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Araştırma Makalesi ● Research Article

Geomorphologic Evolution and Morphometric Analysis of the Upper Basin (Güzelsu) of the Engil River (Van)

Engil Çayı (Van) Yukarı Havzası'nın (Güzelsu) Jeomorfolojik Evrimi ve Morfometrik Analizi

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Abstract: The study area is located in the Eastern Anatolian Plateau found in the Alpine-Himalayan fold mountain belt. The Engil River Upper Basin (Güzelsu) is within the Lake Van Closed Basin, the largest soda lake in this belt in terms of volume and area. This study aims to investigate the geomorphologic evolution of the Güzelsu Basin and support this development with morphometric analysis. With this aim, a Digital Elevation Model (DEM) was created with the aim of quantifying and evaluating field observations and findings, 22 subdrainage areas located in the basin was determined by the DEM. The indices of Hypsometric integral, Hypsometric curve, Basin shape, Elongation ratio, Drainage basin asymmetry, Mountain front sinuosity ratio, Valley width-height ratio were applied to these drainage areas which were formed depending on internal and external processes. When the geomorphological and sedimentological findings in the field studies were evaluated with the applied index results, it was revealed that the basin geomorphology was formed under the influence of tectonism, climate and fluvial processes.

Keywords: Engil River Upper Basin (Güzelsu), Lake Van Basin, Geomorphologic Evolution, Morphometric Analysis

Öz: Çalışma alanı Alp–Himalaya kıvrım dağ kuşağı üzerinde bulunan Doğu Anadolu Platosu'nda yer alır. Engil Çayı Yukarı Havzası (Güzelsu), bu kuşak üzerinde hacimsel ve alansal olarak en büyük soda gölü olan Van Gölü Kapalı Havzası içerisindedir. Bu çalışmada Güzelsu Havzası'nın jeomorfolojik gelişiminin incelenmesi ve morfometrik analizlerle de bu gelişimin desteklenmesi amaçlanmıştır. Bu amaçla arazi gözlem ve bulgularını nicelleştirip değerlendirmek amacıyla Sayısal Yükseklik Modeli (SYM) oluşturulmuş, SYM'den havzada yer alan 22 alt drenaj alanı belirlenmiştir. İç ve dış süreçlerin etkisi ile şekillenen bu drenaj alanlarına Hipsometrik integral, Hipsometrik eğri, Drenaj Havzası Şekli, Uzama Oranı, Drenaj Havzası Asimetrisi, Dağ Cephesi Eğrilik Oranı ve Vadi Tabanı Genişliğinin-Vadi Yüksekliğine Oranı indisleri uygulanmıştır. Yapılan saha çalışmalarındaki

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jeomorfolojik ve sedimantolojik bulgular, uygulanan indis sonuçları ile değerlendirildiğinde, havza jeomorfolojisinin tektonizma, iklim ve flüvyal süreçler etkisi altında oluştuğu ortaya konulmuştur.

Anahtar Kelimeler: Engil Çayı Yukarı (Güzelsu) Havzası, Van Gölü Havzası, Jeomorfolojik Gelişim, Morfometrik Analiz

Introduction

Geomorphology is the investigation of landforms and for this kind of investigation, it is necessary to know the features and distribution of landforms, relationships to other landforms and events in their environment, reasons for the formation and development (Erol, 1993). Geomorphologic processes have an important place in explaining the physical geography conditions of past periods. These processes do not just contain clues about the physical geography conditions in the study area but also about how they affected the environment. Studies performed in order to explain geomorphologic processes need to be supported by an investigation of topographic and geological maps, evaluation of field observations and findings, interpretation of geomorphic shapes, and maps and visuals drawn in relation to the research topic in light of this data. These studies show the power of internal and external forces from past to present and their interactions in the context of causality, distribution and comparison. In recent years, geomorphologic studies, especially after the year 2000 in our country, have been supported by quantitative (numerical) data. These quantitative methods are called geomorphometric indices (Horton, 1945; Strahler, 1952; Schumm, 1956; Bull and McFadden, 1977; Keller and Pinter, 1996; Western et al., 1997).

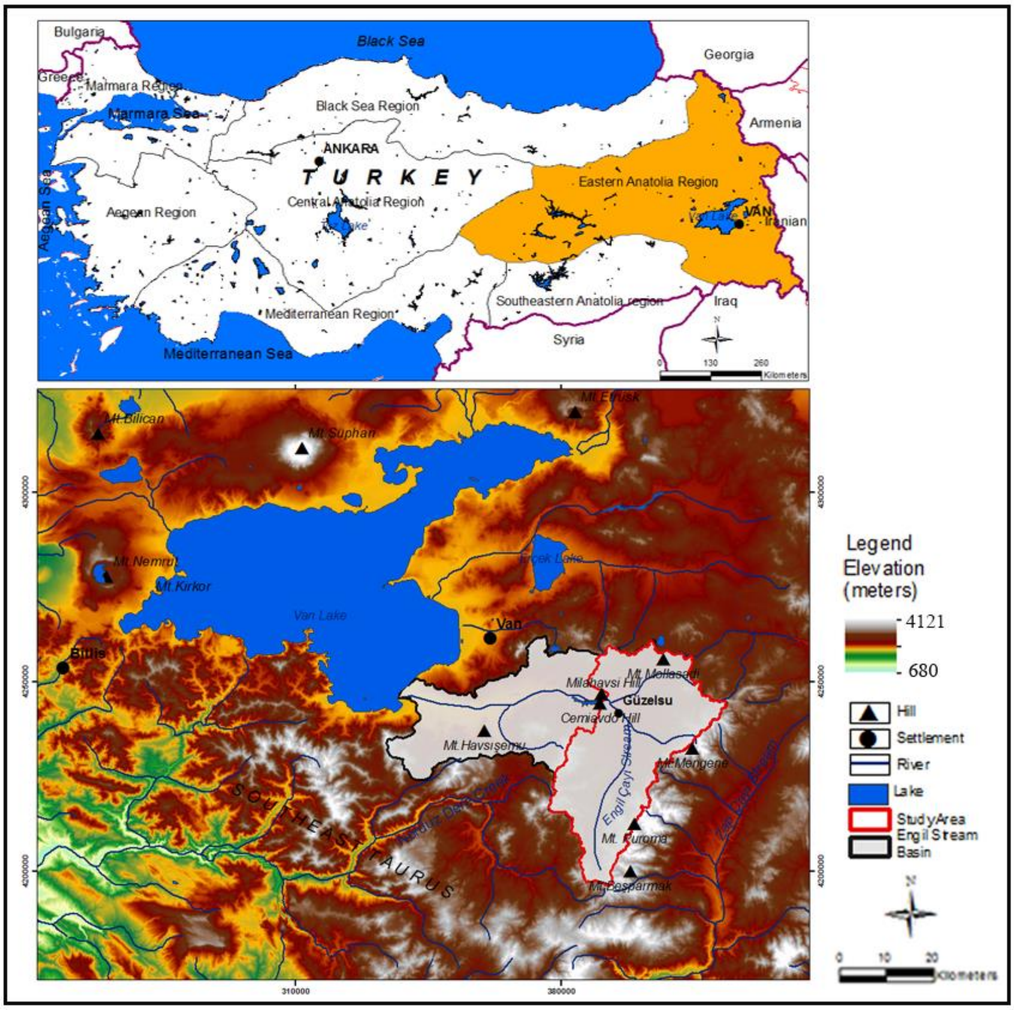
Geomorphometry is a science involving quantitative land surface analysis (Pike, 2000). Data obtained with the aid of geomorphometry may provide, consistent and rapid information about both the drainage evolution in the study area, but also the degree, distribution and character of structural/lithologic control of this evolution (Keller and Pinter, 2002). Quantitative data that are obtained as a result of analysis of morphometric features can allow better interpretation of factors playing roles in the formation and development of basins (Özdemir, 2007). Research to determine the geomorphologic features of fluvial basins are based on field studies and the creation of special geomorphologic maps produced as a result of these studies. However, for quantitative definitions of geomorphologic features in basins and morphologic units within basins, visual data need to be supported by numerical data (Cürebal and Erginal, 2007). Morphometric analyses in studies about morphotectonics are used to determine the degree of tectonic uplift and identify effects of tectonic activity on fluvial basins and networks. The most commonly used analyses in these studies are stream-length gradient index, mountain front sinuosity ratio, valley width-height ratio and drainage basin asymmetry factor (Elbaşı and Özdemir, 2018). Studies about Quaternary alluvial fans are related to sediment and morphology (Denny, 1965; Hooke, 1967; Bull, 1977), while later morphometric studies exceed these studies (Bull, 1977; Harvey, 1984; 1997). Geomorphometric index studies are evaluated within tectonic geomorphology as these types of studies reveal relationships between tectonism-linked geomorphologic processes (Mayer, 1986).

