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Soil Erosion Estimation Using an Empirical Model, Hypsometric Integral and Geo-Information Science – A Case Study

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ABSTRACT

An approach that integrates the Revised Universal Soil Loss Equation (RUSLE) model and Geographic Information System (GIS) techniques was used to determine the soil erosion vulnerability of a forested mountainous watershed. The spatial pattern of annual soil loss rate was obtained by integrating geo-environmental variables in a raster data format based geoinformatics methods and tools. Thematic layers including rainfall erosivity (R), soil erodability (K), slope length and steepness (LS), cover management (C), and conservation practice (P) factors were computed to determine their effects on average annual soil loss in the Mitrovica city. The serial thematic map of annual soil erosion shows a maximum soil loss of 112.61 $ton \cdot ha^{-1} \cdot y^{-1}$ with a close relation to grass land areas, degraded forests and deciduous forests on the steep side-slopes (with high LS). The geographic age of the region shown by the hypsometric analysis was mature to old stage. The serial erosion maps compiled with the RUSLE model and GIS can serve as effective inputs in deriving strategies for land planning and management in terms of environment concerns.

Keywords: GIS, RUSLE, geomorphology, hypsometry, soil erosion.

INTRODUCTION

Soil erosion is a serious geo-environmental concern by water agent. It has a major effect on land degradation, water quality and agricultural production which have problems for human sustainability (Sharda et al. 2013). Mainly, soil erosion associated with the land degradation in regions of the river catchments. River catchments are very dynamic and vulnerable because to different natural and anthropogenic activities. In Indian context, soil erosion by water is the most severe problem. Nowadays, soil erosion has announced the most severe environmental concern given by a number of researchers that threatens the entire world by reducing the acreage of agricultural production, losing the topsoil and nutrients from the soil (Hoyos 2005; Hlaing et al. 2008; Prasannakumar et al. 2011, 2012; Arekhi et al. 2012; Pradeep et al. 2014). Turnage et al. (1997) showed the three different types of soil erosion methods in east Tennessee area and they compared to RUSLE model for erosion risk assessment. Millward and Mersey (1999) used RUSLE model for soil conservation planning within the mountainous tropical watershed, Sierra de Manantl´an Biosphere Reserve (SMBR), Mexico region. Van Remortel et al. (2001) described the RUSLE soil erosion models at regional landscape scales has been the difficulty in obtaining an LS factor suitable for use in geoinformatics applications. Angima et al. (2003), in their study had been used the RUSLE for soil loss estimation at the Kianjuki catchment in central Kenya in order to determine the erosion hazard in the area and target locations for appropriate initiation of conservation measures. Shi et al. (2004) had taken GIS and RUSLE model to develop conservation-oriented watershed management strategies in the Wangjiaqiao watershed in the Three Gorge Area of China. Referring Stolpe (2005) stated aout that the comparison of the RUSLE, EPIC and WEPP erosion models as calibrated to climate and soil of south-central Chile. Another hand Fu et al. (2006) studied to estimate the impacts of no-till practice on soil erosion and sediment yield in Pataha Creek Watershed, a typical dryland agricultural watershed in southeastern Washington. Nyakatawa et al. (2007) did a study for long-term monitoring of conservation tillage with poultry litter application on soil erosion estimates in cotton plots using RUSLE model as well. Shamshad et al. (2008) used the RUSLE model to prepare the erosivity maps for Pulau Penang region in Peninsular Malaysia. They were applied three different modelling procedures for the estimation of monthly rainfall erosivity (EI30) values. As well as, Trinova et al. (2009) pointed out that the erosion risk scenarios in the Mediterranean environment using RUSLE and GIS for Calabria (Italy) region. Baskan et al. (2010) had taken RUSLE model for soil erosion risk by geostatistics in a Mediterranean Catchment, Turkey and was evaluated the use of the sequential Gaussian simulation (SGS) for mapping soil erodibility factor of the RUSLE methodology. Prasannakumar et al. (2011) was chosen RUSLE model with remote sensing and GIS tool for soil loss prediction and identifying the areas with high erosion potential. Prasannakumar et al. (2012) showed a comprehensive study to determine the soil erosion vulnerability of a forested mountainous watershed in Kerala (India). As well as Ranzi et al. (2012) used the RUSLE empirical model to assess catchment erosion, and is coupled with a sediment accumulation and routing scheme to model suspended sediment load in the Lo river basin (Vietnam) at a monthly time series. Xu et al. (2012) focused on the RUSLE–IDM coupled model to reveal soil erosion risk in different scenarios of Bohai Rim, China. Zhang et al. (2013) used RUSLE model to estimate soil erosion at regional landscape scales and they developed LS TOOL in Microsoft's.NET environment using C++ with a user-friendly interface. According Kumar and Kushwaha (2013), the RUSLE-3D model integrated into GIS environment for predicting the soil loss and the spatial distribution of soil erosion risk a Shivalik sub-watershed of India. Mallick et al. (2014) described the soil erosion risk in semi-arid mountainous watershed area in Saudi Arabia by RUSLE model using remote sensing and GIS tool. Durigon et al. (2014) evaluated soil cover in a Brazilian Atlantic rainforest watershed using NDVI time series from Landsat imagery for calculating the cover management factor (C factor) using RUSLE model. The latest advantages in geospatial technologies have provided very useful methods for surveying and identifying the various aspects of watershed terrain behavior and also the integrated modeling approach utilizing the parameters of controlling soil erosion. Numerous studies carried out by geospatial technologies for quantitatively assessment of soil erosion hazard (Millward and Mersey 1999; Sharma et al. 2001; Ma et al. 2002; Zhao et al. 2002; Onyando et al. 2005; Pandey et al. 2007; Ismail and Ravichandran, 2008; Jianrong et al. 2008; Singh et al. 2008; Kouli et al. 2009; Krishna Bahadur 2009; Naik et al. 2009; Vijith et al. 2012). To evaluate the average annual loss from an area, RUSLE model is often used. In order to adopt the RUSLE, an input dataset including: rainfall, soil, slope, crop, and land management are needed in detail. In developing countries including Kosova, all the necessary data are often not available, thus those requires time, money, and effort to prepare such datasets. In the present study, an attempt has been made to assess the spatial distribution of potential soil erosion and rate of soil erosion for Mitrovica region by an efficient, fast, and simple methodology using the satellite images and geoinformatics, despite the lack of direct observation data. The present study has focused on use of RUSLE model for estimation of the soil loss in the Mitrovica region. The hypsometric analysis was performed for the recognition of the geomorphic age of the study area. The outcomes of the study was thoroughly discussed to get the erosion prone hot spot regions for taking the decision of remedial measures for better management practices in the Mitrovica region.

