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Assessing and Mapping Erosion Risk for Velikoy Sub-watershed within Coruh River Basin in Turkey

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Abstract

Vegetation on earth surface is the integral part of the world ecosystems in functioning for varying spatial and temporal scales. Along with other benefits, land-use as a forest can dramatically reduce the soil erosion and water pollution by protecting the soil surface from erosive effects of rainfall. The objective of this study was to determine rill/interrill (surface) erosion risk by using the RUSLE equation for Velikoy sub-watershed (417 km^2) which has rich forest-resources within the Coruh River Basin located at northeastern Turkey. Land use and cover (C factor), rainfall and runoff (R factor), soil erodibility (K factor), slope length and steepness (LS factor), and management support practice (P factor) were identified as the sub-factors for the RUSLE equation and were multiplied to estimate soil loss by rill/interrill erosion. Results showed that the mean surface soil erosion from the sub-watershed was around 3.9 t ha^{-1} yr^{-1}. Of the total study area, 8.2% was estimated as the areas of high and very high risk for the potential surface soil erosion that also indicates prioritization for the implementation of the erosion conservation measures.

Keywords
Velikoy Watershed, Surface Water Erosion, RUSLE, Coruh River Basin

Çoruh Nehri Havzası'nda Bulunan Veliköy Alt Havzası'nın Yüzey Erozyon Riskinin Belirlenmesi ve Haritalandırılması

Özet

Yeryüzündeki bitki örtüsü, farklı zamansal ve mekânsal ölçeklerde işlevler gören dünya ekosistemlerinin önemli bir parçasıdır. Diğer birçok işlevinin yanı sıra, arazi kullanımı olarak orman ekosistemleri toprak yüzeyini şiddetli yağmurların erosif etkisinden önemli ölçüde koruyarak toprak erozyonu ve su kirliliğini önemli ölçüde azaltırlar. Bu çalışmanın amacı; Türkiye'nin kuzeydoğusunda yer alan Çoruh Nehri Havzası'nda zengin orman kaynaklarına sahip bir alt havza olan Veliköy'ün (417 km^2) yüzey erozyon riskini RUSLE yöntemiyle belirlemektir. Bu amaçla, RUSLE denklemini oluşturan bitki örtüsü (C), yağış (R), toprak erodibilitesi (K), yamaç uzunluğu/eğim (LS) ve koruma faaliyeti (P) faktörleri birbirleriyle çarpılarak yüzey erozyonuyla kaybolan toprak miktarı tahmin edilmiştir. Çalışmanın sonunda, bu alt havzadan yüzey erozyonuyla kaybolan toprak miktarı yaklaşık 3.9 t ha^{-1} yıl^{-1} bulunmuştur. Üretilen toprak kaybı haritaları Veliköy alt havzasının %8.2'sinin erozyon potansiyeli açısından yüksek ve çok yüksek riskli alanlar sınıfına girdiğini göstermiştir. Dolayısıyla, gerçekleştirilecek erozyon kontrol faaliyetleri öncelikli olarak bu alanlarda yoğunlaştırılmalıdır.

Anahtar Sözcükler
Veliköy Mikrohavzası, Erozyon, RUSLE, Çoruh Nehri Havzası

1. Introduction

In the first quarter of 21st century, the importance of sustainable management of natural resources has been magnified in order to supply the goods for current and future generations. Among the others, soil erosion, on the other hand, is regarded as the major environmental problem that threatens the effectiveness of the sustainable management practices around the world (CEC 2006). Misuses of lands, irregular and/or over-grazing of pastures, deforestation, urbanization and improper agricultural practices in recent decades are the major causes for increasing soil losses across the world (CMTUEP 2005; Tufekcioglu et al. 2012). Due to such destructive management practices, about 24 billion tons of fertile topsoil is lost globally every year via both wind and water erosion (IASS 2015). As a result of this soil loss, in return, severe environmental problems including decrease in agricultural production, siltation in river beds and reservoirs, land degradation, and even desertification are experienced in many parts of the Earth (Cerdan et al. 2010; Buttafuoco 2012).

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Around the world, nearly 1.2 billion people are negatively affected by this chain processes while of the 135 million local people are also forced to abandon their land worldwide (MEF 2006).

Similarly, in Turkey, Kantarcı (1993) stated that country's the most important environmental problem is soil erosion. High levels of soil erosion including medium, severe or very severe are all continued to be observed in almost 80% of land surface across Turkey, particularly seen in mountainous regions with less or loss of vegetative cover (DPT 2001). Rugged topographic feature with an average elevation of 1132 m above m.s.l (about 4 times higher than Europe) is the main contributing factor for the higher intensive erosion across the country. Because of the degradation in the natural resources, over 10 million people have left their habitat for the better supply of goods and livelihood improvement (CMUSEP 2015). Thus, erosion control works such as afforestation, rehabilitation and terracing have started in Turkey for the first time in 1950's (Colak 2010). These studies have gained even more momentum over the last decades. In this context, total land of the country has separated into 25 main hydrological basins by the General Directorate of State Hydraulic Works to prioritize these basins and to take further actions. Among those, Coruh River Basin is the unique one in regards it's varying climatic and topographic settings.