This study aims to investigate the geomorphologic evolution of the Engil River Upper Basin (Güzelsu) located in the Eastern Anatolian Plateau uplifted linked to compressional tectonics and support the investigation results with morphometric analyses. The study area, located in the Lake Van Closed Basin, presents geomorphic results of tectonic and climatic processes. The geomorphic results of tectonic and climatic processes are identified and explained in this study to illuminate lacustrine basin development processes. The study also presents an indirect morphotectonic approach to water level change in Lake Van.

Study Area and Geographical Features

Güzelsu Basin is located in the Eastern Anatolian Plateau and comprises the upper sections of the Engil River in the Lake Van Closed Basin (Map 1). The Lake Van Closed Basin is bounded by high volcanic mountains (Nemrut, Bilican, Süphan, Etrüsk Mountains) in the west and north, with mountain ranges of the southeastern extension of the Taurus in the south and east (Map 1). The lowest elevation within the lake basin is 1648 m forming the lake shore.

The highest point in the Güzelsu basin is the Katük Hill peak (3641 m), the lowest elevation is the valley floor between Cemiavdo Hill and Milahavsi Hill, which the western end of the basin and the river (1931 m) (Map 2).



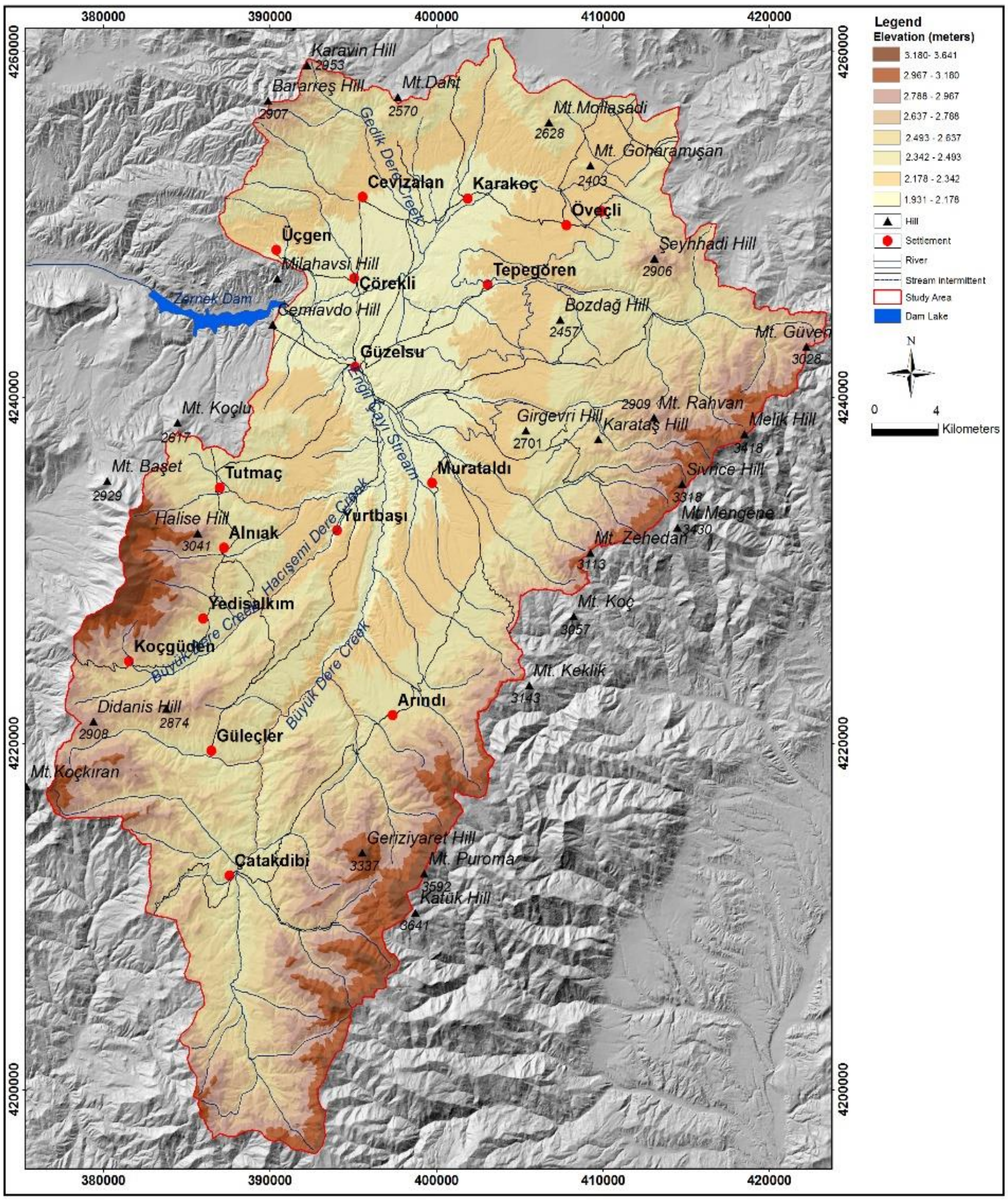
Map 1. Location Map of the Güzelsu Basin (rearranged from HGM, 2004)

The Engil River Basin has 2568 km^2 area and is the largest fluvial basin in the Lake Van Closed Basin. The Engil River Basin found southeast of the lake is within the mountain ranges of the southeast Taurus and generally has an E-W orientation (Map 1). The basin drained by the Engil River empties into Lake Van and is one of the most important water resources feeding the lake. The Güzelsu Basin forming the study area comprises the upper sections of the Engil River Basin and has an area of 1410 km^2. The axis of morphological extension is SSW-NNE (Map 2).

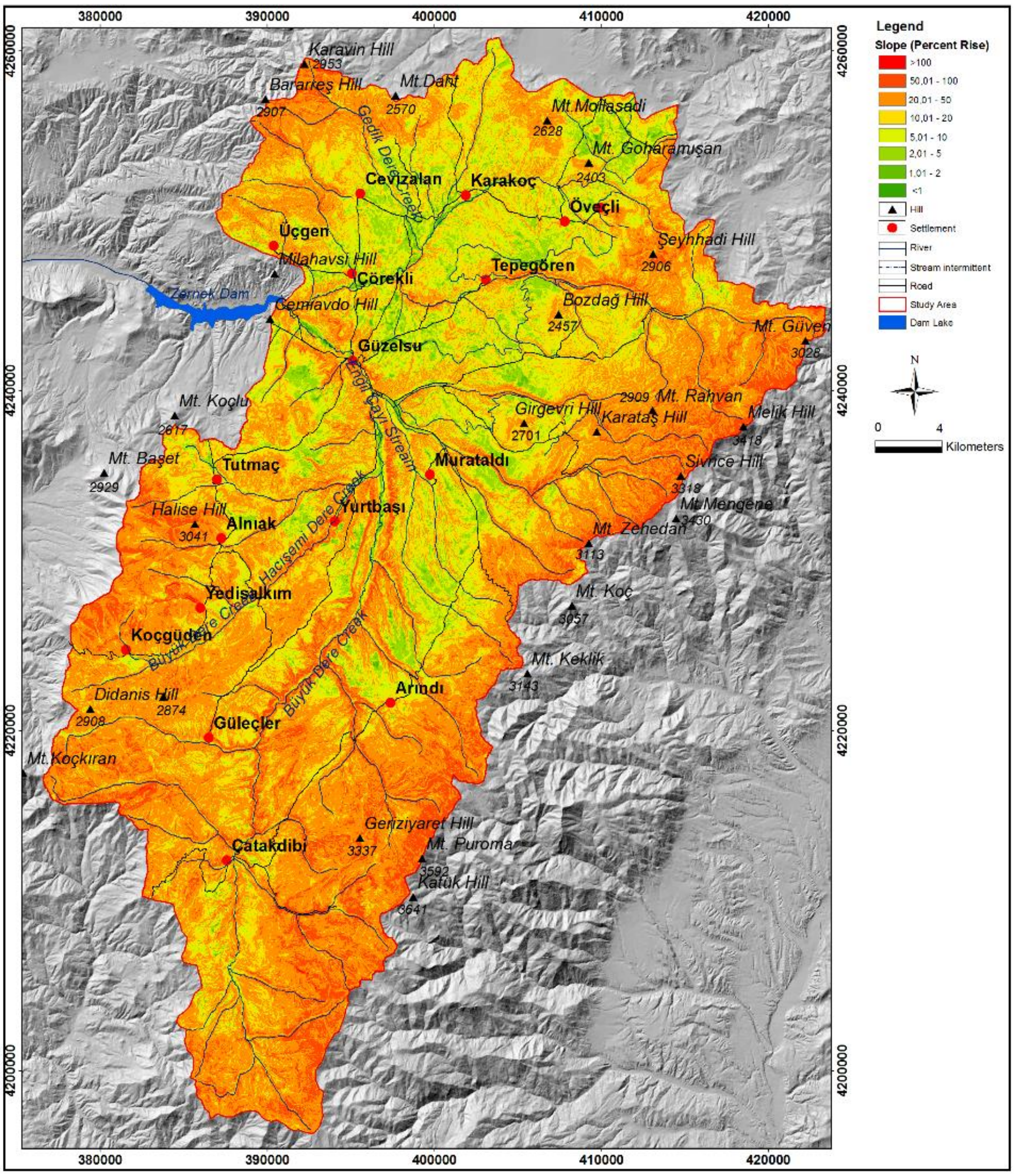
In the Güzelsu Basin, minimum slope is %0, maximum slope is the %169 and mean slope is %25.81. The slope values on the floor of the basin are low, while the areas on the slopes of mountainous masses surrounding the basin and in deep valleys formed by rivers have high values (Map 3). The maximum slope values are measured in the highest sections (Puroma Mountain and the west of Mengene Mountain) of the Güzelsu Basin. The slope variability is very high in these areas. This situation is linked to tectonic movements.