STUDY AREA

Mitrovica is a city located in the north of Republic of Kosova, less than 50 km from the capital city, Pristina (Maliqi and Penev, 2019). The study zone extends along Sitnica and Iber river. It is located between the Latitude 42°57'02" and Longitude 20°54'36" in the North and Latitude 42°52'13" and Longitude 20°54'19" in the South. (Fig. 1). The minimum elevation is 500m and the maximum ekevation is 950m. Referring the meteorological data in the Republic of Kosova, the weather in the study region is continental with warm summers and cold snowy winters. Based on WorldClim – Global Climate data geoportal (www.worldclim.org), the annual average precipitation is 720 mm and moderate winds blowing predominantly from the northeast, average speed ranges 20 m/sec to 4.4 m/sec. In entire Kosova, and also in the present study are the temperature vary from –10 °C to –26 °C in the winter and from 20 °C to 37 °C in the summer. The landscape consists of hills and plateaus of flattened surfaces, with the study area of two main climatic seasons: wet and dry season. The dry season begins in March and lasts till September with a wet season between October and February. The Mitrovica region lies close to main road that links the capital city (Pristina) and the industrial city (Mitrovica) as well as within study area extends the railway (railway station). The Trepça mine are located less than 10 km from Mitrovica city center. The vegetation of the study region is covered by water bodies, barren area, rock surface, shrubs, grasslands and moderate forests.

Geological and hydrogeological settings

The study area is located within the Vardar zone of the Dinaride Alpine Belt, consisting of Palaeozoic basement rocks, Jurassic-Cretaceous sediments and rocks of ophiolitic affinities. These rock units have been foliated during the early Tertiary (Heinrich and Neubauer, 2002). During the late Tertiary, the Balkan Area was heavily affected by plutonic, sub-volcanic and volcanic processes with the deposition of mainly granodioritic magmas at depth, andesites, dacites and quartz latite flows and dykes as well as pyroclastic rocks, mainly tuffs, lapilli tuffs and ignimbrites. The Triassic is represented by a horizon of massive limestone whose hanging wall is composed of a conglomeratic-sandy interval (metasandstones and meta-conglomerates), which grades upwards into meta-pelite and psammitic schists, phyllites, phyllitoides, meta-sandstones etc. The sedimentary member of the Jurassic (known only in the peripheral parts of the geological map southeast of Stanterg) is represented by a unit of marly-sandy rocks of low crystallinity, whose place in the stratigraphic column is not clearly defined. The Tertiary sedimentary-volcanogenic complex is dominant in the deposit area, making up about 80% of the rock exposure. At its base it is composed of alternating, loosely bound conglomerates, sandstones and slates, which gradually grade upwards into andesitic pyroclastic rocks, tuffs and flows (volcanic phase I). Volcanic phase II is represented by latite flows and quartz latite dykes, flows and tuffs of limited distribution, linked to a magmatic center. The geological–structural block of the Stanterg deposit is described as a folded recumbent structure with an intruded volcanic neck (plug) and surrounding breccias in the core of the Stanterg anticline. The limestone-schist contact is marked

