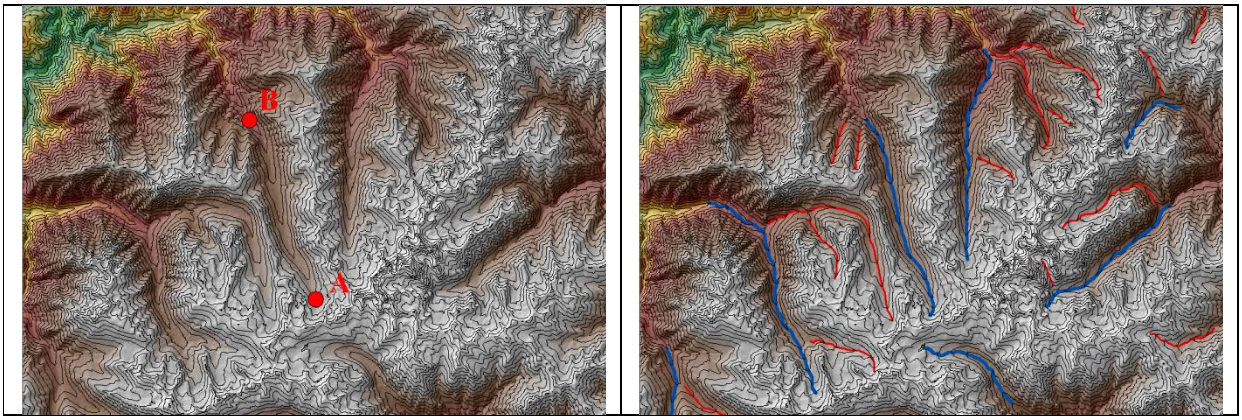


Figure 7- Determination of the glacial valleys over the DEM. The points A and B in the left figure correspond to the starting and the ending points of the valley. The red and the blue lines are the glacial valleys (main and tributary) drawn for this example (right figure).

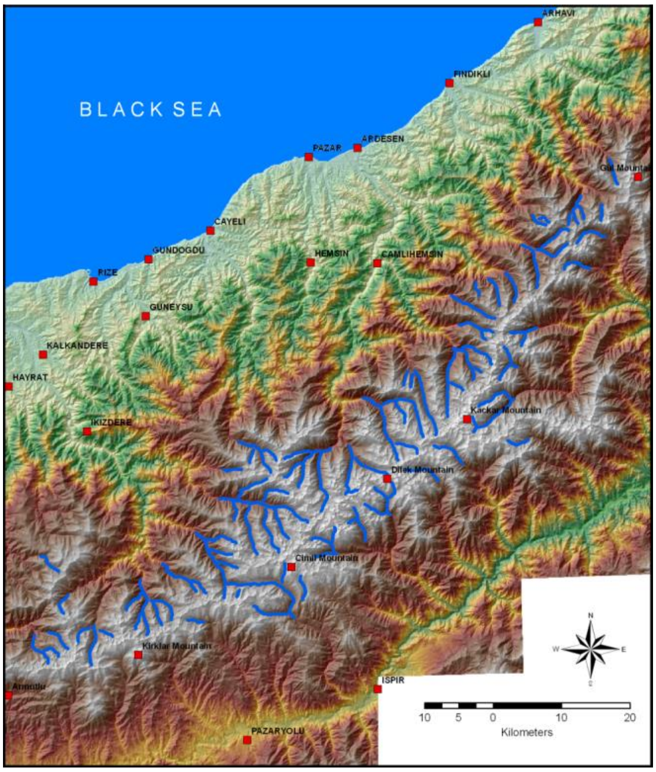
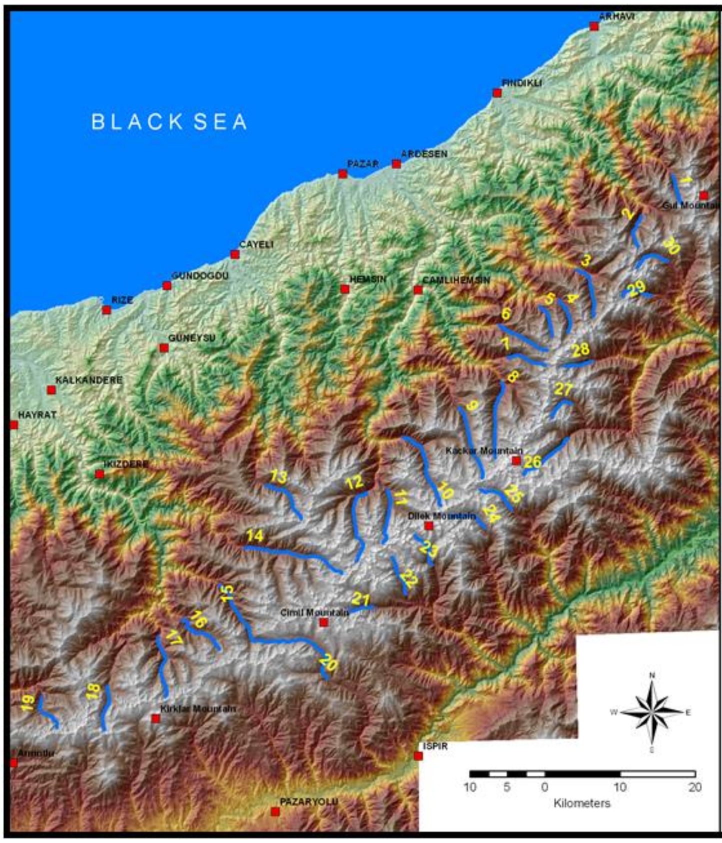