Data and Method

The Güzelsu Basin forming the study area offers important geologic and geomorphologic evidence containing clues about the physical geography conditions in the Neogene and later periods. This study is important for both the Engil River Basin and the Lake Van Closed Basin. The first study about valley development processes in the Lake Van Closed Basin is important to explain and compare development processes for other valleys in the basin. The study area was investigated for geologic and geomorphologic data belonging to the Neogene and Quaternary periods, with this data examined with identifications and observations during field studies. The studies were supported by quantitative geomorphometric methods.



Map 2. Physical Map of the Güzelsu Basin (rearranged from HGM, 2004)



Map 3. Slope Map of the Güzelsu Basin (rearranged from HGM, 2004)

(1) Hypsometric integral (H_i) and hypsometric curve (H_c): H_i is an important approach to show which stage of morphological development is occurring in a region (Strahler, 1952). H_c classifies the erosion stages of a drainage area (young, mature, old) showing the efficacy of these processes by shape (Strahler, 1952). H_i and H_c are evaluated together. The hypsometric integral is found using the following formula.

$$H_i = \frac{Elevation_{mean} - Elevation_{\min}}{Elevation_{\max} - Elevation_{\min}} \quad (1)$$

(2) Drainage basin shape (B_s); The drainage basin shape index is used as a complementary method in tectonic geomorphology. B_s is a planimetric measurement between the two most distant points in a basin (Cannon, 1976; Ramirez-Herrera, 1998).

High values of B_s represent long basins, while low values represent rounded basins. Lengthened basin shapes characterize tectonically active areas. The basin shape index is found with the following formula.

$$B_s = \frac{B_l}{B_w} \quad (2)$$

here B_l; is the length of the basin and B_w; shows the width of the basin.

(3) Elongation ratio (R_e); the elongation ratio was used as a marker proving recent tectonic activity by Bull and McFadden (1977). R_e is the diameter ratio of a circle with the same area as the maximum length of the basin studied. This ratio reveals the character of the shape of the basin and contributes to our interpretation of the formation processes of the basin. R_e is calculated using the basin area (A) and maximum basin length (L) in the following formula. When R_e <0.5, the mid-basin axis extends and this value indicates tectonically active basins. As the R_e value increases, the tectonic effect is understood to reduce.

$$R_e = \frac{2(\sqrt{A} / \sqrt{\pi})}{L} \quad (3)$$

(4) Drainage basin asymmetry (*AF*); Calculation of *AF* is a rapid method to quantitatively determine the slope of the topography (amount of tilting) (Hare and Gardner, 1985; Cox, 1994; Keller and Pinter, 2002). The asymmetry factor of a basin determines which edge of a drainage area the flow is closest to and was developed to identify the direction in which the topography tilts. The basin asymmetry factor is calculated from the following formula;

$$AF = 100(A_r / A_t) \quad (4)$$

In the formula, A_r is the area on the right of the flow in the drainage basin, while A_t represents the total area of the drainage basin. *AF* values close to 50 show very little or no tilting, while higher or lower values show the tilting of the basin due to active tectonics. *AF* provides better results in basins without anomalies due to climate or plant cover, similar to lithology (Keller and Pinter, 2002).

(5) Mountain front sinuosity ratio (S_{mf}); This value is used to differentiate tectonically active mountain fronts from inactive mountain fronts by taking note of age (Bull and McFadden, 1977; Keller and Pinter, 2002). The mountain front sinuosity ratio is calculated from this formula;

$$S_{mf} = \frac{L_{mf}}{L_s} \quad (5)$$

where, S_{mf} is the mountain front sinuosity ratio, L_{mf} is the length of the mountain front along the clear slope break at the base of the mountain and L_s is the length of a straight line along this slope break (Keller and Pinter, 2002).

(6) Valley width-height ratio (V_f); One of the important indices used to understand the tectonic effect of uplift is the valley width/height ratio (V_f). The shape of a drainage area can be determined by the V_f index (Bull and McFadden, 1977; Keller and Pinter, 2002). The valley width/height ratio is calculated from this formula;

$$V_f = \frac{2V_{fw}}{(E_{ld} - E_{sc}) - (E_{rd} - E_{sc})} \quad (6)$$

where V_{fw} is the width of the valley floor, E_{ld} is the elevation of the left valley section, E_{rd} is the elevation of the right valley section and E_{sc} is the elevation of the valley floor (Keller and Pinter, 2002).

In line with the aims of the study, a digital elevation model (DEM) was created from topographic maps of the study area. A total of 22 subbasins was created using the ArcHydro module on the DEM and indices were applied to these basins and the Güzelsu Basin.

Results and Discussion

Geologic and Geomorphologic Evolution of the Güzelsu Basin

The general evolution of the region was shaped as a result of continent-continent collision developing linked to the closure of the Neo-Tethys along the Bitlis suture zone (Şengör et al., 1979). Eastern Anatolia is a tectonic region characterized by a certain deformation style in Neotectonic period (McKenzie, 1972; Şengör, 1980; Şaroğlu and Yılmaz, 1984). Shaping of the Eastern Anatolian Plateau began with the closure of the Neo-Tethys ocean between the Indian Ocean and the Mediterranean, and subduction of Afro-Arabian Plate toward the north throughout the Middle Miocene. The formation of the North and East Anatolian Fault systems is linked to the rupture of the Red Sea and extension in Aegean Sea (Jolivet and Faccenna, 2000).

The study area is found just north of the collision region of the Arabian Plate and Anatolian Plate. As a result of the Arabian Plate compressing Anatolia from the south, Bitlis-Pötürge-Malatya nappes emplaced on the Southeast Anatolian autochthonous in the Miocene. After the final emplacement of this allochthonous mass, faulting with various orientations occurred in the region (Sümengen, 2008). The study area displays geological ordering from young to old moving from high sections toward the center of the basin. The oldest units appear to be Paleozoic and Mesozoic units belonging to the Bitlis-Pötürge-Malatya nappes in the high south sections of the basin, while the youngest units are Plio-Quaternary and Quaternary aged units in the center of the basin. This situation gives the study area the feature of being a geologic basin (Map 4).

Earlier Neogene

The geological structure of the area formed in the Middle-Late Alpine period. Forces affecting the area had north-northwest orientation until the Lower Miocene and then south-southeast orientation after the Lower Miocene (Acarlar and Türkecan, 1986). The extension axis of the basin comprising the study area complies with the direction of compression after the Lower Miocene (Map 4).

The Güzelsu Basin is a tectonic-sourced basin in the form of a bowl. The bowl forming linked to the compressional regime and faulting in the Upper Miocene later gained the features of a small intermontane basin. Erosion and depositional activities intensified linked to this tectonic formation. The correlation between tectonism and geomorphology is directly proportional to the dimensions of the geomorphologic structures (Şaroğlu and Güner, 1981).

