EVALUATION OF EROSION PRONE AREAS IN ARDAHAN DISTRICT CENTER WITH MORPHOMETRIC INDICES

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ABSTRACT

In this study, which evaluated potential areas for surface and gully erosion using morphometric analyses in the central district of Ardahan where is located in northeastern of Turkiye, stream power index, compound topography index and slope position index calculations were performed. Based on the findings, stream power index values in the study area ranged from -15,89 to 12,15. The stream power index shows positive values on the Upper Pliocene- Lower Pleistocene andesite bedrock, particularly in the western part of the Ardahan Plain. These areas are where gully erosion is well developed. Compound topographic index values range from -6.908 to 14.194. Negative index values are observed on the tuff-agglomerate and metamorphic rocks in the southeast of the study area and on the faulted topography in the northern part. Therefore, these lands are important for the development of surface and finger erosion. Land surfaces with a slope of "0" and a compound topography index of "100 +" correspond to the Ardahan Plain alluvial field and the older alluvial fields in the southern part. These flat and nearly flat lands were identified as areas where material eroded from the bedrock was deposited.

1.0 INTRODUCTION

The soil we live on is considered a living layer, developed over thousands of years by living organisms, along with time, climate, and vegetation, through the biochemical and physicochemical processes of the bedrock. The formation of an average 2,5 cm thick layer of soil requires a long period of approximately 500 years (Bahtiyar, 2003).

The danger of erosion, which is considered to be one of the issues that attracts more attention especially in today's conditions, is losing its productivity as the top surface of the soil is eroded and transported as a result of both natural conditions and human activities and accumulated in lower areas. The Word erosion is derived from the Latin Word "erode" and is translated into Turkish as "gnawing" (Atasoy & Özşahin, 2014). Soil erosion, which is considered as a slow-developing mass movement, creates difficulties in diagnosing it because many parameters that form the soil come together in a complex structure and complete their development over a long period of time. After the 1950s, food demand increased in parallel with global population growth and technological advances. To meet demand, agricultural land was expanded through the destruction of vegetation, the removal of trees from forest, and slash-and-burn practices. Erosion, which normally occurs under human influence, has transformed into accelerated erosion (Mater, 2004).

The first studies on soil erosion were conducted by German scientist Ewald Wollny in 1988 with his work "Pioneer of soil and water conservation reserch" (Baver, 1938). Wollny

suggested that soil properties, surface runoff, slope conditions, and vegetation caused compaction in the soil development of soil erosion. These views led American geographers to focus on soil erosion in the 1930s (Nelson, 1958). Soil erosion was studied quantitatively by American geographers in 1912 in overgrazing areas in Utah (Sampson & Weyl, 1918; Chapline, 1929). Studies aimed at determining soil erosion increased sharply after the 1920s (Bennet & Chapline, 1928). Pilot studies were initiated in states within the Corn Belt of the USA to understand the development of soil erosion. Based on reports from the pilot areas, Smith and Wischmeier developed equations for soil erosion (Smith & Wischmeier, 1962). Some of the equations are presented in Table 1.

Table 1. Equations developed for the prediction of soil erosion since the first half of the 20th century.

Equation (for erosion prediction)	Founder of equality
$X = C.S^{1.4}.L^{1.6}$	Zinng, 1940
$A = C.S^{7/5}.L^{3/5}.P$	Smith, 1941
$A = f(T*S*L*P*K*I*E*R*M)$	Van Doren & Bartelli, 1956
$A = R*K*L*S*P$	Wieschmeier, 1959
$S = 1280. Q^{0.46}.(1,43-0,26. \log A)$	Dendy & Bolton, 1976
$G = \int Di.dx + \int Dr.dx = Gi + Gr$	Foster et al., 1977a
$Y = 11,8. (Vq_p)^{0.56}.(K).(C).(P).(LS)$	Williams & Berndt, 1977
$Y = 0,001846.Aa^{-0.1187}$	Renard, 1980
$dqs/dx = D_L + D_F$	Foster et al., 1981
$SSY = 4139.A^{-0.44} + 7,77.FSM\ Index - 310,99$	Verstraten et al., 2003
$SSY = 0,0194.A^{-0.2}.R^{0.7}.Sl^{0.3}.SE^{1.2}.S^{0.7}.V^{0.5}$	Lawrance et al., 2004

This study evaluated the impact of tectonic activitiy on surface and gully erosion, defined as the natural erosion state, using morphometric indices in the Ardahan district center, located in the northeastern most part of Turkiye. In this context, the current status was determined by including the stream power index, compound topography index, and slope position.

