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Terrain morphometry and soil erosion topographic factor (LS) in upper Alazani basin (Georgia)

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ABSTRACT

Terrain morphometry, landforms, and the resulting LS component are generally acknowledged as important factors in soil erosion studies. The aim of this research was to identify and analyze terrain morphometric elements in the upper Alazani basin, as well as determine their impact on soil erosion. We examine terrain morphometry, identify landforms, and calculate the LS factor for the upper Alazani valley in this analysis. Arc map 10.8 was used to perform all calculations. For the measurements, an SRTM 1 arc-second DEM (resolution 30m) was used. The slope angle and slope aspect were calculated using the D8 algorithm. MFD analysis was used in order to calculate the flow path. As a result of it The flow accumulation was computed. Stahler's method was chosen to calculate stream order, which allows drainage density to be calculated. The slope position and the topographic position index (TPI) were computed. TPI values were obtained in order to obtain landforms. The MFD algorithm was used to compute the LS factor. In general, the LS factor is higher in Alazani's left tributaries than in its right tributaries. The maximum values were found in the Alazani headwaters, in the Samkuristskali channel, which is a tributary of the Alazani, and in the Stori channel. These results demonstrate that the upper Alazani valley has a high erosion potential. Future work should concentrate on the DEM resolution, which also has an impact on overall soil loss.

Keywords: Soil erosion, Landforms, LS, RUSLE, Alazani, Georgia

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Introduction

The fluvial geomorphological processes in the river basin are generally accepted to be complex and multifaceted. Many factors can affect the volume of runoff in a river basin, including glacial sediment, rockfall, sheet, rill, and gully erosion, weathering, etc. Soil erosion in river basins and the resulting sediment supply are inextricably linked [1], and they are the dominant geomorphic processes in many regions of the world [2]. Numerous experiments have already shown that these processes manifest differently in different geographical environments; for example, water erosion is a frequent and serious concern that impacts all European countries, although at different degrees [3]. In this case, a major current focus is on how topography plays a key role. Soil erosion models were the first to use topography factor modeling.

There are numerous methods for modeling the factors affecting soil erosion. The (Revised) Universal Soil Loss Equation - (R)USLE - is one of the most widely used models. Because of their simple, robust forms, USLE [4] and RUSLE [5] are still the most commonly used equations for estimating soil erosion [6]. The (R)USLE equation calculates average annual soil erosion by multiplying several factors together, including: rainfall (R) factor (MJ mm ha 1 h 1 y 1); soil erodibility (K) factor (Mg h 1 MJ 1 mm 1); slope length and steepness (LS) factor (dimensionless); cover management (C) factor (dimensionless), and support practice (P) factor (dimensionless).

Geomorphological research has been critical in the development and application of soil erosion assessment tools [3]. All terrain factors include terrain curvature, slope aspect, steepness, length, and direction [6]. Once runoff begins to flow across surface areas and into streams, the quantity and size of material transported increases with its velocity [3]. For soil erosion modeling, LS is the most important topographic factor.

The original equation for LS calculation is below:

LS=L*S (1)

L= (λ/22.13)m (2)

m=β(1+β) (3)

β=(sinθ)/[3*(sinθ)0.8+0.56] (4)

Where λ is the slope length, m is a variable exponent calculated from the ratio of rill-to-interrill erosion and β is the factor that varies with slope gradient.

S=10.8 sinθ+0.03, slope gradient≤9%

S=16.8 sinθ-0.50, slope gradient>9% (5)

Where, S is the slope factor, and θ is the slope angle.

USLE and RUSLE were originally designed for gently sloping cropland with a one-dimension topography factor (LS) [7]. In newer research for catchment-scale studies, the one-dimensional slope length factor of individual slopes in the USLE was replaced by the upslope contributing area to respect the topography of complex watersheds or vast two- or three-dimensional areas [8]. As a result, new methods and modifications to existing ones emerged. The most commonly used are the unit stream power method [9,10], the multiple flow direction method [11,12], and the upslope contribution area method and its improvement [13]. The authors of the paper [12] compared the values of the LS factor calculated by various methods with field data and concluded that MFD performed better than other methods in calculating the slope length and LS factor.