Figure 8- All glacial valleys determined in study area.



ID	Valley Name
1	ALACAGOL
2	ABU
3	TUNCA
4	ERGUSU
5	TOPLUCA
6	KACKAR
7	AVUCUR
8	KAVRAN
9	PALOVIT
10	ELEVIT
11	TATOS
12	VERCENIK
13	INCESU
14	SALAR
15	SEYTAN
16	GOLPALA
17	ARZAVAN
18	ANZER
19	BADIR
20	BUYUKOVIT
21	GASURLUK
22	AKTAKAN
23	ANADAK
24	SOROH
25	DAVALT
26	HASTAF
27	BULUT
28	ONBOLAT
29	OZGUVEN
30	BICAKCILAR

Figure 9- Main glacial valleys determined in study area.

Table 2- Number of glacial valleys identified in the area.

	NUMBER OF MAIN VALLEYS	NUMBER OF TRIBUTARY VALLEYS
North of area	19	49
South of area	11	14

Length of valleys refers to the distance between starting and ending point of valleys. These two points are connected by a line that runs parallel to the valley floor. The lengths for all 30 main valleys are computed. These values are shown in the graphs in Figure 10 for the northern and southern parts separately.

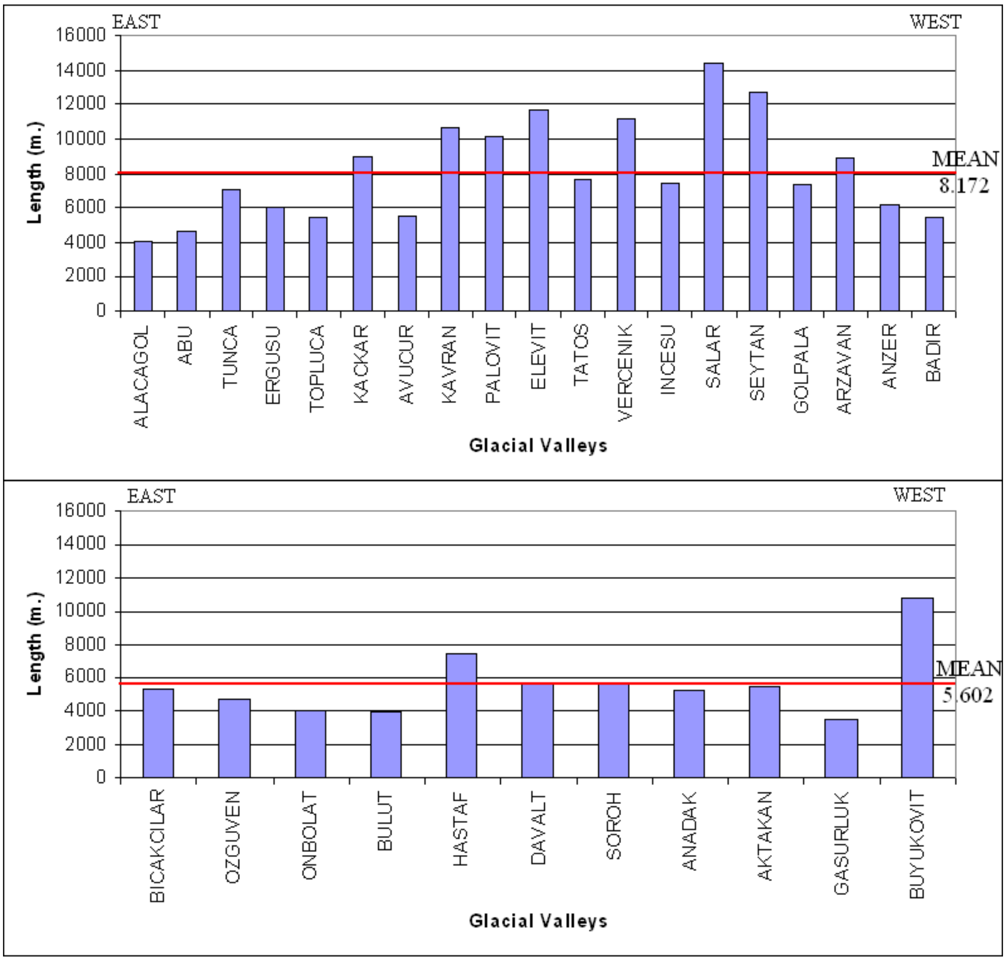


Figure 10- Length of glacial valleys on northern (upper) and southern (lower) sides.

The longest, the shortest and the average lengths are 14390.3, 4027.4 and 8172.2 for the northern part and 10770.8, 3466.6 and 5602.9 for the southern part respectively. It is very clear that the northern part valleys are longer than the southern part. Salar and Alacagöl valleys in the north; and Büyükovit and Gasurluk valleys in the south are the longest and the shortest valleys, respectively.

Elevation values refer to the start (upper) and end (lower) points of the valleys. These points are extracted from DEM and are listed in Table 3. The difference between these two elevations are computed and listed in the last column in the same table.

In the northern part, the maximum, minimum and average elevations of the upper points are 2928.8, 2425.4 and 2744.8 m, and of the lower points are 2237, 1506 and 1805.5 m respectively. These values for the southern part, in the same order, are 2926.8, 2610.6 and 2788 m for upper points and 2366, 1939.9 and 2154.8 for the lower points. Accordingly, the valleys in the southern start to develop at higher elevations compared to the northern part. This is best illustrated by the comparison of lower elevations on both parts. The lowest elevation in the northern part is 1506 m that belong to Tunca valley whereas in the southern part the lowest elevation is 1939.9 observed in Onbolat valley.