1.1 Geographical Characteristics of the Study Area

The Ardahan district center is a study area located within the borders of Ardahan Province in northeastern Turkiye, encompassing an area of 120.031 hectares through which the Kura River and its tributaries flow (Figure 1). The study area consists of volcanic, sedimentary, and metamorphic rocks. 70,36% (84.455 ha) of the study area consist of volcanic andesite, basalt, tuff, agglomerate, dacite, and pyroclastic rocks. Andesite constitutes the largest proportion of volcanic rocks (43,84%- 52.622 ha). This Upper Pliocene-Lower Pleistocene rock group surrounds the Ardahan Plain. The most abundant volcanic rock group in the distribution consists of basalt, tuff, and agglomerate (14,28%). This Upper Miocene-Lower Pliocene volcanic rock group exhibits a fragmented appearance in the east of the study area and around the plain floor (Table 2). To the west of Ortatepe in the southeast of the study area, the Pliocene tuff- agglomerate series, dissected by Ağıl Creek and its tributaries, are cut by east-west and northwest-southeast trending faults. Upper Pleistocene basalt bedrocks are exposed in the south of this volcanic rock group. Pyroclastic rocks of the Upper Pliocene volcanic rock group form a group cut by north-southwest trending faults in the extreme southeast of the study area (Karaköse et al., 1994; Figure 2).

Quaternary alluviums, which cover a wide area from the central part of the study area westward and form an intramountain plain, were formed by the Kura and its tributaries, carrying material from the surrounding andesite, basalt, tuff, and agglomerate bedrock groups. Old alluviums are located in the south of the study area, westward from Ağılyolu Hill and in the southern part of Karayolu Hill. Upper Pleistocene conglomerate, sandstone, and mudstone bedrock groups are located in the south of the study area between Kayak Hill and Kartal Hill, north of the tuff-agglomerate series in the southeast, and northeastward from the northwest of Feto Hill. These metamorphic rock series are subject to faulting extending in northwest-southeast and northeast-southwest directions. In terms of structural geology, the faults within the study area are considered to be within the Eastern Anatolian compressional regime. The faults in and around Ardahan exhibit northwest-southeast and northeast-southwest extensions, and secondary fault lines intersect these fault lines et acute angles (Karaköse et al., 1994; Figure 2).
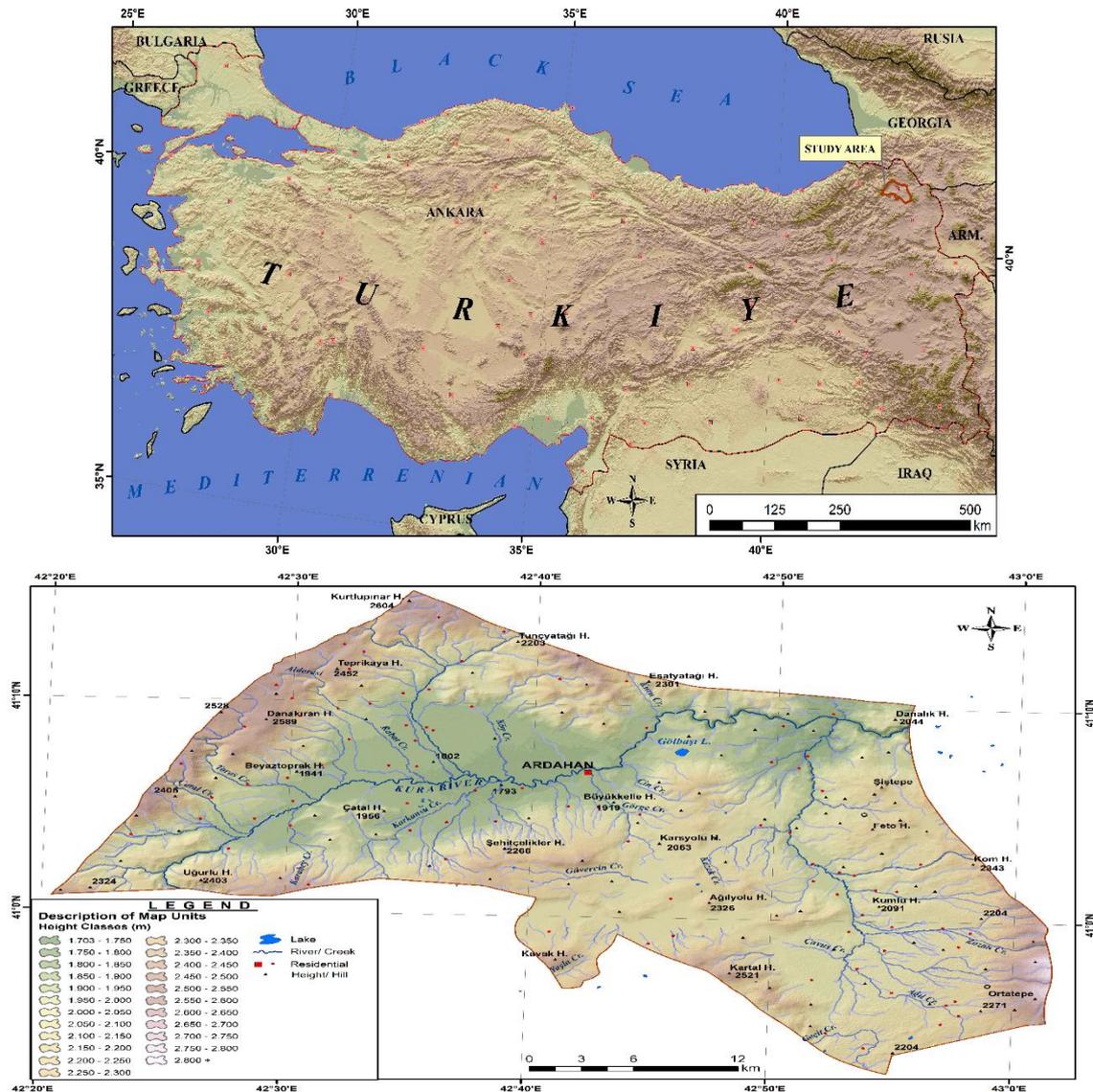