Because of the spatial nature of (R)USLE factors, they can be integrated with geographic information systems (GIS) [2]. The reliability of the calculated slope length and slope gradient (LS) factor is determined by the availability and precision of topographic data [14]. The LS factor is calculated in several steps, including depression filling, flow-direction and slope-steepness calculations, obtaining the slope length, and calculating the LS factor [6]. The combination of geographical information systems (GIS) and computer processing power allows better resolution input data to be used for modeling studies and projects [8]. GIS-based methods are one of the few ways to investigate the role of spatial variability in soil properties, rock types, and a variety of other geologic and climatic properties in landscape evolution [3]. The resolution and quality of the digital elevation models used in the study are a separate topic of discussion. It is well known that producing topographical map-based DEMs takes some time. In contrast, 2m resolution DEM yields lower mean LS values than 25m resolution DEM. As a result, the soil loss would be overestimated [8]. As a result, as grid sizes would be increased, the relative computation errors of the LS factors increased [14]. So far, it has not been systematically investigated whether different DEM resolutions produce different LS-factor values and whether the use of high-resolution DEMs produces higher L-, S-, and LS-factors [8]. According to studies, SRTM has a slight advantage over ASTER when using publicly available DEMs [15].

The goal of this research is to describe and analyze morphometric elements of terrain in the upper Alazani basin and assess their influence on soil erosion.

Study area

The upper reaches of the Alazani River are included in the study area (fig.2.A). The study area is 5309 square kilometers. The study area is distinguished by its mountainous terrain. The hydrographic network is quite frequent, as shown in fig. 1. The study area has a moderately dry subtropical climate. According to the meteorological stations here, there is 2-3 months of drought per year, with heavy showers following the dry period [16], which contributes to the intensification of floods and mudflows. According to historical records, a mudslide in Kvareli on May 23, 1899, destroyed 25 houses and destroyed 665 desetina (724.85 ha) of arable land and vineyards, killing 50 people [17]. A natural disaster struck Telavi on the night of June 14, 1977. This was due to the wet winter and spring. Previously, the river Telavi had a wide (30-40 m) ravine, a 1.5 km wide debris cone, and a length of up to 6 km. At the time of the disaster, the flow height was 1.6 m, the width was up to 50 m, and the flow rate was approximately 280 m3/s [18. The Tsivistskali flood on June 14, 1977, cost the Soviet farm in Tsinandali 60,000 manats ($ 44,400 at the time) and destroyed the growing vineyards [18]. There are numerous cases that are similar. This is why topography and morphometric analysis of topography are critical in assessing these fluvial geomorphological processes in the study area.

Methods and Materials

The primary source of information for this study was elevation data. The DEM used in the study, SRTM 1 Arc-Second (resolution 30 m), was obtained from www.earthexplorer.gov.com. It was projected WGS 84, UTM, 38N projection. All calculations were carried out in the following order in the software Arc map 10.8:

1. The Fill Sink tool was used to eliminate DEM anomalies;
2. The D8 algorithm was used in order to calculate slope angle and slope aspect (fig. 2.G and H);
3. MFD analysis was used to compute flow direction, the most basic geomorphometric attribute. The number of upstream cells that flow into each cell according to their flow directions was used to calculate flow accumulation. [2]:
4. Stahler method was chosen to calculate stream order (fig. 2.I), which provides a way of calculation of drainage density (fig.2.J);
5. On the basis of slope angle raster, slope position (fig. 2.E) and topographic position index (TPI) (fig. 2.F) were calculated [19]
6. TPI values were used for the purpose of obtaining landforms [19]. To make landforms smoother focal statistics (5X5) was used;
7. LS factor was calculated with the MFD algorithm [12].
8. Based on the filled DEM hill shade of the study area was created and it was used only for visualization of the results.

Results

As outlined in the introduction, the main purpose of this work was to analyze the morphometric features of the study area that directly or indirectly affect erosion and denudation, based on this analysis we performed a landform classification and determined the LS factor in this section.

Table 1. *Hypsometry of Stydy area, covered area and percent*

Elevation (m)	Area (sq. km)	Percent
100-200	72.0751	1.356
200-500	1843.371	34.72
500-1000	1457.1252	27.45
1000-1500	963.2614	18.14
1500-2000	466.627	8.79
2000-2500	302.001	5.69
2500-3000	190.7485	3.59
3000	14.5491	0.27

Table 2. *Slope (degree) of study area*

Slope	Area (sq. km)	Percent
0-5	1544.341	29.09
5--15	1478.729	27.85
15-30	1352.307	25.47
30-45	815.9882	15.37
45-	118.1547	2.22

Table 3. *Slope Apect of study area*

Aspect	Percent
Flat	3.8
N	10.73
NE	12.28
E	13.09
SE	13.19
S	13.07
SW	11.52
W	11.92
NW	10.40

According to Table 1, a large portion of the study area (34.7%) is located between 200 and 500 meters above sea level. This hypsometric step is best suited for resettlement and agricultural activities. In the 500–1000-meter hypsometric step, it lags slightly (27.4%). The area above 2500 meters is very small, accounting for only about 4% of the study area.