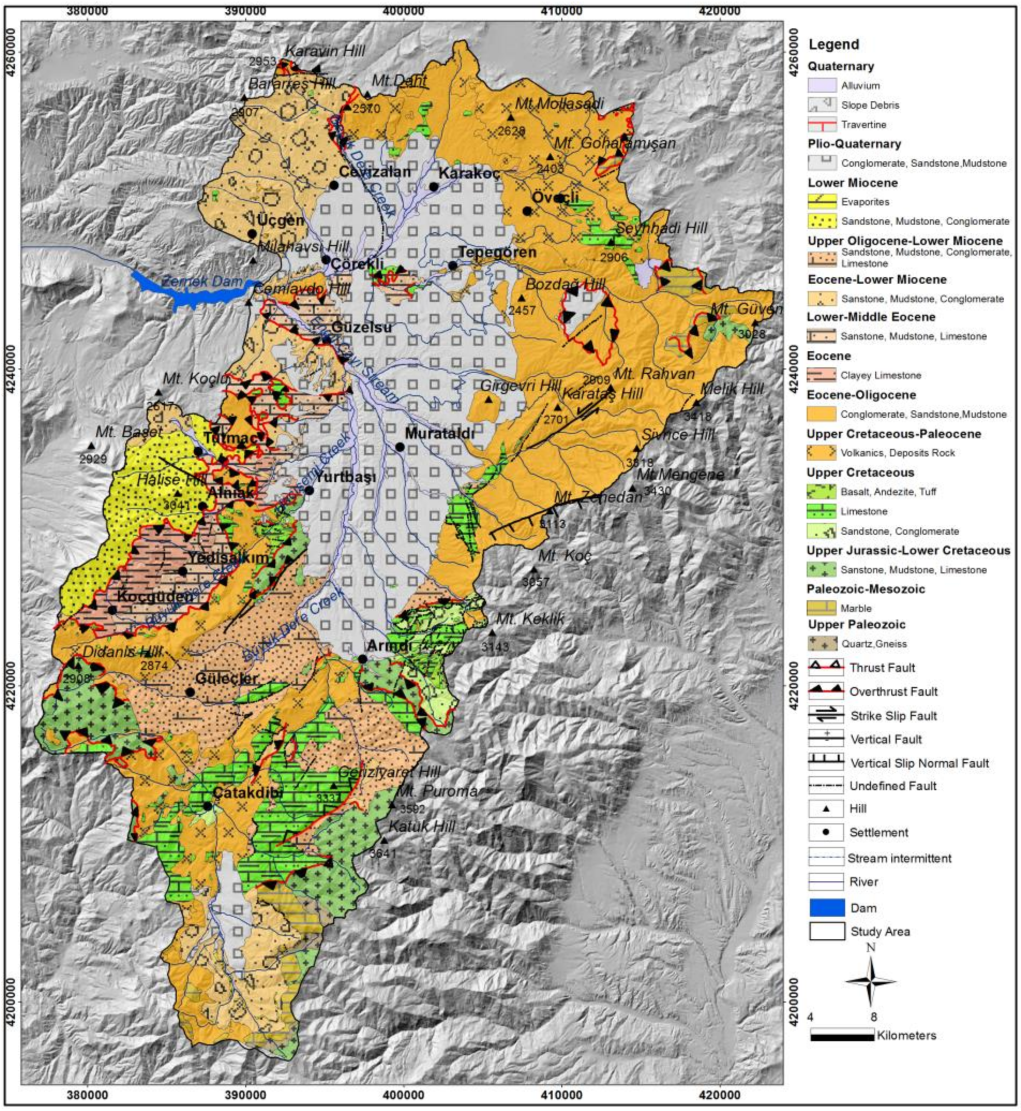
Neogene faults and formations

In the Neogene, Anatolia came under the effect of vertical and horizontal tectonics with compression from the south by the Arabian plate. Especially in Eastern Anatolia where the study area is located, this compressional regime caused both uplift and faulting. Faults and folds characterize the geologic structures in the Lake Van Basin (Şaroğlu and Güner, 1981; Güner, 1984; Şengör et al., 1985; Yılmaz et al., 1998; Toker and Şengör, 2011; Şengör et al., 2008; Çukur et al., 2013).

Folding and faulting were very effective during development of the Güzelsu Basin. The basin is cut by east-west and southwest-northeast striking reverse faults and strike-slip faults. Additionally, the normal fault controlling the west edge of the basin has southwest-northeast strike. Normal faults striking the same direction are observed south of the basin (Acarlar and Türkecan, 1986). Most of the folds are structures affecting formations related to ophiolitic melange and melange and are observed east of Lake Van. Generally, there are NE-SW striking broad anticlinals and synclinals not showing local continuity (Şengör et al., 2008). The Güzelsu Basin formed linked to a compressional regime in the Neogene. These types of basins can be explained as intermontane basins (Fig. 1) (Şaroğlu and Güner, 1981).

Located within the study area, Lake Van and surroundings completed geomorphologic formation in three stages. An erosional period extending until the Upper Pliocene caused a mature topography and drainage to form. In the second stage in the Early Pleistocene, deep excavation and incision of this drainage occurred. In the third stage, Late Pleistocene processes involving changes in the lake level and affecting deposition and current morphology occurred (Acarlar et al., 1991).

Linked to these processes in areas with intense tectonic movements, erosion of the basin in sloped and high areas and depositional activities continued toward the basin floor. Fluvial processes speeded up these erosion and deposition activities. This depositional material commonly observed within the basin is called the Büyükçay Formation. The depositional thickness is about 400 m (Acarlar and Türkecan, 1986).



Map 4. Geological Map of the Güzelsu Basin (rearranged from Sümengen, 2008)

Photograph 1. High Mountain Ranges Surround Güzelsu Basin

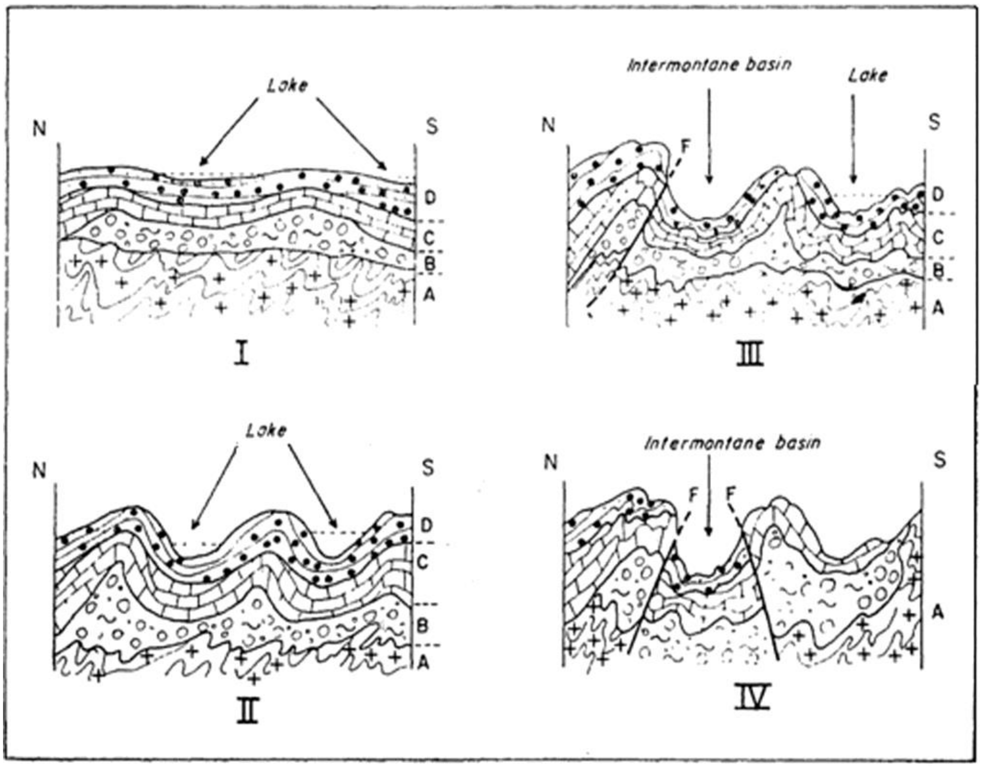


Figure 1. Sections Showing the Geomorphological Development of Eastern Anatolia in Neotectonic Period and Morphology-Structure Relations (from Şaroğlu and Güner, 1981)

Plio-Quaternary Period

Lacustrine sediments can provide important insights into past lake levels (Smith, 1991). Major changes in lake level, in turn, represent a powerful tool for understanding paleoenvironmental and paleoclimatic conditions in continental regions (Machlus et al., 2000; Adams et al., 2001). The level changes of Van Lake in the past 600 thousand years were examined. (Çukur et al., 2014). Two major uplifts and one regression were detected during this period. It was stated that the water level of Van Lake decreased in the first 15 thousand years of the last 30 thousand years and increased in the second 15 thousand years. These changes not only shed light on the climate oscillations in the study area, but also clarify the erosion and accumulation processes. The depression, became an lacustrine environment in the Plio-Quaternary, filled with material transported from the surrounding high mountain slopes. Alluvial fans, mountain geomorphology and sediment systems may offer important records about climatic environments (Harvey, 1996; 1997; 2002). This Plio-Quaternary-aged depositional material is called the Büyükçay Formation. The Büyükçay Formation contains important geomorphologic information in terms of basin formation and development. The Büyükçay Formation comprises fine-moderate-thick bedded, dirty yellow, light gray and light white color sandstone, siltstone and conglomerates (Photo 3), (Acarlar and Türkecan, 1986).

Overlying older units above an angular unconformity, the unit was deposited mainly in preserved intermontane lacustrine and terrestrial fluvial environments. Occasional small-scale clayey lacustrine limestones and travertine formations are observed within the unit (Sümengen, 2008). The age of the unit was identified as Plio-Quaternary (Balkaş et al., 1980).

Photograph 2. A Cross Section of Büyükçay Formation Formed by Lacustrine Interlayered Stream Sediments

Today's Topography

The Quaternary period played an important role in shaping the topography of the study area. Processes shaping the basin and their features provide clues about the development of topography.

When the study area is evaluated along with the Lake Van Closed Basin morphology in which it is located, the Lake Van Basin developed as part of the Euphrates River paleo-valley system in the E-W striking Muş-Van Basin (Erinç, 1953; Blumenthal et al., 1964; Wong and Degens, 1978; Şaroğlu and Güner, 1981; Güner, 1984; Degens and Kurtman, 1978; Şengör et al., 1985; Yılmaz et al., 1998; Şengör et al., 2008; Kuzucuoğlu et al., 2010; Çukur et al., 2013). However, the Güzelsu Basin comprising the study area has SSE-NNW strike, and does not comply with this orientation (Map 1).