Table 3- Elevation properties of the main glacial valleys.

ID	NAME	START POINT (M)	END POINT (M)	HEIGHT (M)
1	ALACAGOL	2664.0	2051.0	613.0
2	ABU	2623.0	1723.6	899.4
3	TUNCA	2463.0	1506.0	957.0
4	ERGUSU	2558.0	1748.7	809.3
5	TOPLUCA	2698.4	1791.9	906.5
6	KACKAR	2805.4	1613.1	1192.3
7	AVUCUR	2642.6	1890.8	751.8
8	KAVRAN	2854.0	1657.5	1196.5
9	PALOVIT	2902.2	1997.4	904.8
10	ELEVIT	2915.0	1595.7	1319.3
11	TATOS	2928.8	2010.7	918.1
12	VERCENIK	2900.3	1860.0	1040.3
13	INCESU	2836.3	1988.3	848.0
14	SALAR	2829.4	1765.4	1064.0
15	SEYTAN	2686.0	1652.3	1033.7
16	GOLPALA	2582.1	1692.2	889.9
17	ARZAVAN	2695.9	1635.0	1060.9
18	ANZER	2821.1	2237.0	584.1
19	BADIR	2745.6	1887.0	858.6
20	BUYUKOVIT	2682.0	2186.0	496.0
21	GASURLUK	2610.6	2200.4	410.2
22	AKTAKAN	2877.3	2111.5	765.8
23	ANADAK	2894.6	2177.7	716.9
24	SOROH	2926.8	2366.0	560.8
25	DAVALT	2890.5	2301.0	589.5
26	HASTAF	2818.0	2085.1	732.9
27	BULUT	2807.6	2236.6	571.0
28	ONBOLAT	2669.4	1939.9	729.5
29	OZGUVEN	2697.9	1962.4	735.5
30	BICAKCILAR	2794.0	2135.9	658.1

Elevations of the northern and southern part valleys are plotted on the graphs separately to investigate the general trend on both sides (Figure 11). The valleys in both graphs are in accordance with their geographic position located from east to west. The most characteristic feature of these graphs is that the starting elevations of the valleys, on both parts, is maximum in the middle part of the area which gradually decreases towards east and west.

The end points of the valleys do not display a regular trend. For the southern part there is slight decrease in elevation from west to east. The northern part, on the other hand, seems to be consistent in lower elevation around 1700 m with minor and sudden variations.

Elevation difference (height) shows a great variation in the southern and northern parts. These values are shown in the last column in Table . There is a difference of about 670 m between the averages of the northern and the southern part valleys. The valley with the maximum height difference is Elevit valley with 1319.3 m in the northern part. The valley with minimum difference is Gasurluk valley in the southern part with an elevation of 410.2 m.