According to the data reported in table 2, which illustrated the slope angle value distribution the area is almost evenly distributed as a percentage, however comparing the results, we will see that the steep slopes cover a large part.

The slope aspect is another factor that does not directly affect soil erosion but is affected by the amount of heat and light received from the sun as well as the characteristics of the vegetation, which in turn affects depletion and runoff. Table 3 shows that slopes with an east, southeast, or south aspect predominate in the study area. This means that the area receives a lot of heat and light, and weathering processes will be active due to a lack of vegetation and relevant geological conditions.

The next step, the flow direction gives us a very good idea of the alluvial cones, allowing us to make a visual interpretation of the evidence for this is in fig.2.D. Automatic delineation of alluvial cones requires additional data and field surveys. In our case, we used flow direction raster to calculate flow accumulation, which in turn we used in further calculations, for example, we used it to automatically draw a stream network, after which we calculated the drainage density displayed in fig.2.I and J respectively. It is evident that the maximum values (1 km/km2) are on the alluvial cones near the Alazani channel. This figure is also important because it can affect the shape of the river hydrograph during storm events. A high drainage density indicates a high risk of flooding and a high bifurcation ratio, which means that the higher it is, the higher the risk of flooding. We used a flow accumulation raster to show the profile graph of some tributaries (in this case Duruji (fig.1.A) and Shavkaba (fig.1.B)). It shows the change in elevation of the surface along a line. In both cases, especially in the case of Duruji, the channel gradient is quite high.

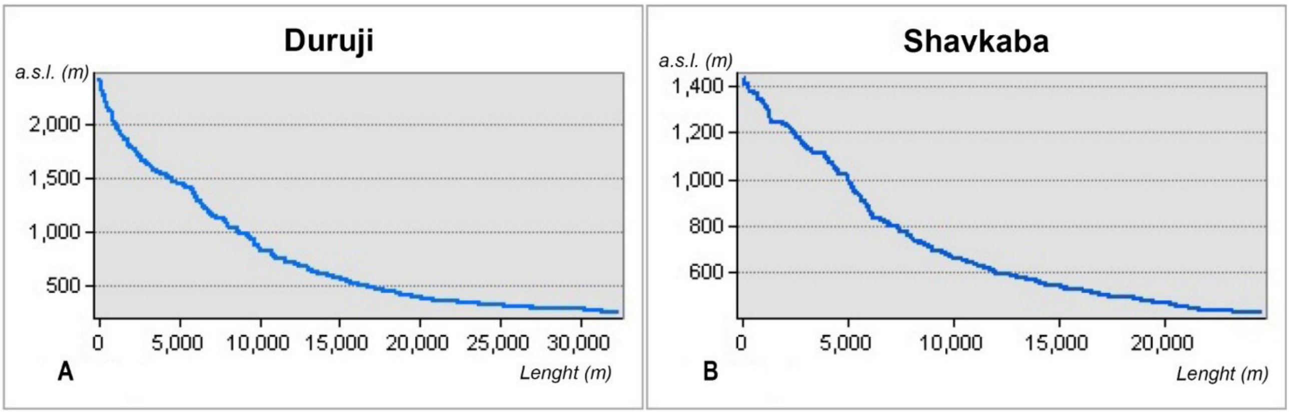

Fig. 1. *A. Profile Graph-Duruji; B-Profile Graph-Shavkaba*

The next step was landform classification. From fig.2.B it can be seen that we have identified 10 landforms. It helps us to identify various geomorphological features, including the visual interpretation of alluvial cones.

Finally, there is the topographic (LS) factor for the study area. It stands to reason that the high LS values corresponded to the highland valleys. Figure 2.C shows that the highest values are found in the Alazani headwaters, in the Samkuristskali channel, which is a tributary of the Alazani, and in the Stori channel. According to fig. 2.C, the LS factor is relatively high in the case of Alazani's left tributaries compared to right tributaries.

Our findings strongly support previous predictions. It should be noted, however, that in this case, the LS values describe the overall picture and indicate the spatial distribution of the min and max LS values.

Conclusion

Prior works have documented the importance of the LS factor in soil erosion studies. In this paper, we used the Weiss and MFD algorithms to delineate landforms and assess the LS factor in the upper Alazani valley's terrain morphometry. Our results provide compelling evidence that the study area is characterized by high erosion potential. Our results are in general agreement with previous studies in the landform classification. Our current findings expand prior works with the assessment of LS factor for the study area. Our results mean that the upper Alazni valley is very sensitive to the factors affecting erosion. In our case, we analyzed only the topography factor. An important question for future studies is to analyze each factor to see and/or calculate overall soil loss in the study area. Future work should focus on the DEM resolution because it has a huge influence on the maximum values of LS factor, which on the other hand affects the results of soil loss. However, our calculations give the general overview of the spatial distribution of minimum and maximum LS values but further detailed calculations need better DEM resolution.