Coruh River Basin (CRB), located at the northeastern part of Turkey which is one of the most mountainous basins, had the high rates of soil erosion and associated sedimentation (average 290 m^3/km^2 per year) in its river system and ultimately in the reservoirs of dams. The lifespan of these dams was dramatically affected by severe siltation process (Tufekcioglu and Yavuz 2016). On the other hand, the river has a greater potential for hydroelectric energy production due to high rates of flow regime. Indeed, there are 16 dams and 162 river type hydroelectric power plants in CRB either in operation or under construction by the General Directorate of State Hydraulic Works. Meanwhile, the existed poverty in the rural areas of the Basin has an important impact on the degradation of the natural resources and the protection activities to take (Ozveren and Tekin 2014). Moreover, it is also crucial to know the areas of intense erosion for applying the proper conservation practices first and foremost. In this context, it is necessary to model and map the amount of potential surface soil losses within the basin by monitoring different erosion processes. In this way, the areas with high erosion risk can be identified and the activities can be concentrated on these critical source areas within the CRB.

The purpose of this paper was therefore to estimate surface soil losses by water erosion in Velikoy sub-watershed within the Artvin province in Turkey. The most known Revised Universal Soil Loss Equation (RUSLE) methodology was adopted which was combined with Geographic Information Systems (GIS), remote sensing technologies using very-high-resolution (0.5 m) optical satellite data and statistics techniques as well.

2. Material and Method

2.1. Study Area

The study area, Velikoy sub-watershed, covers 417 km^2 and located at the northeastern part of Turkey within the Coruh River Basin (CRB) (Figure 1). The elevations in the study area ranged from 630 m up to 3150 m with the mean of 1808 m above m.s.l. The study area which has undulated and partially hilly landforms shows continental climate with warm to hot summers and cold winters. The average temperature and precipitation from 1972 to 1996 in Velikoy sub-watershed were 9.7 °C and 598 mm, respectively, that was recorded at the elevation of 1100 m above m.s.l. The major land-use types in the study area are forest (32%) and degraded forest (13%) followed by grazed pasture (28%) and agricultural fields (22%) (Dinc 2017). *Abies nordmanniana*, *Picea orientalis*, *Pinus sylvestris*, *Fagus orientalis* and *Quercus sp.* are dominant tree species in mix stands of Velikoy's forest-rich site. Soils are moderately deep with a major soil textural unit of sandy loam (Duman 2017).