Figure 1. Location map of study area.

Table 2. Distribution and ages of the main rock groups forming the central district of Ardahan (produced from MTA 1/25.000 scale F48 and F49 sheets).

Lithological Units	Age	Area (hectare)	Rate (%)
Alluvium	Quaternary	16.899	14,079
Alluvial fan	Quaternary	1.423	1,186
Andesite	Upper Pliocene- Lower Pleistocene	52.622	43,840
Basalt	Upper Pleistocene	3.139	2,615
Basalt- Tuff- Agglomerate	Upper Miocene- Lower Pliocene	17.137	14,277
Dasite	Upper Pliocene	45	0,037
Old alluvium	Quaternary	2.762	2,301
Pyroclastic rock	Upper Pliocene	6.158	5,130
Tuff- Agglomerate	Pliocene	5.354	4,461
Slope debris- Debris cone	Quaternary	1.284	1,070
Conglomerate- Sandstone- Mudstone	Upper Pleistocene	13.208	11,004
TOTAL		**120.031**	**100**

The elevation values in the central district of Ardahan are between 1.703 and 2.859 m. The highest point in the study area, with an average elevation of 2.071 m, is composed of pyroclastic rock groups forming the northeastern part of Ortatepe in the southeastern part.
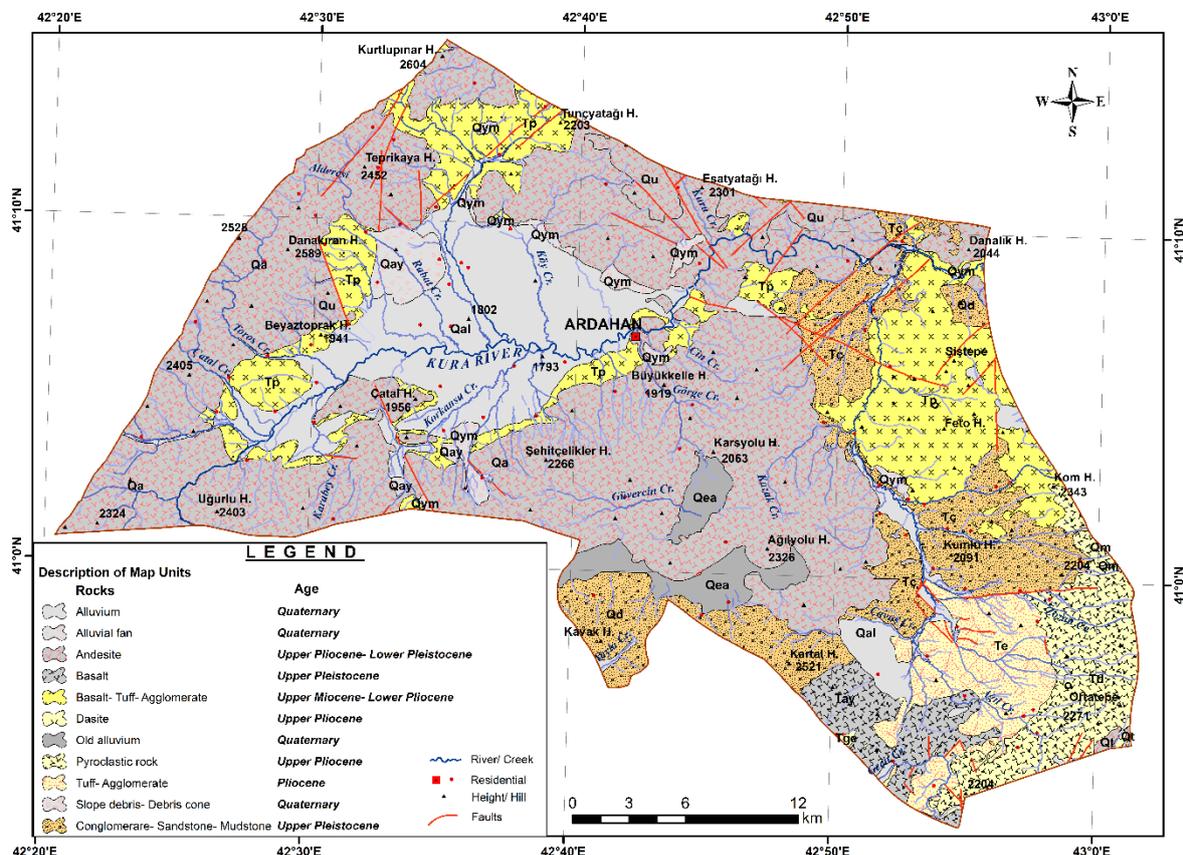
Figure 2. Geological map of Ardahan district center.