Photograph 3. A Section of Clayey Lacustrine Units within Büyükçay Formation

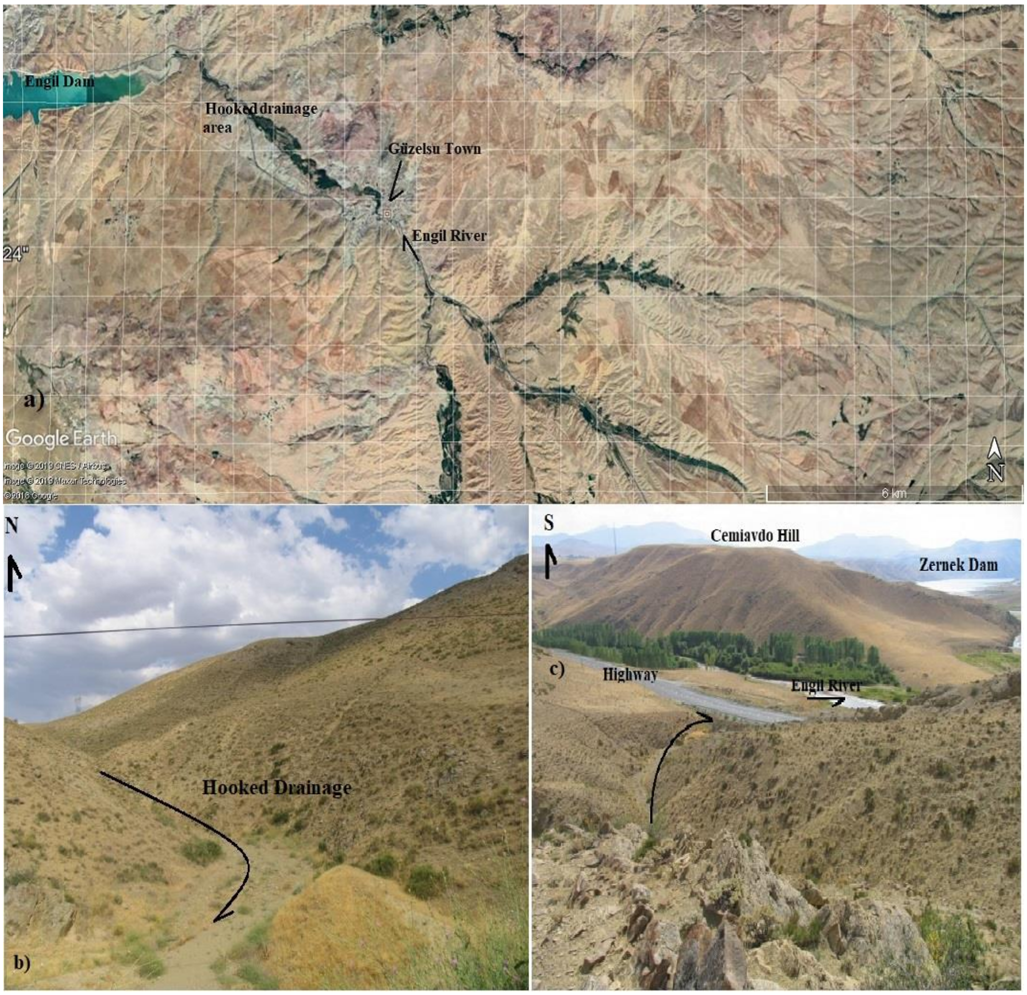
The Engil River flows northwest within the Güzelsu Basin and forms a 45º angle bend in the south of the basin north of Cevmiavdo Hill and turns west (Photo 5). The Güzelsu Basin has bowl shape and is the area with most stream tributaries (Büyük Creek, Hacışemi Creek, Sütboğazı Creek, Gedik Creek) along the whole fluvial basin (Maps 1, 2, 3). Of these tributaries the Büyük Creek is the largest tributary and flows parallel to the axis of the bowl (SSE-NNW) formed by the upper basin. The fluvial tributaries have deeply incised the Büyükçay Formation and Quaternary-aged alluvium is observed to have deposited (Map 4).

Before reaching the bend in the river, the tributaries hook mixing with the main river and showing hooked drainage network. This situation is observed at the river mouths of subdrainage basins numbered 1, 2 and 3 in the northwest of the study area (Map 5).

The tributaries flow in different directions and unite east of Güzelsu (Van) sub-district and flow toward the northwest. The river bends northwest of the Güzelsu sub-district between Cemiavdo Hill and Milahavsi Hill turns west and continues to flow toward Lake Van. This bend is also the point at which the bowl morphology ends.

The Büyükçay Formation found in the Güzelsu Basin has NE-SW striking oval-like distribution in the basin. The northern sections of this formation reach elevations of about 2250 m, while the south sections reach elevations of 2450 near Arındı Village. This situation shows that tectonic activity was greater in the south of the basin during the Neogene. The Büyükçay Formation reaches a final elevation of about 2000 m west of the Güzelsu sub-district located in the bowl of the upper basin.

Rivers in the Lake Van Basin transported large amounts of sediment into the lake during its 600-thousand-year past (Litt et al., 2009; Stockhecke et al., 2014). Most stratigraphic, tectonic and climatic studies of the Lake Van Basin terraces evaluate lake level changes and regional climatic events during and after the ice ages and are related to determining elevations of different shorelines and their ages (Degens and Kurtman, 1978; Valeton, 1978; Kempe et al., 2002; Kuzucuoğlu et al., 2010). The water level changes seen in a closed basin lakes in most recent ice ages can be said to be effective in closing the basins.



Photograph 4. View from the (A) Google Earth, (B) South and (C) North of the Hooked Drainage in the Direction of Grabbing of the Side Streams after Grabbing

Photograph 5. View of Grab Bend from Milahavsi Hill

Morphometric Analyses

The effects of tectonic activity on drainage systems in basins with drainage controlled by active faults can be explained using modelling and morphometric approaches with geomorphic indices. With this aim, data from measurable parameters belonging to topography in a drainage basin (height-elevation and slope), and digital data from topographic maps and aerial photographs can reveal the degree of effect of tectonics in a field. In the stage of creating raw digital data, digital field modeling methods (Digital Elevation Model-DEM) are used to ensure benefit in terms of sensitivity of data (Erginal and Cürebal 2007). In this study, the hypsometric integral (H_i), hypsometric curve (H_c), drainage basin asymmetry (AF), drainage basin shape (B_s), elongation ratio (R_e), mountain front sinuosity ratio (S_{mf}) and valley floor width-height ratio (V_f) indices were used. All indices were applied to 22 subdrainage basins determined in S-SE, SW and NW on DEM (Map 5). In this section, the indices and results will be evaluated under separate headings.

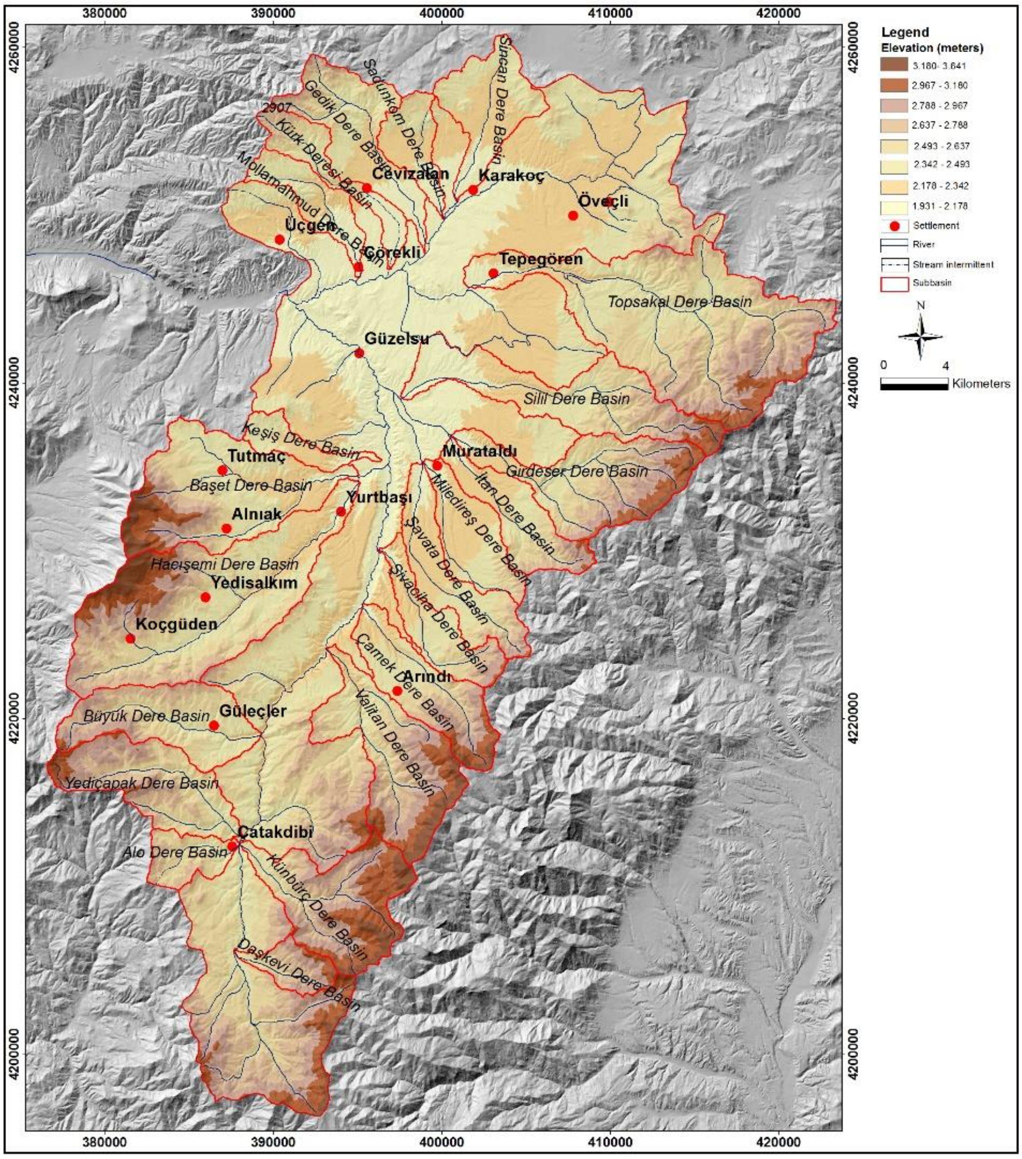
***Hypsometric integral (H_i)*:** To understand the stages of development in a region, an evaluation of the hypsometric curve and calculated H_i value obtained from drainage areas with different dimensions make it possible to represent which stage of young-balanced-mature the basins are in (Akyüz et al., 2010).