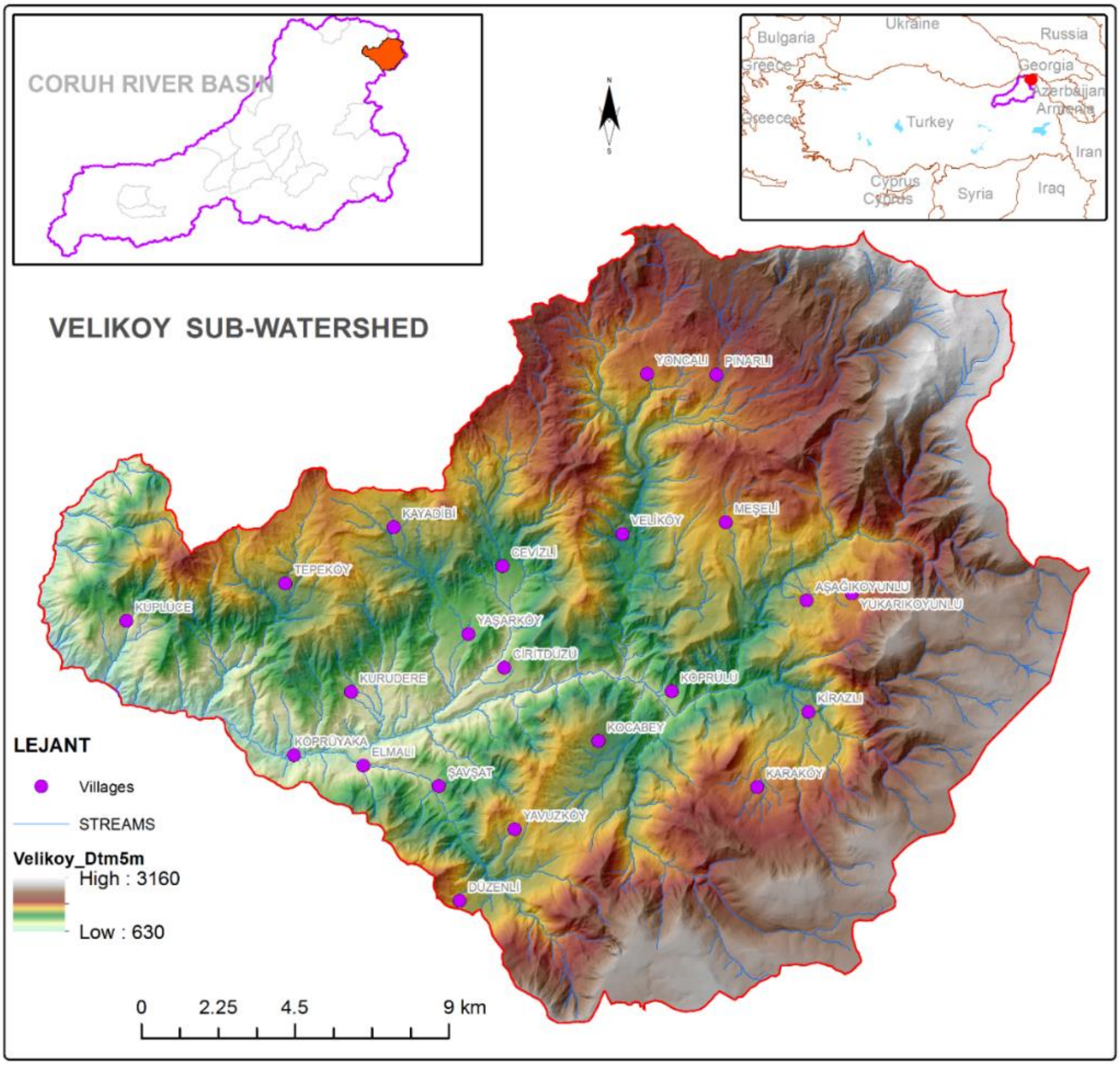

Figure 1: Velikoy sub-watershed within the Coruh River Basin in Turkey

2.2. Dataset

In this study, 0.5 m resolution pan-sharpened images of WorldView-2 satellite belonging to the year of 2011 were used as remote sensing source. These images were composed of red (630-690 nm), green (510-580 nm), blue (450-510 nm) and near-infrared (770-895 nm) bands. The preprocessing of them was performed by the data provider. Other materials used in the study were 1:25000-scale topographical maps of the Turkish General Command of Mapping (GCM), digital stand maps of the Turkish General Directorate of Forestry Service (GDF), 5-m-resolution digital terrain model (DTM) and the climate data obtained from the Turkish Meteorological Service (TMS).

2.3. Methodology

In order to predict the amount of potential surface soil loss and to model its spatial distribution, an approach was adopted in which RUSLE methodology was combined with GIS, statistics, and remote sensing techniques as well as many field measurements (Wischmeier and Smith 1978; Renard et al. 1997). In this method, the soil loss in the area was calculated as;

$$A=R\times K\times LS\times C\times P \quad (1)$$

where A was the average soil loss (t ha^{-1} yr^{-1}), R was the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K was the soil erodibility factor (t h ha^{-1} MJ^{-1} mm^{-1}), LS was the slope length and steepness factor, C was the cover management factor, and P was the soil conservation factor. According to the RUSLE equation, the average soil loss in the unit area was calculated as a composite of these 5 factors that affect erosion. However, it is important to point out that the RUSLE model was not configured to estimate the gully and streambank erosion in particular, but rill and interrill erosion on the topsoil surface (Wischmeier and Smith 1978).

The R factor values were calculated for the sub-watershed using monthly and annual rainfall data from Savsat meteorological stations over the past 23 years (1972-1996). The equation was used to calculate the R-factor developed by Wischmeier and Smith (1978);

$$R = \sum_{k=1}^{12} 1.735 \text{ x } 10^{(1.5\, log10(pi^2/p) - 0.08188)} \tag{2}$$

Afterward, the R-values were spatially distributed throughout the sub-watershed using the equation proposed by Renard and Foster (1998) in GIS.

$$\text{Rnew} = \text{Rstation X (Pnew/Pstation)}^{1.75} \tag{3}$$

In order to calculate the K factor, 40 soil samples (depth of 15 cm) from the study area were taken in randomly selected sample plots (Duman 2017). These soil samples were analyzed in soil laboratory using Walkley and Blake's (1934) wet burning method for organic matter determination as well as Bouyoucos's (1962) hydrometer method for texture analysis. Then the soil erodibility (K-factor) of RUSLE was calculated using Torri et al. (1997, 2002) equations;

$$K = 0.0293\left(0.65 - D_G + 0.24{D_G}^2\right) exp\left[-0.0021\left(\frac{OM}{f_{clay}}\right) - 0.00037\left(\frac{OM}{f_{clay}}\right)^2 - 4.02 f_{clay} + 1.72{f_{clay}}^2\right] \tag{4}$$

$$D_G = -3.5 f_{clay} - 2.0 f_{silt} - 0.5 f_{sand} \tag{5}$$

where OM was the organic matter content in percent, f_{clay} was the clay, f_{silt} was the silt and f_{sand} was the sand content in friction within each soil sampled.

As a next step for the K-factor map creation, the Great Soil Groups (MFAL, 2014) map for Turkey was updated with the collected 40 soil samples from the watershed, then by using the Inverse Weighted Distance (IWD) function in the ArcGIS program the measured K-factor values were interpolated to areas with similar soil types found in the other parts of the watershed.

The calculation of the LS factor was performed with the help of 5-m-resolution Digital Terrain Model. In ArcGIS software, the equation proposed by Moore and Burch (1986) was used as;

$$LS = \left(\frac{Flow\ Acc\ x\ Cell\ Size}{22.13}\right)^{0.4} x \left(\frac{Sinslope}{0.0896}\right)^{1.3} \tag{6}$$

In the calculation of the C-factor, an approach was used in which regression analysis combined with remote sensing methods was integrated in the GIS environment. This approach, which was explained in detail by Vatandaslar and Yavuz (2017), based on predicting C-values of the whole watershed with the help of Normalized Difference Vegetation Index (NDVI) of sampling plots from the field. These operations were performed in ArcGIS 10.2 and SPSS 16 software. Eleven different C-factor models were developed for the Velikoy micro-catchment. Among 11 developed C- factor models, the following cubic C-factor equation was chosen based on the highest coefficient of determination value (R^2=0.83);

$$\text{C-factor} = 0.590 - 1.105 \text{ x NDVI} - 0.1212 \text{ x NDVI}^2 + 0.725 \text{ x NDVI}^3 \tag{7}$$

where C-factor was the value of the cover management factor for a particular pixel in the satellite imagery, NDVI was the value of the Normalized Difference Vegetation Index of that pixel.