Slope conditions in the study area vary between 0 and 66,49°. The average slope of the study area is 8,2°. The areas with the highest slopes in the study area are the areas around Uğurlu Hill, located west of the Ardahan Plain, and the Çatal and Toros creeks flowing to the north. Surface and gully erosion throughout the study area, particularly in the western sections where slope values are high, occur at the intersection of the andesite-tuff-agglomerate series located in the north and southwest of the Ardahan Plain (Figure 3).
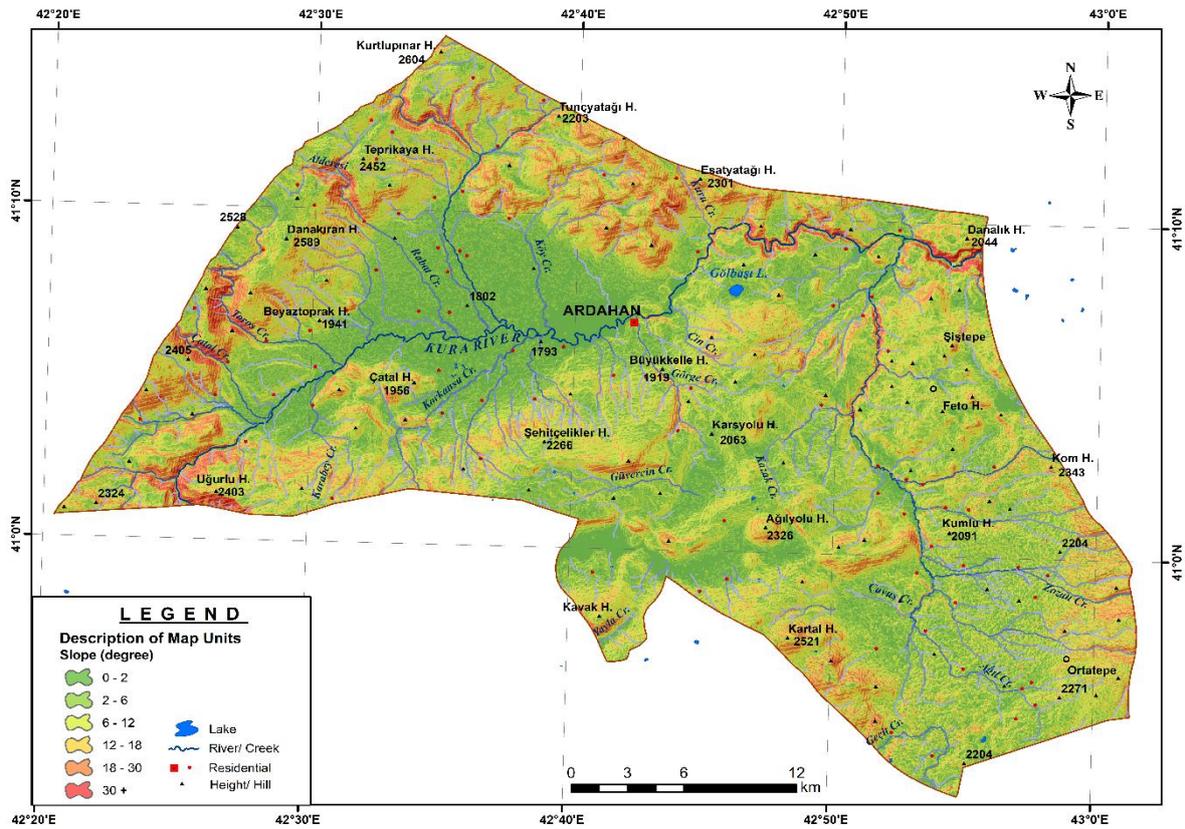

Figure 3. Slope map of Ardahan district center.