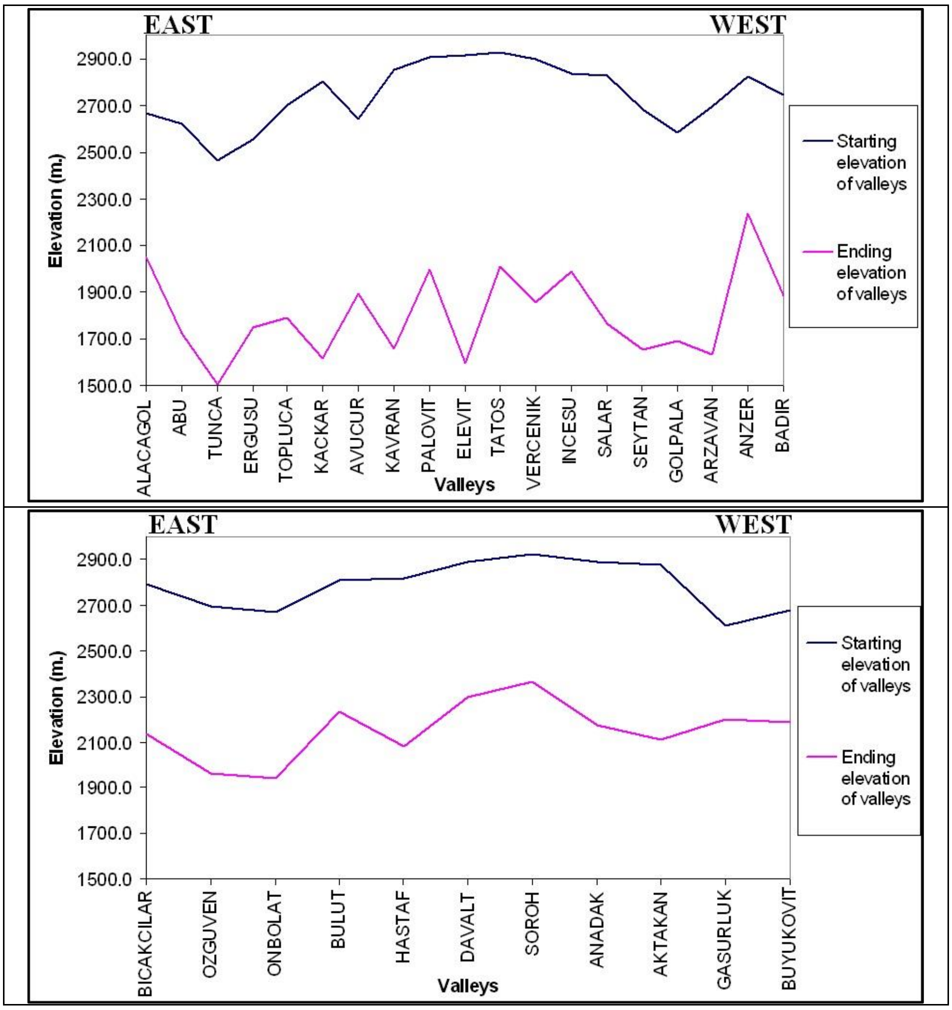


Figure 11- Start and End elevations of glacial valleys for the north (upper) and south (lower) parts of the area.

2.3. Comparison of Cirques on Northern and Southern Sides

Cirque is steep bowl-shaped hollow occurring at the upper end of a mountain valley, especially one forming at the head of a glacier or stream. They can be easily seen from contours map and DEM. Cirques in study area are digitized manually using the DEM and digital contour map. For each cirque a gate point of bowl is determined and starting from this point the cirque is digitized manually backward to crest or divide. A close up view of some cirques is shown in Figure 12 as an example. A total of 1222 cirques are digitized and saved as new layer (Figure 13).

Location refers to the site of the cirque in relation to the main drainage divide that separates the study area into two as north and south. This analysis therefore shows the distribution of the cirques in two parts of the area. According to the diagram prepared from the location of the cirques (Figure 14) 820 are located on northern part, and remaining 402 on the southern part.

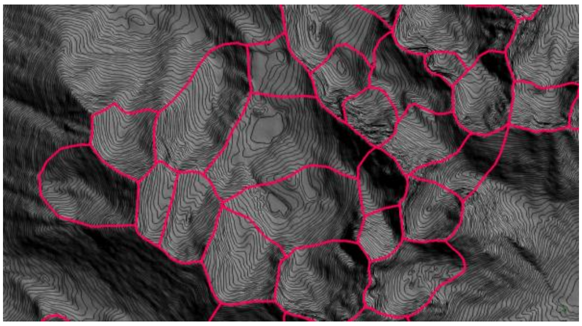


Figure 12- A close up view of the area showing digitization of glacial cirques.