Lastly, the P factor was taken as "1" (ineffective) since no erosion control activity was carried out in the study area. The soil loss predicted by the RUSLE gives only the cumulative amount of surface erosion by water. It should not be considered that all of the eroded materials have transported to out of the sub-watershed (Tufekcioglu and Yavuz 2016). Therefore, equation stated below was used to calculate how much of it leaves from the catchment as "sediment delivery ratio" (SDR) (Boyce 1975);

$$\text{SDR} = 0.5656 \text{ x B}^{-0.11} \tag{8}$$

where "B" was the total watershed area (414) in km^2. Then SDR was calculated as 0.29. Finally, by multiplying the value of the SDR by the A-value derived from the RUSLE, the sediment yield of the sub-watershed was calculated.

3. Results and Discussion

The C-factor values were ranged from 0.00 to 0.59 with a mean of 0.05. The lower C-factor values (from 0 to 0.2) was attributed to the dense vegetation (intact forest 32 %, degraded forest 13% and grazed pasture 28% = 73%) existed across the sub-watershed (Figure 2). The areas of the yellow color in the map associated with higher rates of C values indicating a high risk of surface soil erosion (Figure 2). In the interactive map, these areas were also identified as agricultural fields around the villages and/or partially overgrazed pastures in the uplands.

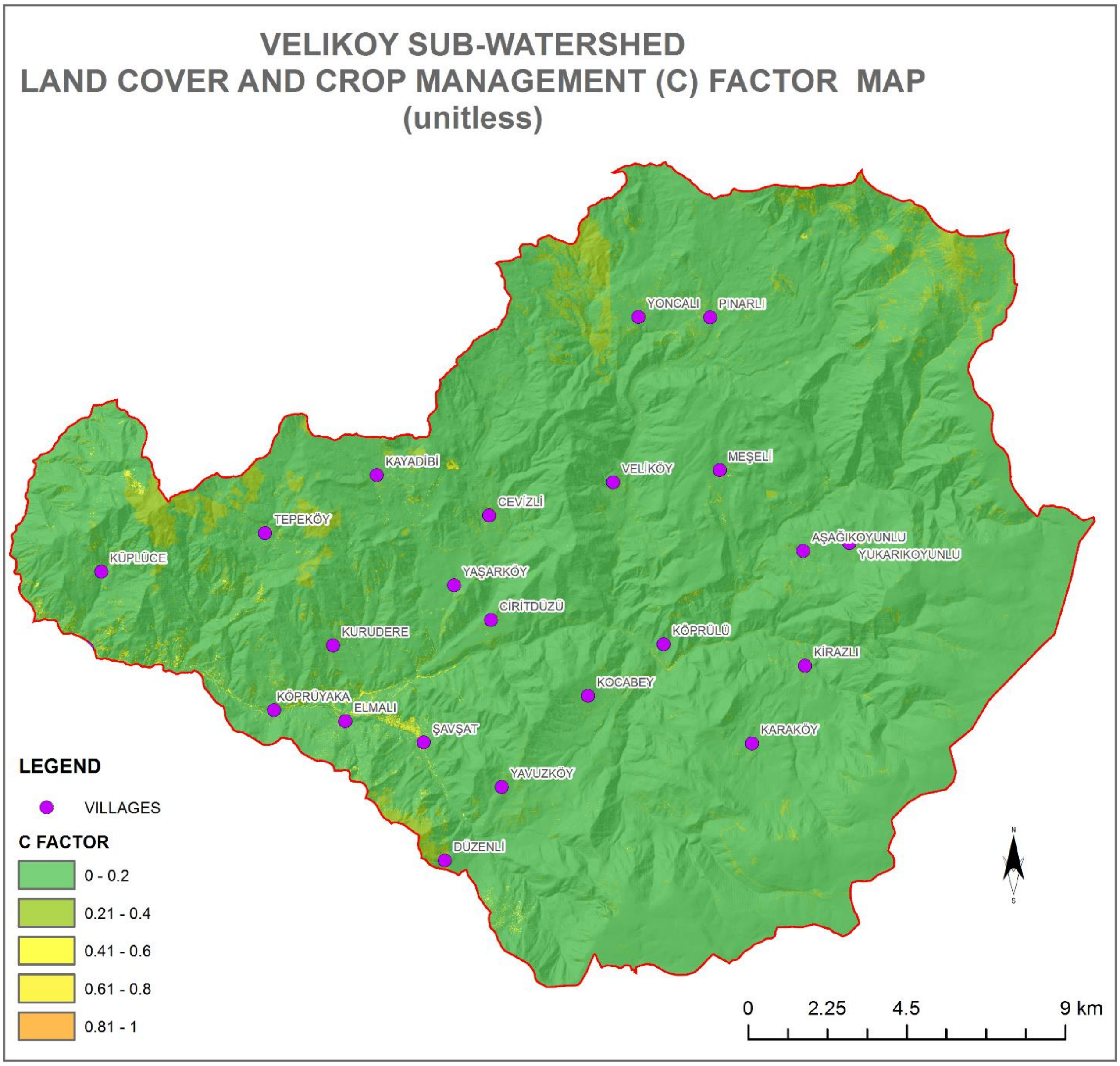

Figure 2: Spatial distribution of the C values; C-factor map

The K-factor values were ranged from 0.00 to 0.05 with a mean of 0.04 t h ha^{-1} MJ^{-1} mm^{-1}. The areas of the light and dark-blue color in the map (easy and very easy erodible soils) were associated with higher rates of K values indicating an elevated risk of surface soil erosion compared to the other areas in the watershed and dominated most of the watershed area (Figure 3). The high rate of erodible soil was mainly due to dominant soil textural unit identified as "sandy loam".