2.0 MATERIALS and METHODS

2.1 Materials

Digital Elevation Model is used as the basic data by many researchers (Waikar & Nilawar, 2014; İmamoğlu, 2020; Yıldırım, 2021). In this context, 17 topographic and geological sheets (F49a4; F48c2-3-4; F49c1-2-3-4; F49d1-2-3-4; G49a2; G49b1-2; F50d4 ve G50a1) at a scale of 1/25.000 published by the General Command of Mapping were used in the creation of the elevation model and geological map of the study area. ArcGIS software was used in the production of morphometric analyses, and the distribution of the main rock groups was calculated in Excel software.

2.2 Methods

To determine the surface and gully areas in the study area and to conduct morphometric analyses of the stream power index, compound topographic index, and slope position, 10 m isohypse series were first drawn manually on topographic maps of the Ardahan Central District. WGS 84 Zone 38N was used to coordinate the isohypse and other layers. The digitized isohypse series were converted to a Digital Elevation Model (DEM) using the "topo to raster" plugin within 3D Analyst. The generated DEM was first "filled" with the ArcHYDRO tool. "Flow direction" and "flow accumulation" operations were performed with this data, respectively. To calculate the stream power index and compound topography index, the "slope" analyses of the study area was calculated as "%" using the "Surface" plugin in ArcGIS. The data generated in raster format was processed with "Map Algebra" in acoordance with the literatüre.

spi= ln(flow accumulation+.001)*((eğim/100)+.001)= ln((DAi*tan(Gi) (Galzki vd., 2015)

DA= Drainage area
Gi= Tangent of the slope
   =Ω= pgQs (Bognauld equation)
Ω= Flow power per unit length of the flow channel (W/m)
P (rho)= Water density (1.000 kg/m3)
g= Gravitational acceleration (9,8 m/s2)
s= Channel slope

According to Bognaul's equation, the stream power index per length of stream in the channel is calculated as the kinetic energy in Watts per unit length, multiplied by stream flow rate, gravitational acceleration, and slope. Therefore, erosion occurs depending on the bedrock resistance of the streambed.

The compound topography index (cti) value calculation was created by comparing the raster format maps of the flow total and slope to each other.

cti= ln(flow accumulation+.001)/ ((eğim/100)+.001)

The slope position map provides information about whether the valley is concave, convex or complex and was created with the "curvature" add-on within the ArcGIS "Spatial Analyst" tool.

3.0 FINDINGS

3.1 Stream Power Index

Streams, with their kinetic energy, corrode the rocks over which they flow in proportion to their resistance. Gully erosion, considered the most severe form of erosion, develops its grooves parallel to the slope values. Streams flowing over steeply sloped, non-resistant rocks erode the topography, creating deep fissures. Soils developing on these lands lose their fertile soil layers to the power of the streams (EVAAL, 2014). Lands with high stream power indexes also indicate ongoing tectonic activity (Schumn et al., 2000; Burbank & Anderson, 2001).

In the central district of Ardahan, stream power index values range from -15,89 to 12,15. The average stream power index was determined to be 0,13, indicating that the erosion phase

continues in the study area and that gully formations are under the control of external forces. The areas with the highest spi (stream power index) values in the study area are the Upper Pliocene-Lower Pleistocene andesites in the west. The areas around Uğurlu Hill, through which the Kura River flows, and the areas immediately north of this area between Çatal Creek and Toros Creek are areas where gully formations are well developed. The Kura River, located northeast of the study area, flows through a high-gully formation from north of Gölbaşı Lake to south of Danalık Hill. The development of high spi values in this area is directly related to tectonic activity. In addition, the Kura River is directed by the fault, parallel to the structure. This area, which flows within the northeast-southwest fault, is located approximately 6 km west of Danalık Hill (Figure 4).

Areas with high second-level spi values within the study area are the land surfaces extending from the northwest of Ardahan Plain, forming a convex arc up to Esatyatağı Hill. Beyond this area, andesite fields dissected by the Yayla and Güvercin creeks to the south, and Upper Pleistocene basalts southeast of Kartal Hill, have moderate spi values.