Distribution of cirques according to elevation zones differs in both parts of the area (Figure 15). They start from 1700-1800 m zone on north side; while at south side the lowest ones exists at 2300-2400 m zone. In addition, cirques have maximum density between 2900-3000 m on north side whereas the density on south side is between 3050-3150 m. Therefore, the cirques in the southern part are exposed at higher elevations. This is best highlighted in the difference histogram in Figure 16 indicating that the cirques are developed more in the northern part up to elevation of about 3000 m after which is more dominant in the south side.

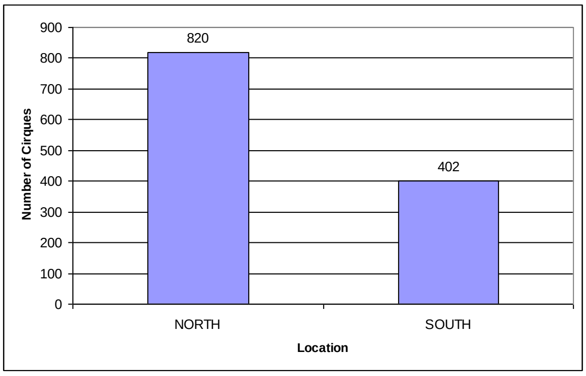


Figure 14- Distribution of cirques according to main aspect sides.