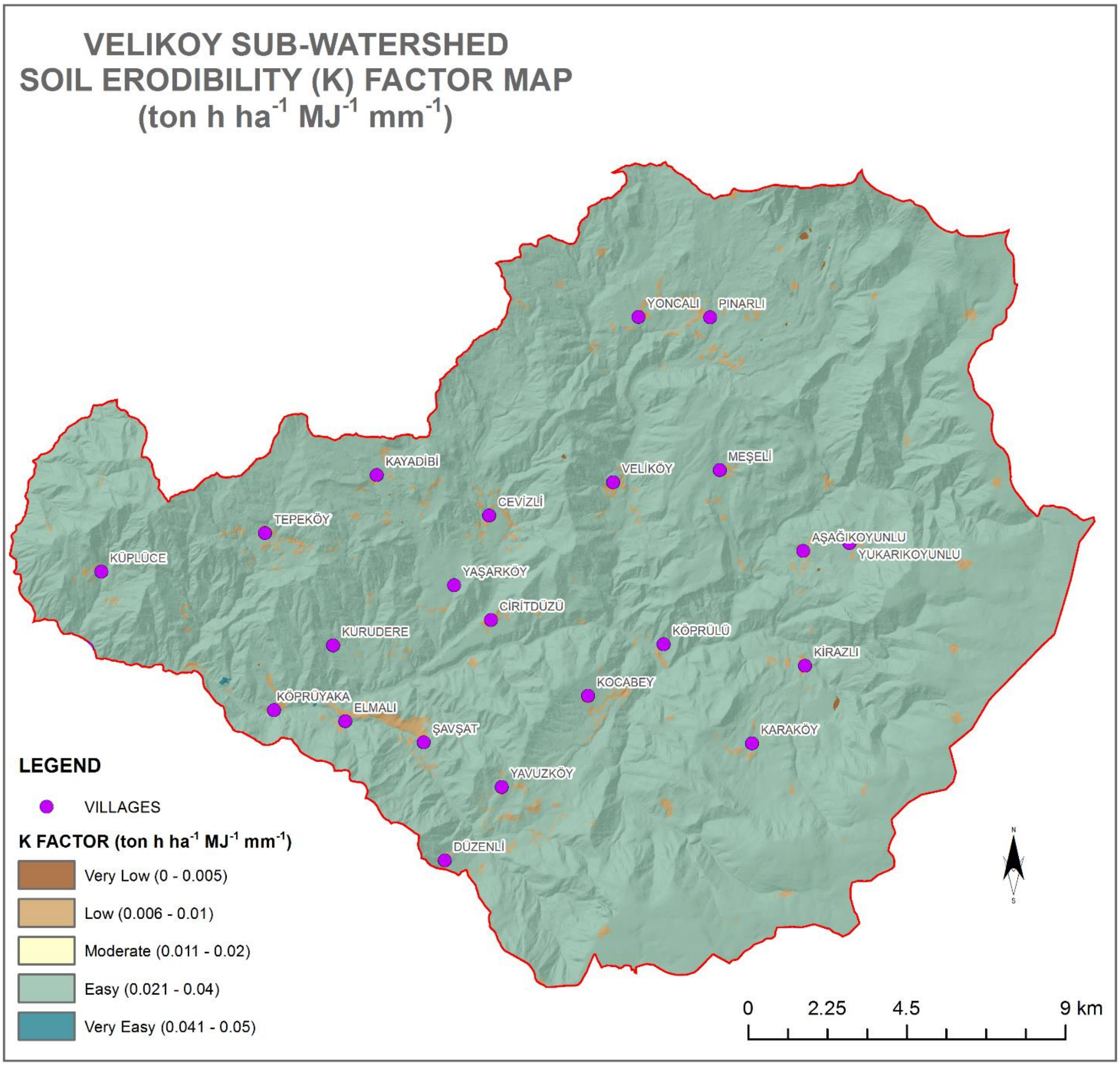

Figure 3: Spatial distribution of the K values; K-factor map

The LS-factor values were ranged from 0.00 to 6417 with a mean of 9.9. The areas of the dark reddish color in the map were associated with higher rates of LS values indicating a high risk of surface soil erosion compared to the other areas in the watershed. The higher LS factor value, the more surface erosion potential due to increasing effects of steep slope and the hillslope length.