The minimum, maximum and mean elevation values for basins were obtained on DEM as histogram data. The H_i values in the east and southeast of the basin vary from 0.29-0.45, while in the SW they are 0.33-0.55 and in the NW 0.38-0.44. The highest integral values were measured in the SW in Keşiş Dere basin (basin number 1). This basin is located close to the basin capture area. When the hypsometric integral values of the basins are evaluated in general, the basins are determined to be in the advanced young stage with a moderate degree of tectonic effect (Table 1).

Table 1. H_i, B_s, R_e and AF Values for Selected River Basins in Güzelsu Basin

S-SE					SW				
Subbasins	H_i	B_s	R_e	AF	**Subbasins**	H_i	B_s	R_e	AF
Daşkevi Dere Basin	0.38	1.78	0.33	64.6	Keşiş Dere Basin	0.55	2.51	0.24	58
Künbürç Dere Basin	0.45	1.33	0.39	49.9	Başet Dere Basin	0.33	1.70	0.37	19.6
Valitan Dere Basin	0.42	1.72	0.33	66.2	Hacışemi Dere Basin	0.34	2.47	0.30	34.2
Çamek Dere Basin	0.38	2.47	0.30	34.1	Büyük Dere Basin	0.36	2.14	0.32	50.7
Şivaciha Dere Basin	0.40	2.43	0.28	58.8	Yediçapak Dere Basin	0.38	2.36	0.32	51.3
Şavata Dere Basin	0.29	2.71	0.26	54.12	Alo Dere Basin	0.47	1.44	0.39	48.7
Miledireş Dere Basin	0.31	2.30	0.30	60		**NW**			
İtan Dere Basin	0.39	2.49	0.28	45.7	Mollamahmud Dere Basin	0.44	2.02	0.28	46.2
Girdeser Dere Basin	0.42	2.28	0.30	84	Kürk Dere Basin	0.44	3.25	0.22	48.1
Sili Dere Basin	0.31	3.39	0.24	60.56	Gedik Dere Basin	0.41	1.94	0.28	64.19
Topsakal Dere Basin	0.38	1.98	1.30	34.2	Sadunkom Dere Basin	0.38	1.92	0.32	79.1
					Sincan Dere Basin	0.43	1.50	0.33	45

The lower reaches of the chosen basins are located on the floor of the Engil River Valley. Linked to this, the hypsometric integral values are found to be below 50 in subdrainage areas close to the basin floor.



Map 5. Subbasins where Morphometric Indices are Applied in the Güzelsu Basin (rearranged from HGM, 2004)

***Hypsometric curve (H_c)*:** Strahler (1952) classified three types of typical stages of dissection (erosion) in drainage areas based on the shape of the hypsometric curves as (i) young stage, (ii) mature stage and (iii) old stage. Concave-shaped curves are related to the young stage in a basin and show the region is less eroded and disrupted. Curves with an "S" shape indicated drainage in the moderate-mature stage and show moderate degree of erosion. Convex curves are formed by old drainage areas, with these areas very eroded and disrupted (Topal, 2018).

Hypsometric curves are drawn based on elevation-area distribution on DEM. The curve created for the Güzelsu Basin has a concave appearance. This situation is a result of the majority of the upper basin being equivalent to the basin floor (Fig. 2). When the hypsometric curves are evaluated for the subdrainage areas, basins of Keşiş Dere and Alo Dere (basins 1 and 6) in the SW have hypsometric curves with convex appearance, while the other basins display an S appearance (Fig. 3). When the hypsometric curves for the drainage area located east of the Zernek Dam in the Güzelsu Basin are evaluated, apart from Sadunkom Dere basin (number 4 basin), the other basins appear to display convex curves. The hypsometric curves for the basins have falls indicating different periods (Fig. 4). In the drainage areas to the southeast of the Güzelsu Basin, Künbürç Dere basin (number 2 basin) has a convex appearance, while the others have an S-shaped appearance (Fig. 5).

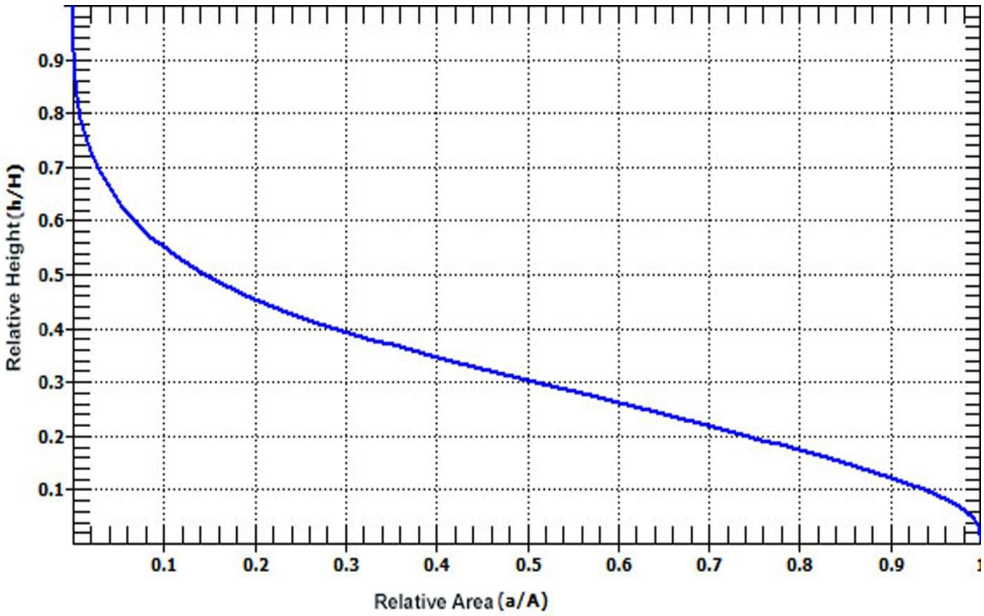


Figure 2. The Hypsometric Curve of the Güzelsu Basin

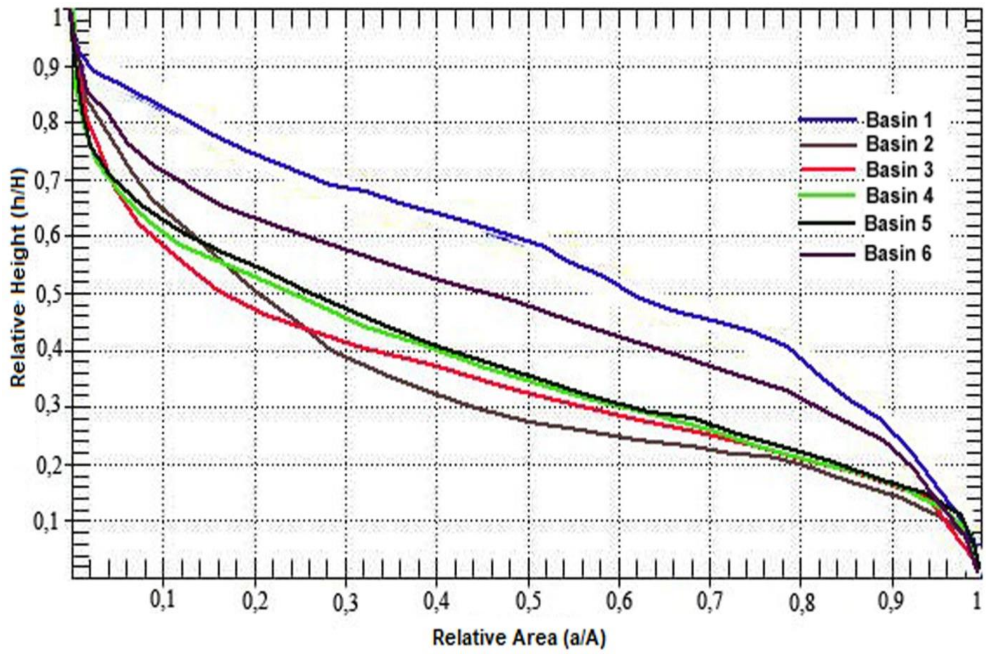


Figure 3. The Hypsometric Curve of the Lower Drainage Areas in the SW of the Güzelsu Basin