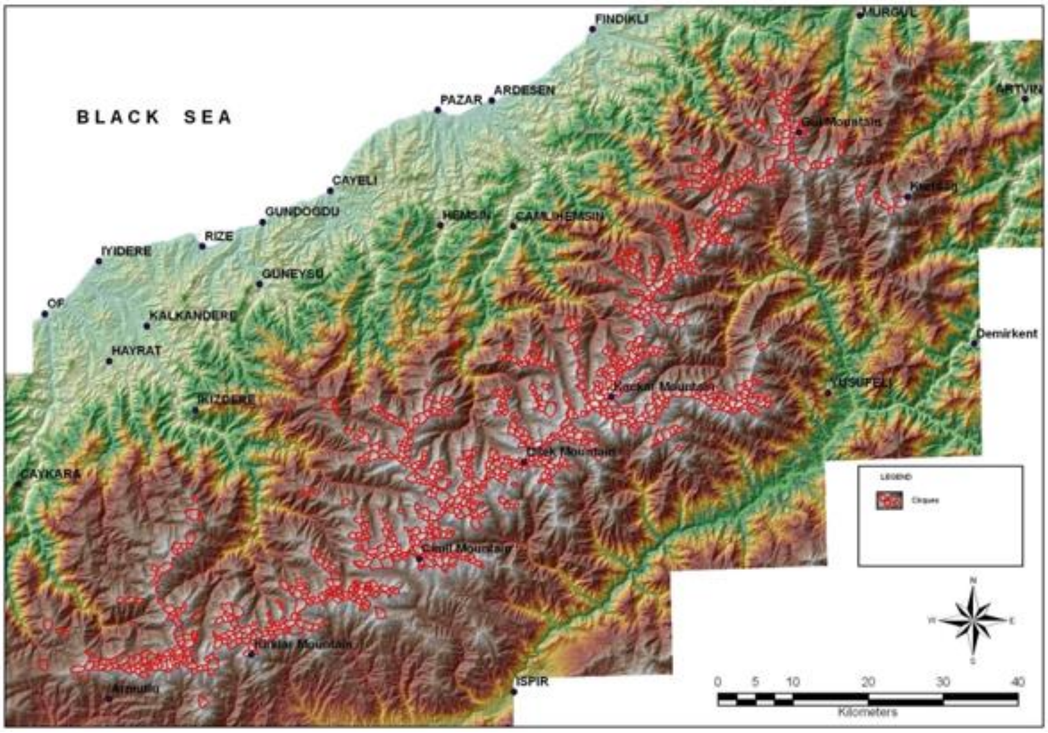


Figure 13- All cirques existing on study area

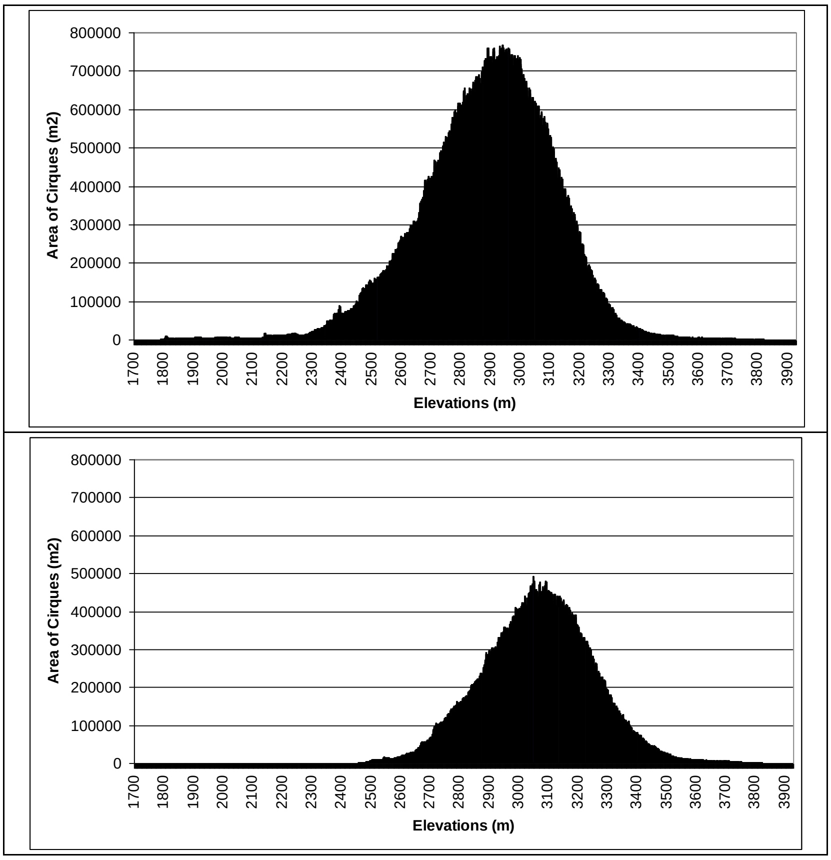


Figure 15- Distribution of cirques according to elevation zones in the north (above) and the south (below)

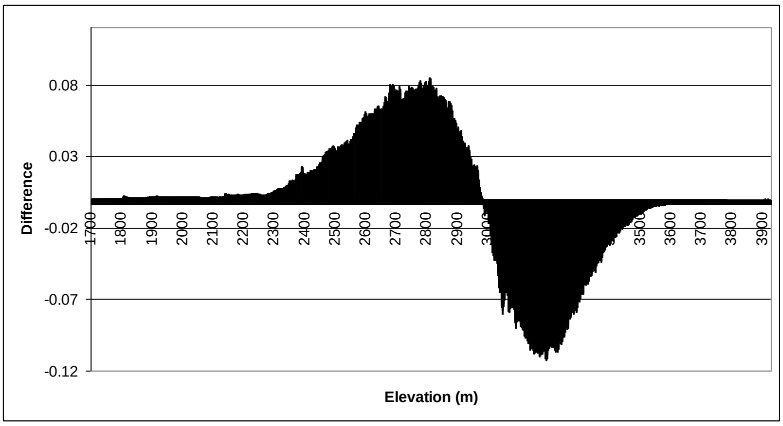


Figure 16- The difference histogram prepared by subtracting the percentage areas of cirques on the south side from north side.

2.4. Comparison of Glacial Lakes on Northern and Southern Sides

A glacial lake is a hollow formed by glaciers as it moves. The lakes are classified into two types as abrasion and deposition lakes based on the mode of glacier movement either vertical or horizontal. The movement of glacier in a cirque area usually is vertical to sub-vertical excavating the floor of the cirque. After glaciers melt and retreat, this hollow is filled by water from the glaciers or by other sources such as precipitation or groundwater. The depositional lakes, on the other hand, are formed by moraine carried by glaciers. Glaciers rupture and transport material in the valley as they move. At the end point of the movement these materials settle down and form a barrier. Behind this barrier water is accumulated forming a depositional lake. In this study all hollows existing in the area are considered as lakes whatever the origin is.

The lakes are identified from the DEM by the help of contour and hydrologic maps and are manually digitized (Figure 17). The highest elevation of the hollow is accepted as boundary of the lake. A new GIS vector layer is generated containing the digitized lakes. In order to test the accuracy, this vector layer is overlaid on analog topographic map and all digitized lake objects are reviewed. The total number of the glacial lakes identified in this study is 685 (Figure 18).

Distribution of the lakes is analyzed by plotting a) number, b) area of the lakes for the northern and southern parts separately (Figure 19). Accordingly, 431 lakes (63 %) are located on the northern and 254 lakes (37 %) on the southern. The distribution according to the area gives, more or less, the same distribution.