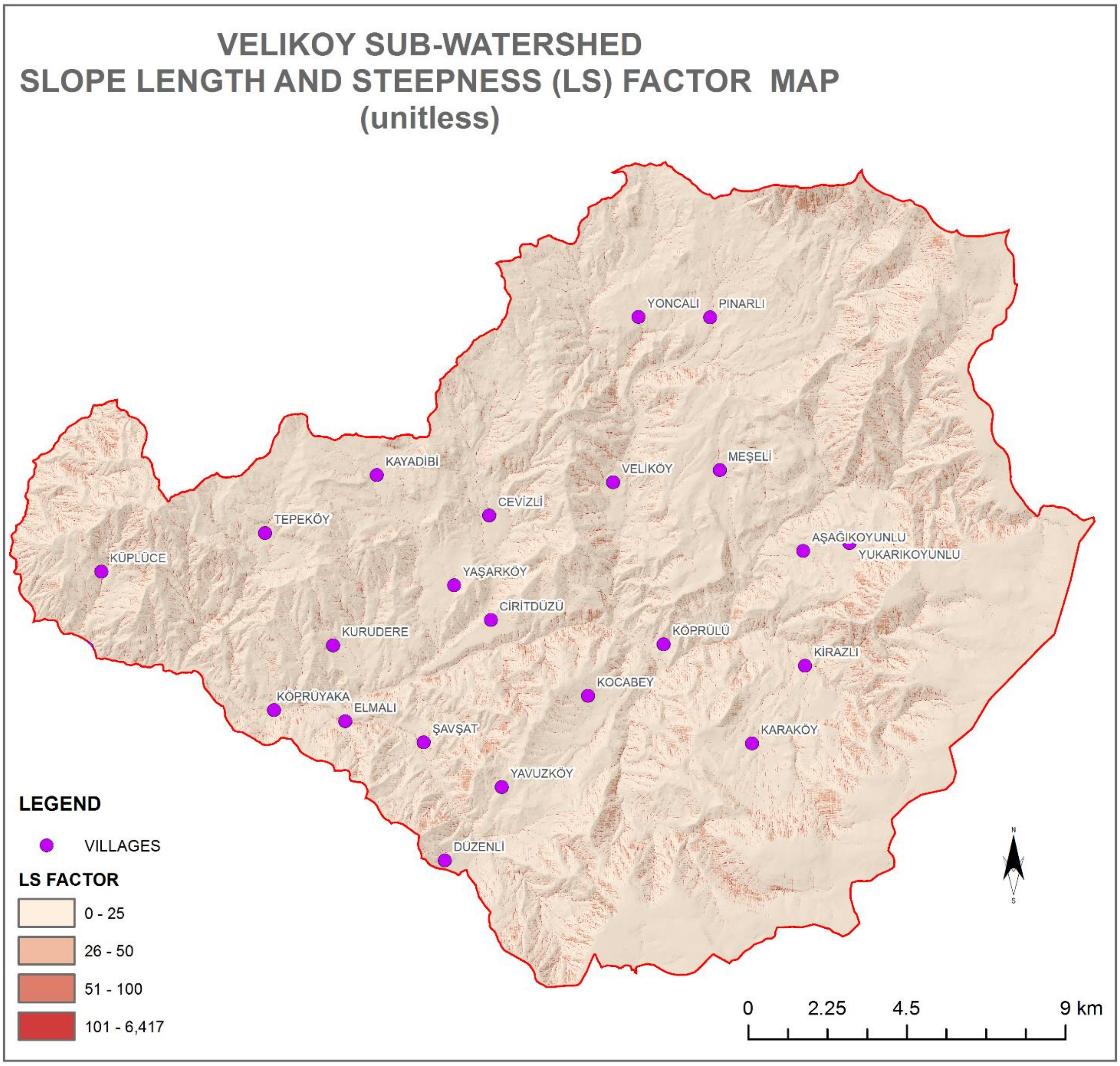

Figure 4: Spatial distribution of the LS values; LS-factor map

The R-factor values were ranged from 133 to 1963 with a mean of 768 MJ mm ha^{-1} h^{-1} yr^{-1}. Due to higher elevation that the watershed extends, annual precipitation could reach up to 1700 mm at the highest point that increased the erosive effects of rainfall (the R-factor) accounted for the higher degree of erosion in the upper watershed (light and dark blue areas) of the studied watershed (Figure 1 & 5). Additionally, the erosive potential of the topsoil even gets greater when the rainfall effects coincided with the high slope degree in the upper parts of the watershed (Figure 1 & 6).