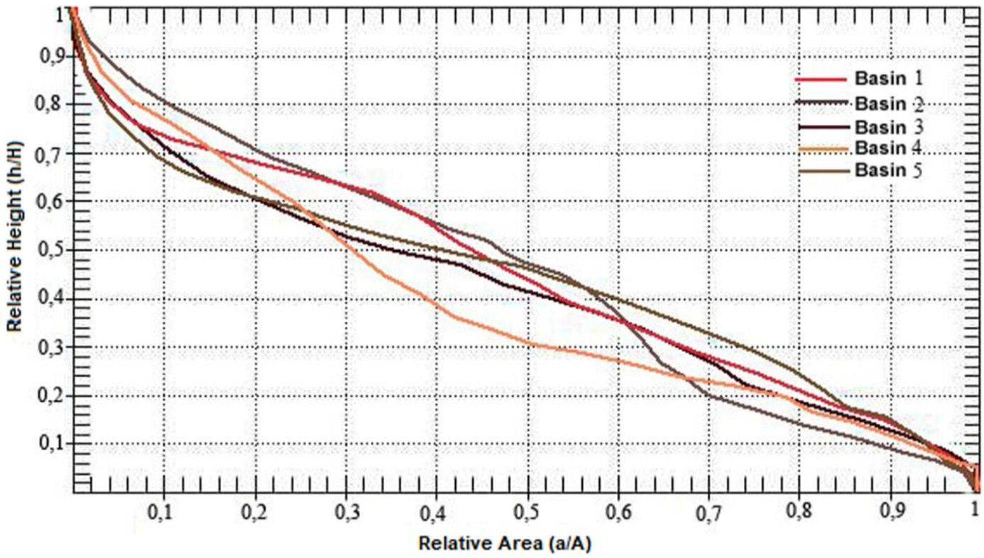


Figure 4. The Hypsometric Curves of the Lower Drainage Areas in the NW of the Güzelsu Basin

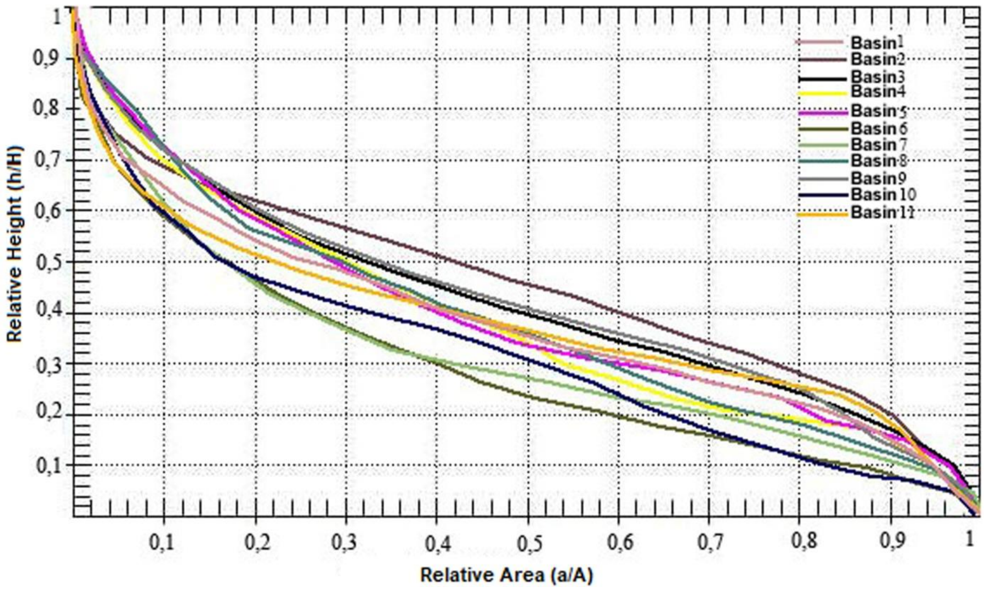


Figure 5. The Hypsometric Curves of the Lower Drainage Areas in the SE of the Güzelsu Basin

Basin shape (B_s): The B_s values for drainage areas determined in the Güzelsu Basin vary from 1.33-3.39 in the SE, 1.44-2.51 in the SW and 1.50-3.25 in the NW. The subdrainage basins in the Güzelsu Basin generally have a lengthened shape. These lengthened drainage basins show high effects of tectonism.

***Elongation ratio (R_e)*:** The elongation ratios for the Güzelsu Basin are 0.4-1.30 in the S-SE, 0.24-0.39 in the SW, and 0.22-0.33 in the SW. Apart from Topsakal Dere basin (number 11 basin) in the SE, all basins have R_e values of about 0.5 or lower.

***Drainage basin asymmetry (AF)*:** The asymmetry factor for the Güzelsu Basin was found to be 69.45. This result shows clear tectonic effects in the upper basin. Linked to the asymmetry, the total length of tributaries entering the main river from the east and southeast (2642.27 km) in the Güzelsu basin is greater than the total length of tributaries joining the river from the southwest (1096.69 km) (Fig. 6). The *AF* values were calculated for all drainage areas apart from the main basin and it appears all basins have asymmetric structure. The asymmetric appearance of the main and subbasins reveal tectonic effects (Table 1).