The lands where the stream power index shows negative values consist of the alluvial lands within the Ardahan Plain, the south-southeast of the study area, the old alluvial lands belonging to the Quaternary located in the south of Ağılyolu Hill, and the alluvial fields through which Çavuş Creek flows (Figure 4).
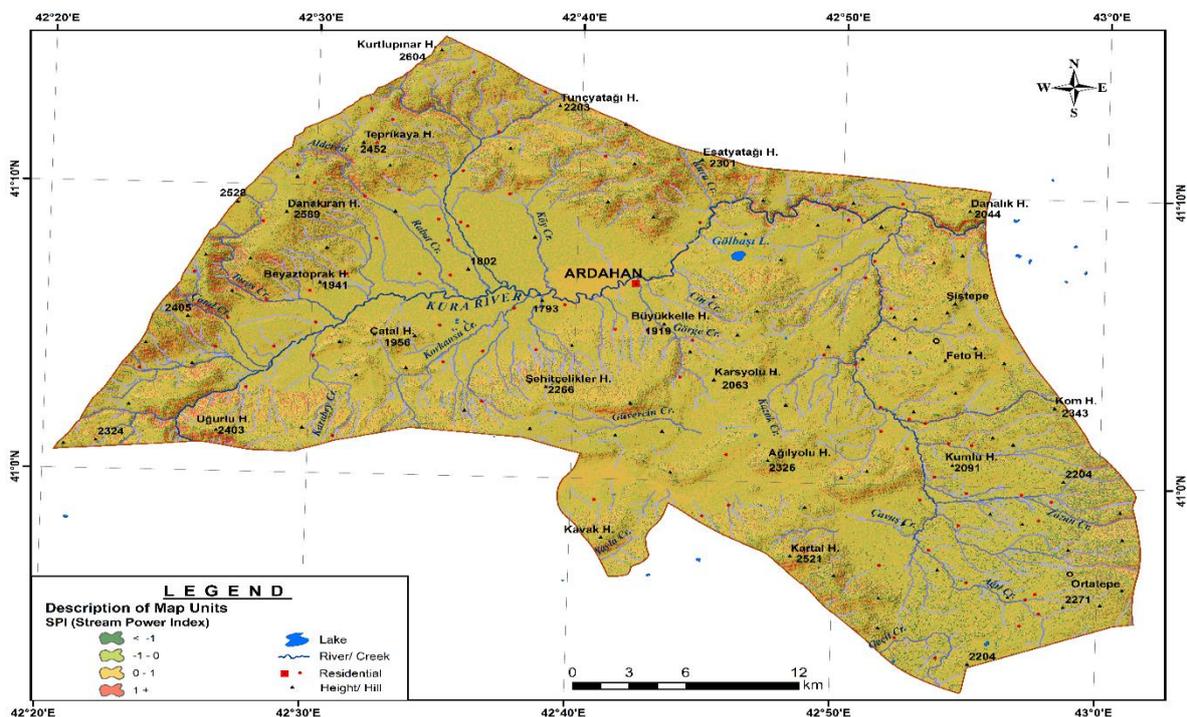

Figure 4. Stream power index map of central district Ardahan.

3.2 Compound Topographic Index (cti)

In contrast to the stream power index, in the calculation of the compound topographic index, surface and finger erosion development areas can be determined by taking the logarithm of the

percentage slope values of the basin area. In the calculation of the compound topographic index, many components that make up the soil, such as the amount of soil organic material, phosphorus content, and clay-silt ratio, are related (Moore et al., 1991). The compound topographic index calculation by Gessler et al.;

cti= ln(As/tanβ) in the formula, As= specific collection area is defined as m2 per unit width perpendicular to the flow direction and β represents the slope angle expressed in radians (Gessler et al., 1995).

In the central district of Ardahan, compound topographic index values range from -6.908 to 14.194. The average cti value was calculated as 28,97. The lowest cti values are found in the plateau areas surrounding the Ardahan Plain and in the areas where Ağıl Creek, which flows over Pliocene tuff-agglomerate series in the southeast, receives its sources. Therefore, these land surfaces were identified as providing suitable conditions for the development of surface and finger erosion. These land surfaces, where the compound topographic index shows negative values, can be considered to have a weak vegetation cover. As a result of degradation of Scots pine forests in the natural environment and their conversion into pasture lands and excessive exposure to animal grazing, the index values on these lands have become negative.