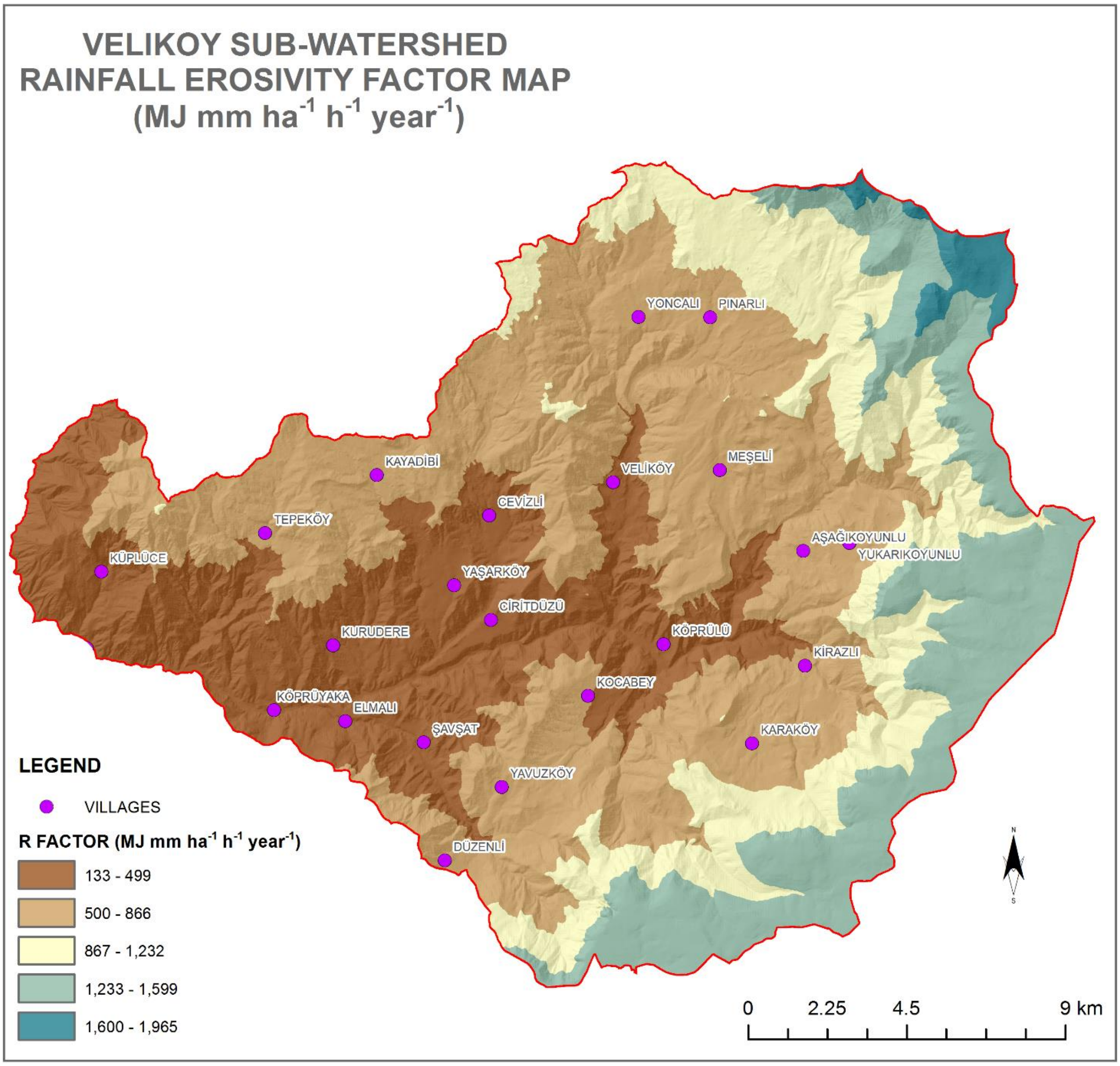

Figure 5: Spatial distribution of the R values; R-factor map

On the other hand, grazed pastures (28%) with dense vegetative cover found in the upper watershed reduced the potential erosional effects initiated by that greater amount of rainfall occurred in high altitudes. Additionally, forest covered about 50% of the study area that promoted a low level of mean erosion rate of 3.89 t ha^{-1} yr^{-1} (Figure 6) compared to the other Coruh River sub-watershed's mean erosion rates ranged from 2.1 to 28.3 t ha^{-1} yr^{-1} (CNHRP-EIAR 2017). However, some purple and reddish parts in Figure 6, where the rate of erosion exceeding 10 t ha^{-1} yr^{-1}, were coincided with activities of agricultural practices including cropping and/or intensively grazed pasture that increased surface soil losses within the watershed.