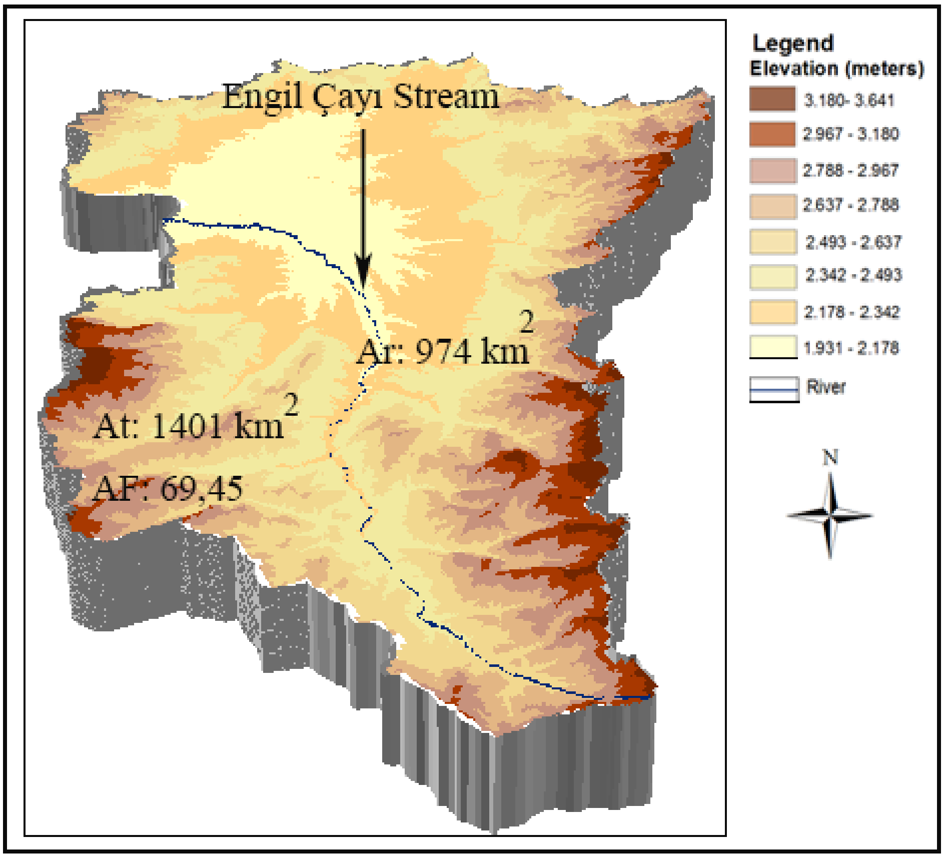


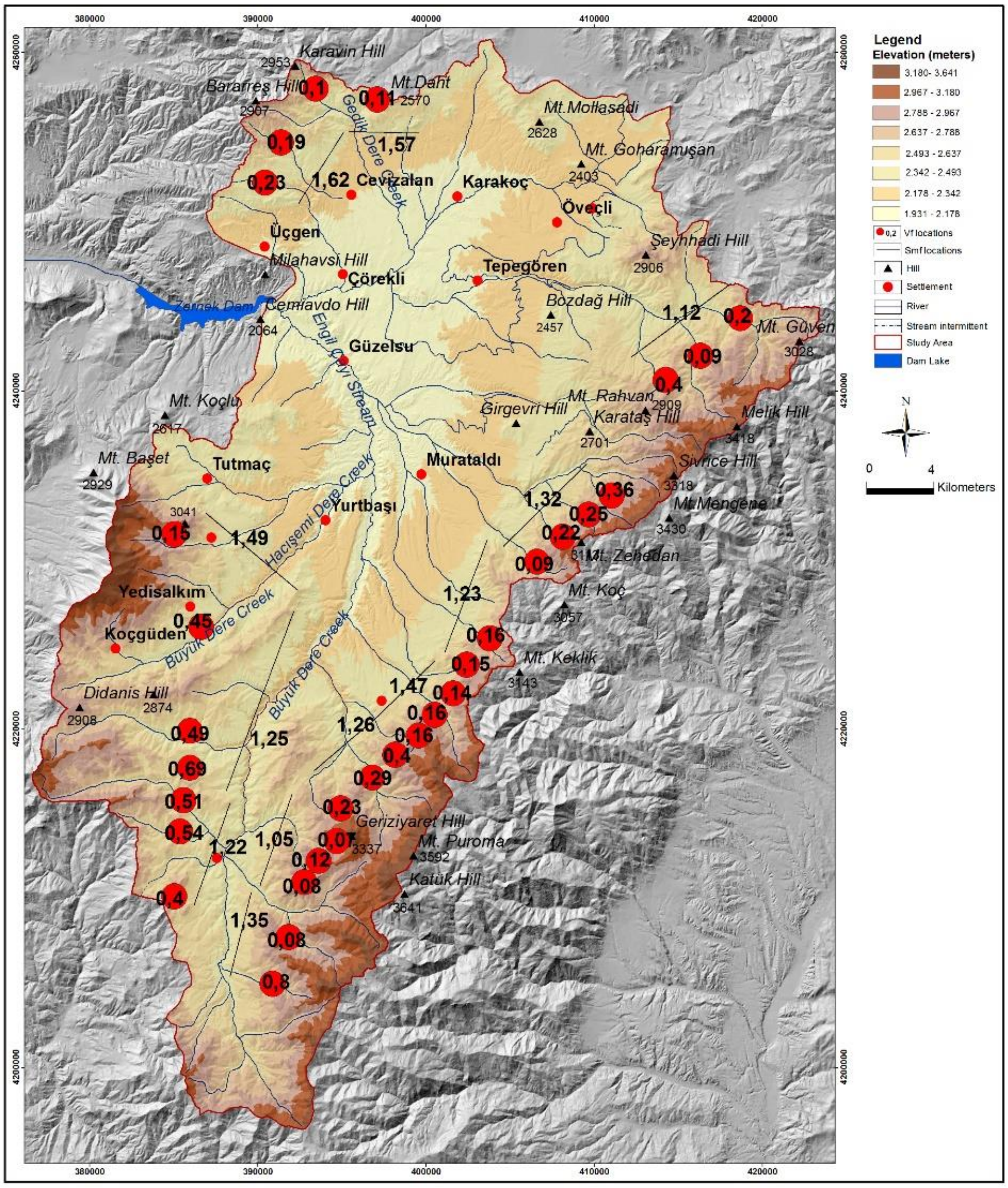
Figure 6. The Asymmetry of Güzelsu Basin

Photograph 6. The View from the Mountain Fronts in the South-West of the Güzelsu Basin

***Mountain front sinuosity ratio (S_{mf})*:** Mountain fronts bounded by active faults have low S_{mf} values (S_{mf}<1.4), while high S_{mf} values (S_{mf}>3.0), indicate nontectonic mountain fronts and here erosion is more dominant (Keller and Pinter, 2002; Silva et al., 2003; Bull, 1977; Pérez-Peña et al., 2010). In the study area,the S_{mf} values are 1.35-1.12 in the S-SE, 1.22-1.49 in the SW and 1.57-1.62 in the NW.

For the whole basin, especially in the S-SE, the S_{mf} values are very low (Map 6). This situation shows greater elevation linked to the compressional tectonic regime.

Valley width-height ratio (V_f): The increase or decrease in V_f values is completely linked to the shape of the valley. "V" shaped valleys have low V_f value with high uplift rates (Bull and McFadden, 1977; Rockwell et al. 1985; Silva et al., 2003; El Hamdouni et al., 2008). In the Güzelsu Basin, V_f values are very low in the S-SE. In the S-SE V_f values are 0.07-0.4, in the SW 0.15-0.69 and in the NW 0.1-0.23. Areas with low V_f values contain deep valleys linked to uplift. 11 basins (Daşkevi, Künbürç, Valitan, Çemek, Şivaciha, Şavata, Miledireş, İtan, Girdeser, Sili ve Topsakal Dere basins) in the S-SE direction in the study area have deep valleys when compared to other basins.



Map 6. S_{mf} and V_f Measurement Points in the Güzelsu Basin (Rearranged from HGM, 2004)

Conclusion

After the Miocene continent-continent collision, intermontane basins formed as a result of compression in the regional surroundings (Fig. 1). The Güzelsu Basin found north of the collision zone is one of these basins. Formed of high and old units and surrounded by mountains, the Güzelsu Basin has morphologic, hydrologic and geologic basin features. The role of regional tectonics was great in attaining the current shape of the basin. Currently the 1600 m elevation difference between the lowest and highest areas within the basin reflects the power of tectonism.

The environmental conditions beginning the formation of the Güzelsu Basin in the Pliocene are represented by lacustrine and fluvial environment sedimentation in the basin (Büyükçay Formation). These units are observed at higher elevations in southern sections of the basin linked to tectonism. These Plio-Quaternary-aged units are observed at elevations nearly 200 m higher in the southern sections compared to the north. This situation indicates that in the basin tectonism was more effective in the south and relatively less effective in the north. At the same time, this shows the direction of compressional tectonics.

The Güzelsu Basin was a closed basin independent of the Engil River Valley before the Quaternary. The Güzelsu Basin was captured by the Engil River in the Quaternary in the west of the basin and added to the Lake Van Closed Basin. The turn in the west of the Güzelsu Basin in the main bed of the Engil River (Photo 5) is a capture turn; this is supported by findings such as ***i***- the area before this turn (Güzelsu Basin) covers large areas of units belonging to the Büyükçay Formation (Photo 2, 3), ***ii***- these units do not appear outside of the morphologic bowl, ***iii-*** observation of a hooked drainage network immediately above the river bend (Photo 4), and ***iv-*** the lack of similarity between morphologies in the Engil River lower basin and upper basin (Maps 1, 2).

In the process of deep incision of the river occurring in contrast to the uplift of topography linked to compressional tectonics, faulting has an important share. These processes were effective in the capture of the basin by the Engil River. The basin captured in the Quaternary was added to the Lake Van Basin and rapidly emptied by the Engil River. The mean elevation value of the Güzelsu Basin is 2460 m, with a mean slope value of %25.81. The high mean elevation and slope show the basin was exposed to the effects of tectonism.

The morphometric analysis results used in the study comply with observations made in the field. Accordingly, the hypsometric integral value for the main basin was 0.32. The H_i values vary from 0.29-0.45 in the S-SE, 0.33-0.55 in the SW and 0.38-0.44 in the NW. The B_s values for the Güzelsu Basin and selected subdrainages vary from 1.33-3.39 in the S-SE, 1.44-2.51 in the SW and 1.50-3.25 in the NW. All basins have lengthened shape. This situation proves tectonic activity. The S-SE elongation ratio (R_e) is 0.24-1.30, this is 0.24-0.39 in the SW and 0.22-0.33 in the NW. Apart from Topsakal Dere basin (basin number 11) in the SE, and all basins have a R_e value lower than 0.5. Basins with R_e value <0.5 are proven to have high tectonic activity.

The asymmetry factor of the Güzelsu Basin was found to be 69.45. Linked to this, the main river in the study area is fed more from the east and southeast. All subdrainage areas have asymmetric appearance. This situation shows high tectonic effect in the basin. The S_{mf} values are 1.35-1.12 in the S-SE, 1.22-1.49 in the SW and 1.57-1.62 in the NW. All basins, especially in S-SE have very low S_{mf} values. This situation shows uplift linked to the compressional tectonic regime was greater. The Güzelsu Basin has very low V_f values in the S-SE. The V_f values vary from 0.07-0.4 in the S-SE, 0.15-0.69 in the SW and 0.1-0.23 in the NW. These very low S_{mf} and V_f values clearly show the tectonic effect in the upper basin.

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