The highest cti values in the study area are found in the Quaternary Ardahan Plain alluvial fill area, the old alluvium located in the southern part of the center and extending east-west, and the eastern section of Feto Hill. These areas have positive cti values because they are the storage area for sediments carried by Kura River and its tributaries (Figure 5).
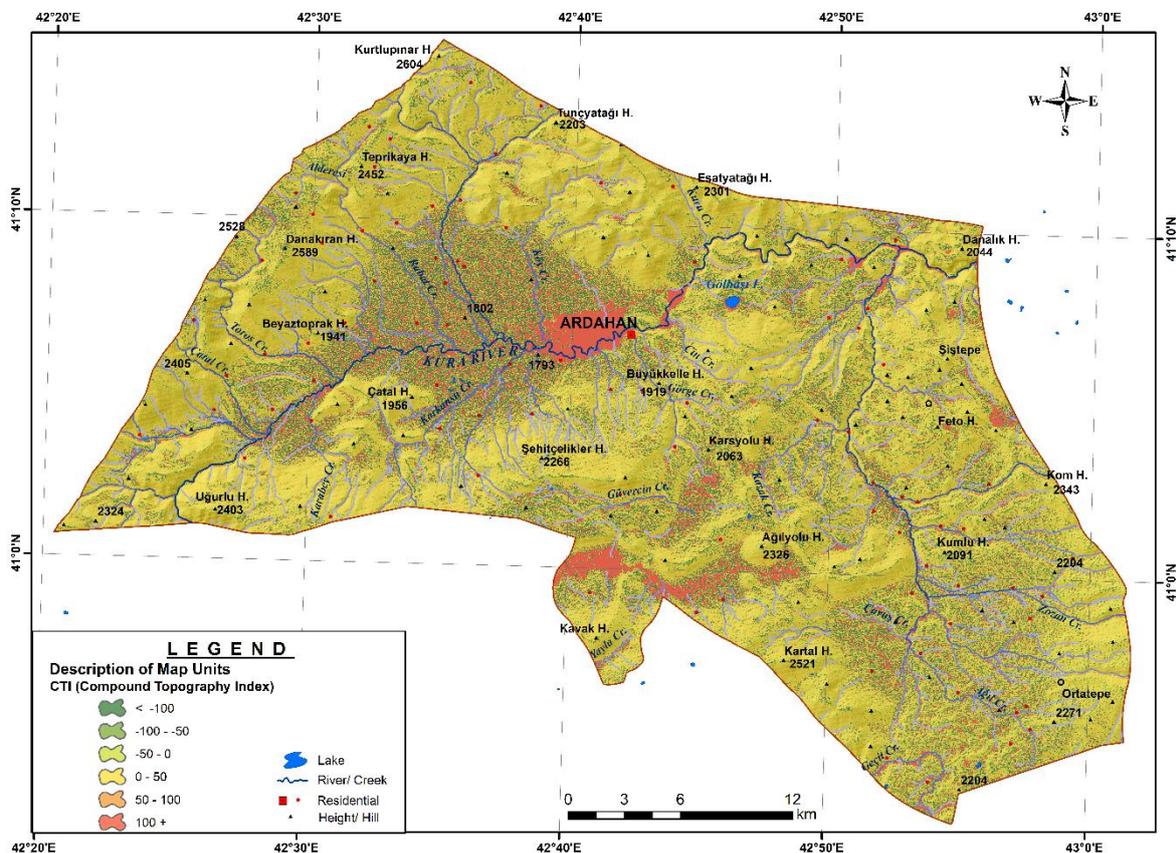
Figure 5. Compound topographic index map of cetral district Ardahan.

3.3 Curvature (Slope Position)

Slope position is particularly important as an indicator of tectonic activity in separating erosional and depositional areas in geomorphological units (Burbank & Anderson, 2001). Surface runoff, which is effective in the development of soil erosion, is shaped by the slope position in the topography. Convex slopes are considered to be at high risk for soil erosion. The lack of a sedimentation platform at the base accelerates sediment transport, which occurs along with surface runoff. Flat slopes are the second-highest risk, while concave terrain surfaces pose the least risk. Laboratory experiments conducted on concave terrain indicate that it poses two to three times less risk of erosion than flat and convex terrain. Laboratory experiments using 30 minutes artificial rainfall showed that concave slopes transported 0,02 t/ha of sediment, flat slopes transported 0,16 t/ha, and convex slopes transported 0,22 t/ha (Şensoy & Palta, 2009; Figure 6).
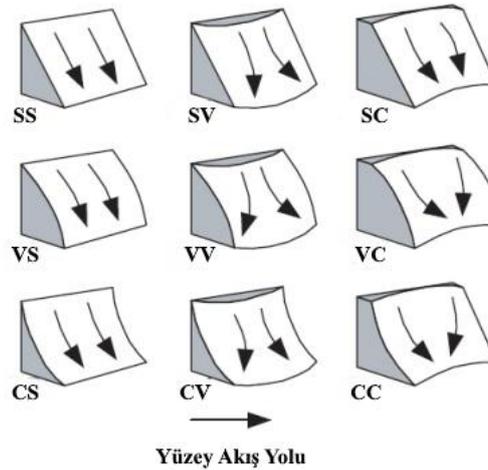

Figure 6. Slope forms and surface flows (Erdoğan, 2013).

Explanation: S-Flat; C-Concave; V-Convex

Depending on the slope position or valley floor flatness index, values ranging from -19,33 to 24,2 were obtained in the study area. The average valley floor flatness index was calculated as -0,08. Based on the slope position, stream power index, and compound topographic index values, it was determined that tectonic activity was weaker in the study area and that erosive forces played a greater role.