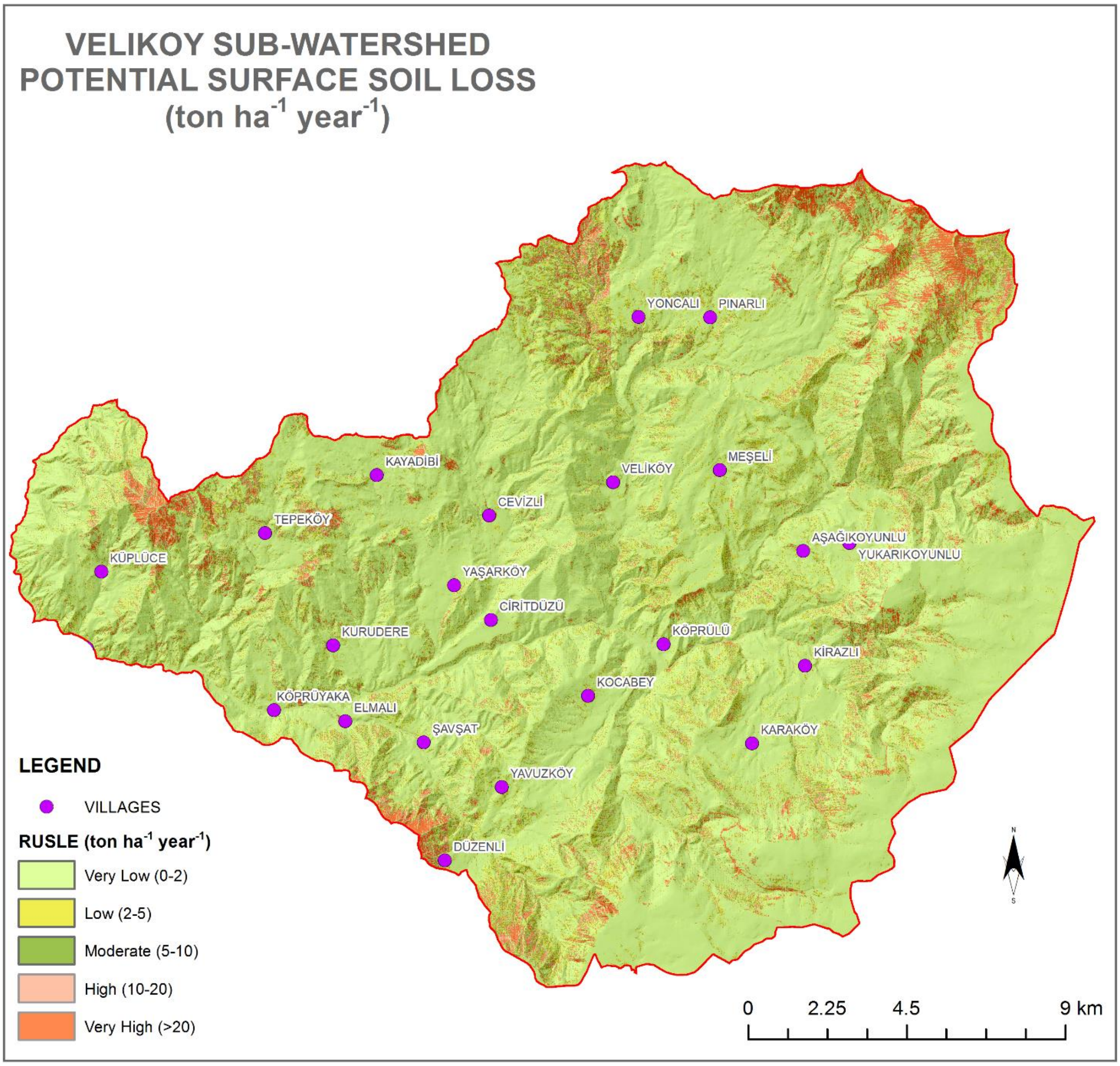

Figure 6: Spatial distribution of erosion risk classes (0-2, 2-5, 5-10, 10-20 and >20 ton ha^{-1} yr^{-1}) for the Velikoy sub-watershed within Coruh River Basin

The comparison of soil loss rate among the RUSLE studies found in literature has a great challenge due to either differing climatologic, topographic and land use setting used in each particular study or using different RUSLE sub-factor (R, K, LS, C) equations. Moreover, in the calculation of these sub-factors the unit (SI vs US) of each formula also needs great attention to get an accurate result in model outputs. Therefore, the studies reported herein were selected for the particular watersheds mainly dominated by the land use of forest and/or grasslands in order to compare with the current study.

Studies conducted in Turkey found somewhat similar soil loss rates to the current study using RUSLE methodology. Ozcan et al. (2008) recorded mean soil loss rates of 1.99, 1.29, 1.21, 1.20, and 0.89 t ha^{-1} yr^{-1} for cropland, grassland, recreation area, and plantation and forest sites, respectively. Demirci and Karaburun (2012) found mean soil loss rate of 2.42 t ha^{-1} yr^{-1} for highly agricultural field dominated watershed (67%). The soil loss rate of 6.75 t ha^{-1} yr^{-1} was recorded within a watershed with high (62%) agricultural land uses (Gundogan et al. 2010). A recent study conducted in Coruh River Basin by Tufekcioglu and Yavuz (2016) reported mean erosion rate of 3.6 t ha^{-1} yr^{-1} in the Yusufeli sub-watershed which is dominated by the land use of forest (%15 high, %43 degraded) and pasture (% 37) within the same Coruh River Basin.

Numbers of studies from the different regions of the world were reported somewhat similar mean erosion rates. A study conducted in the Chianti region of central Tuscany, Italy reported erosion rate of 6.4 t ha^{-1} yr^{-1} from the study area mostly covered by agricultural use (37%) and forest (52%) (Napoli et al. 2016). Arekhi et al. (2012) reported the mean erosion rate of 6.39 t ha^{-1} yr^{-1} from the dry farmland, forestland, and rangeland in the mountains watershed, located in the southeast of Ilam Rovince in western Iran. Another study by Chen et al. (2011) reported a little higher soil erosion rate of 9.86 t ha^{-1} yr^{-1} from agricultural, pastoral and forest lands at the Miyun reservoir watershed in the northern area of Beijing, China.

In the current study, the results showed that over three-third (77%) of the study area fell into a very low erosion risk class (0-2 t ha^{-1} yr^{-1}), while about 8.2% of the total area was identified in high and very high erosion risk class (> 10 t ha^{-1} yr^{-1}) representing greater erosion potential (Table 1). These areas of high risk of erosion should require more attention in terms of conservation measures to reduce soil losses from the Velikoy sub-watershed. In this study, the reason for the given erosion risk class (0-2, 2-5, 5-10, 10-20, >20) determination based on the area distribution of all erosion values in the entire watershed (Tufekcioglu and Yavuz, 2106).

Table 1: Erosion risk class distribution in hectare and percentage for the Velikoy sub-watershed

Erosion Risk Classes	Range of Soil Losses (t ha^{-1} yr^{-1})	Area (ha)	Area (%)
Very Low	0 - 2	32012	76.8
Low	2 - 5	3811	9.1
Moderate	5 - 10	2464	5.9
High	10- 20	1723	4.1
Very High	>20	1689	4.1
Total	-	41699	100

4. Conclusion

Surface soil erosion is an integral part of the aquatic and terrestrial ecosystem in functioning that in most cases reduced the quality of surface water and soil integrity itself. In this study, the rates of soil losses from the Velikoy sub-watershed were estimated by using the RUSLE methodology coupled with GIS and RS techniques. The mean soil loss rate of the watershed was founded as 3.89 t ha^{-1} yr^{-1}. The dense vegetative cover either as forest or as pasture land did reduce the rates of mean erosion from the sub-watershed. However, areas of agricultural uses as crop fields found nearby the villages were increased the soil losses due to greater effects of high rainfall amount, the erodible soil type (sandy loam) and weak vegetative cover for the given watershed. Because of that, agricultural use as cropping needs careful management in order to reduce the high risk of erosion especially in a watershed with high potential of rainfall erosivity (R-factor) like this one. Additionally, the study showed that upper catchments of the watershed with high rainfall effects and hillslope condition were highly susceptible to surface erosion that requires imminent monitoring and targeted conservation measures for each unique condition.

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