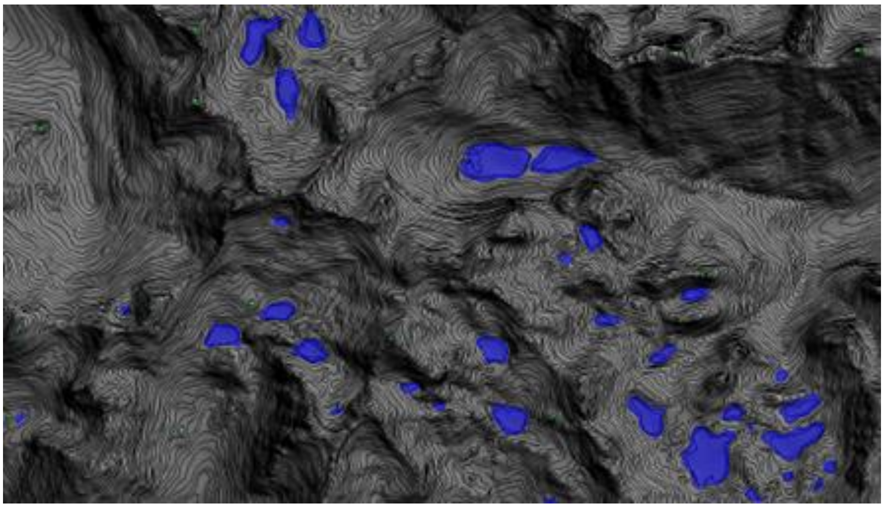


Figure 17- An example of digitization of glacial lakes over the DEM.

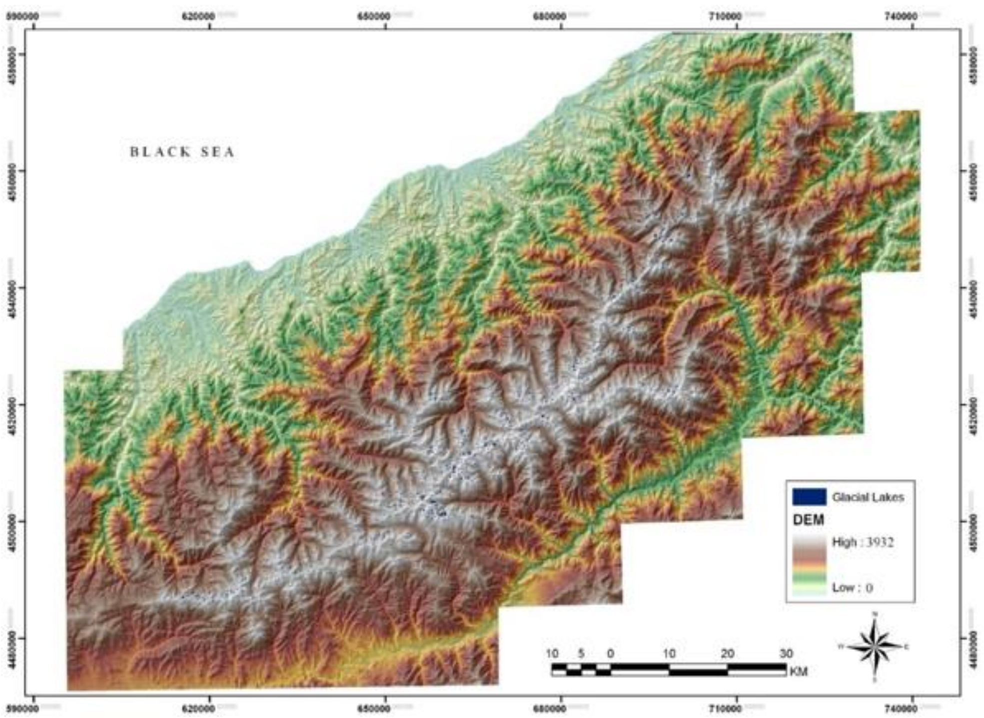


Figure 18- Glacial lakes identified in this study.

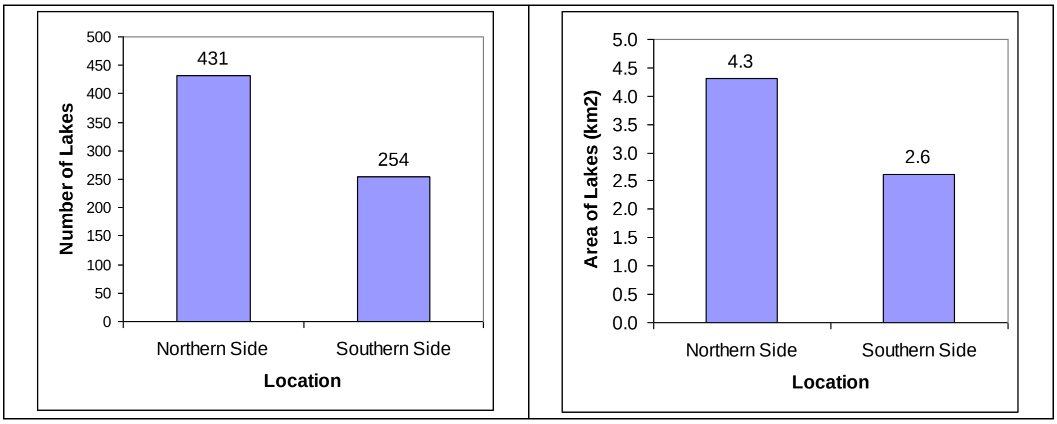


Figure 19- Distribution of number and area glacial lakes according to aspect sides.