In the central district of Ardahan, a parallel pattern exists between the valley floor flatness index and the flow rate index. Positive slope values around Uğurlu Hill to the west of the study area, the lands between the Çatal and Toros creeks, and Danalık Hill to the northeast of the study area indicate that gully erosion has developed on these land surfaces. The flow rate index values confirm this situation. Areas where the slope position index is observed around "0" correspond to flat land surfaces, these areas include the Ardahan Plain, which constitutes the central part of the study area, the old alluvial lands extending east-west in the southern part,

and the areas extending approximately 3 km westward from Gölbaşı Lake. The lands located to the southeast of the study area are more concave in structure (Figure 7).
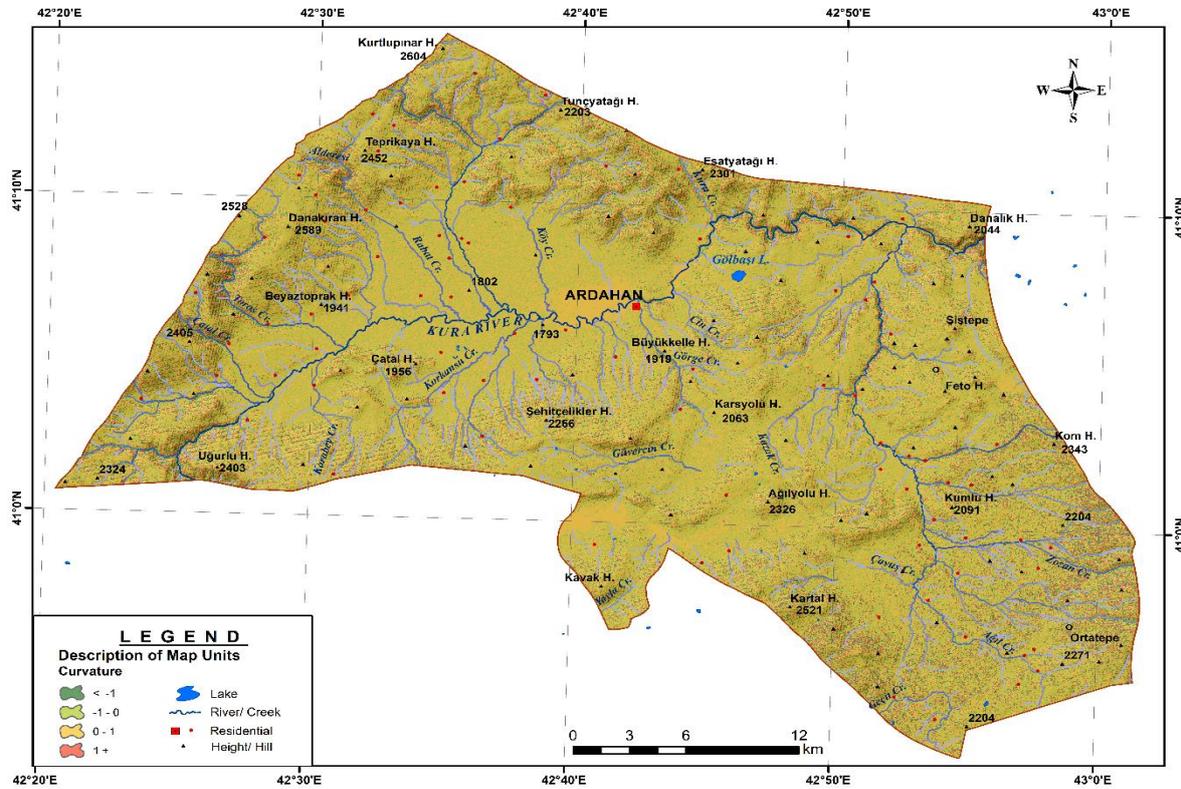

Figure 7. Slope position map of central district Ardahan.

4.0 CONCLUSION

In this study, conductedin the central district of Ardahan using morphometric indices to identify areas prone to soil erosion, utilized Geographic Information Systems. Topographic maps of the study area were digitized to create a digital elevation model for the central district of Ardahan and used as the primary dataset for morphometric analyses. Positive anomalies in the stream power index values obtained from the topography of the western part of the study area and around the Kura River bed in the northeast indicated evidence of gully erosion. The andesite lands located north of the Ardahan Plain are land surfaces where gully erosion develops to a secondary degree.

Findings from compound topographic indeks values indicate that surface and finger erosion develop on the tuff-agglomerate and conglomerate, sandstone, and mudstone terrains to the southeast of the study area. Furthermore, areas with valley floor flatness index values around 0 and compound topographic index values above 100 are considered areas where alluvium and old alluviums form supporting flat lands.

According to the stream power index, compound topographic index and slope position data in the study area, it was concluded that erosive forces replaced internal dynamics in the central district of Ardahan.

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