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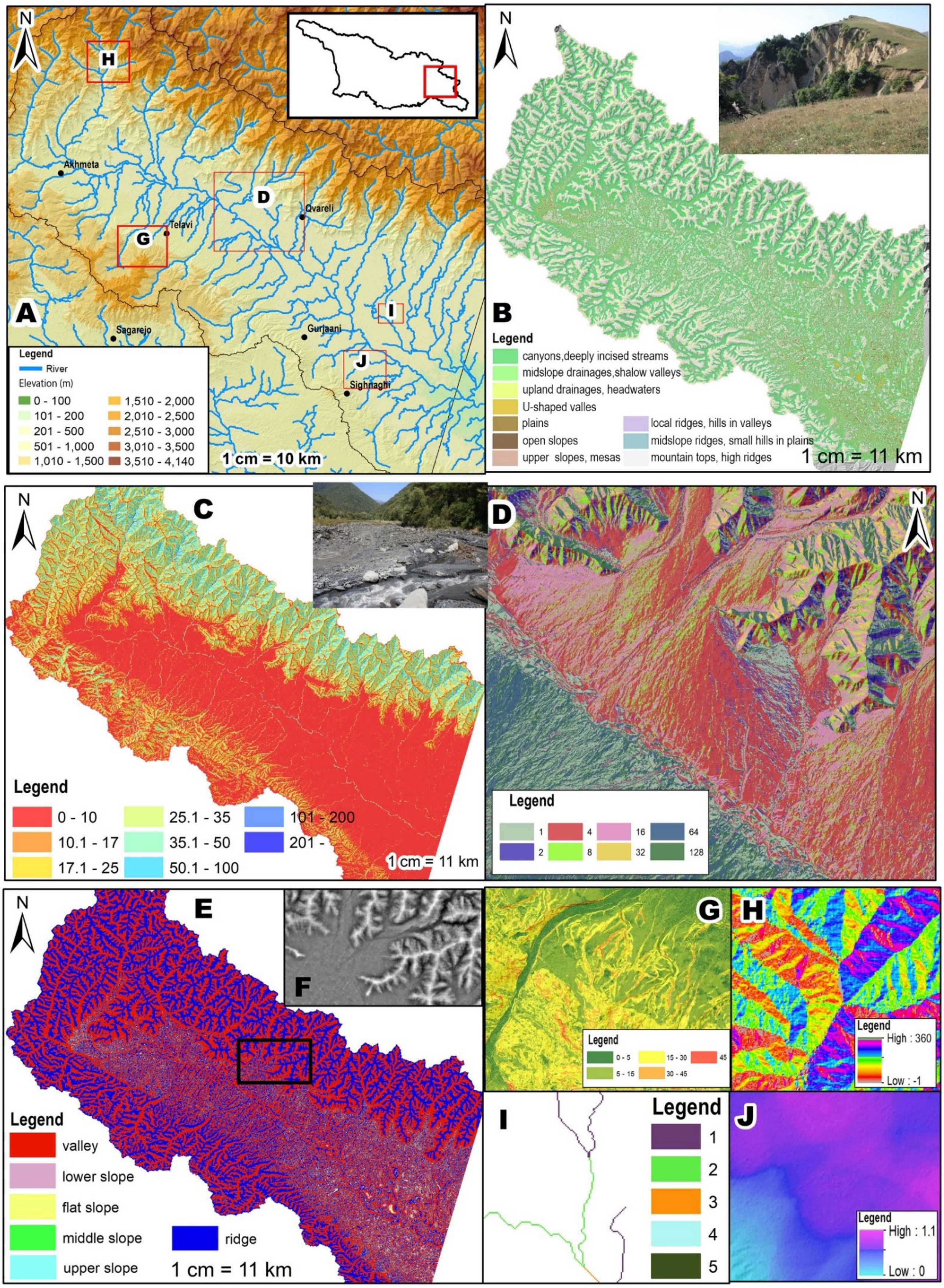

Fig. 2. *A-Study Area; B-Landform Classification; C-LS factor; D-Flow Direction; E-Slope Position; F-TPI; G-Slope angle; H-Slope Aspect; I-Stream Order; J-Drainage Density*

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