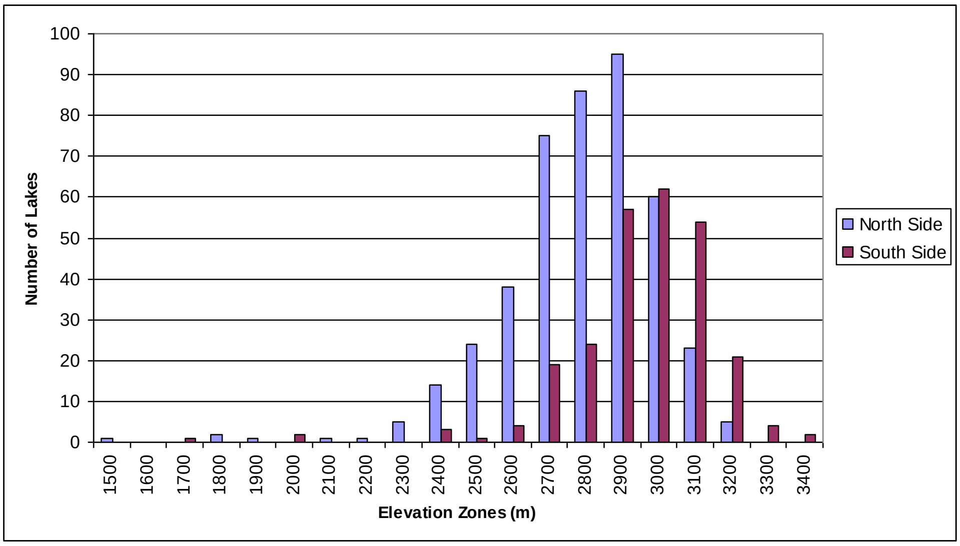


Figure 20- Distribution of glacial lakes according to elevation zones comparing North and South sides.

The comparison of the lakes of the northern and southern parts according to elevation zones is given in Figure 20. The lowest lake on south is located between 1700-1800 m whereas on north side the lowest one is located between 1500-1600 m. Great portion of lakes on north side are distributed between 2700 and 3100 while on south side between 2900 and 3300 m. Therefore, south side lakes are developed at higher elevation than the north side.

3. Conclusion

The glacial shapes determined in investigation area show different properties depending on their locations. Generally on northern side the landscapes are more widespread than the southern (Table 4).

19 of 30 main valleys, 49 of 63 tributary valleys, 820 of 1222 cirques and 431 of 685 glacial lakes are located on northern side of the mountain chain.

The lengths of valleys on northern side are longer. The starting elevations of valleys on both sides are close to each other but the ending elevations are different as on southern side the valleys terminate at about 350 m higher elevations. The average height difference of valleys on northern side is about 300 m more than the southern.

The cirques on northern side are distributed in a wide range of elevation. The density is located around 2950 m however several cirques are determined below the 2300 m. These lower ones might be nivation cirques. On southern side, they are dense around at elevations of 3100 m. Similarly, glacial lakes are located at higher elevation on southern side than the northern side.

All these results indicate that the glaciation is more developed on northern side. This is because of illumination angle and humid conditions. In the study area the northern side gets sun illumination with lower angle, and because of sea effect of Black Sea this side has humid characteristics. Therefore, the glaciation is more developed on northern side of EasternBlack SeaMountain chain.

Table 4- The main properties of glacial landscapes on northern and southern sides of area.

	NORTHERN SİDE	SOUTHERN SİDE
VALLEYS		
Number of Main Valleys	19	11
Number of TributaryValleys	49	14
MeanLengths of Valleys (km)	8.2	5.6
Mean Start Elevations (m)	2744.8	2788
MeanEndElevations (m)	1805.5	2154.8
MeanHeigth of Valleys (m)	939.3	633.3
CIRQUES		
Number of Cirques	820	402
MeanElevation of Cirques (m)	2950	3100
MeanArea of Cirques (m^2)	472700	509681
LAKES		
Number of Lakes	431	254
MeanElevation of Lakes (m)	2838	3001
MeanArea of Lakes (m^2)	9986	10314

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