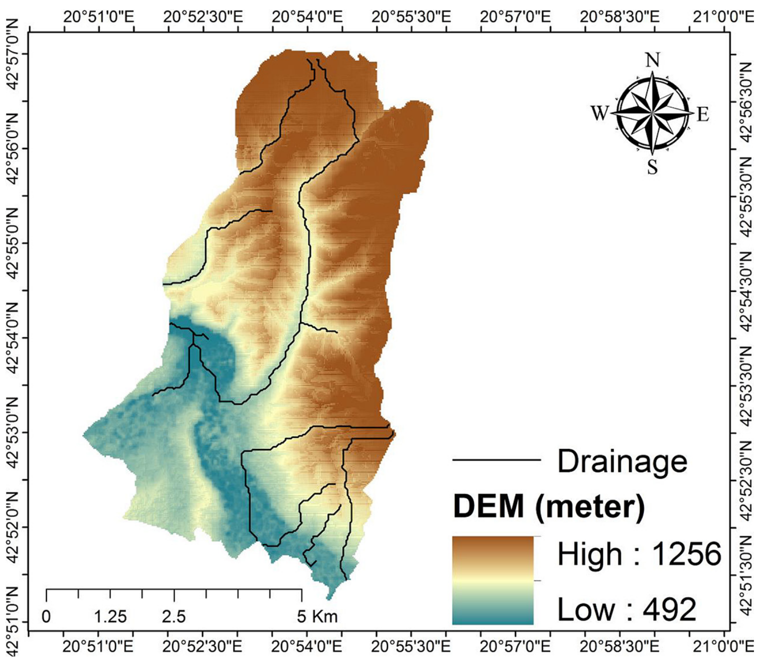

Fig. 1. The study area map shows the location and topographic description of elevation in the Mitrovica city

by the presence of a phreatomagmatic breccia pipe (Schumacher, 1950; Féraud et al., 2007; Strmic´ Palinkaš et al., 2009). Within sedimentary members, however, alteration is less common, mostly connected with narrow zones around fault structures. Hydrothermal processes are directly related to the deposition of Pb-Zn mineralization. They are limited to narrow areas around ore bodies and are seen as pyritisation, silification and carbonatisation. Hydrogeological characteristics of the Trepça region are complicated (Avdullahi 2003). The hydrogeological characteristics in this region are: limestone, tuffites, phyllite, schistes and andesite, as well as the important characetristicks are serpentines, gabbro, diabase, quartzite and other rocks that compose ore field. Another hand, the particular importance for the hydrogeology of the region is the possibility of determining the surface under which the Paleozoic limestone are placed under the cover of tuffites. All rocks in the explored region are porous, but the importance of porosity is not the same. Depending on the lithological composition, hypsometric level and size of rock measures, the porosity value is broad enough. According Aston (1982), the formation of pores, and the relation to the rock measures, we can distinguish two genetics types of porosity: primary and secondary. As well as, the size of pore and the way that granules communicate between its pores, in the region there three types of pores: cracks, the caverns and inter granular (Motyka 1998). Based on the hydrogeological properties all rocks of the region are divided into two groups: indescribable and collector's rocks. In the explored region, although the limestone is spread in a relatively small area as a good hydrogeological collector, it is interrupted by a large number of cracks with irregular shapes. The tuffites serie is a very porous rocky mass. They can easily infiltrate the surface waters. In essence the tuffites are spread in a very large area and cover the major part of the paleo-relief, solving the hydrogeological concerns of this series, thus it is of great importance for the region. The indescribable rocks (schistes, phyllite, diabase, and gabbro) are also spread in the region as much as the above mentioned rocks, their impact on hydrogeological conditions are not small. However, as hydrogeological collectors, their impact on the direction of underground water movements most often create indescribable screens showing the importance of these rocks, from the hydrogeological point, in the Mitrovica region.

MATERIALS AND METHODS

Model description

The RUSLE model requires several parameters including: amount of average annual soil loss as a combined function of rainfall-runoff erosivity, soil erodability, slope length and steepness factor, cover and management, conservation support-practices factor. As mentioned Renard et al. (1997), the model has been widely used for predicting average annual soil loss in both agricultural and forest watersheds, in order to compute the soil erosion factors effectively. The average annual soil loss per unit area and per year was calculated using following equation, which can be expressed as:

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

where: A – the average annual soil loss (ton·ha^{-1}) for a period selected for average annual rainfall; R – the rainfall erosivity factor (MJ mm ha^{-1}·h^{-1}·year^{-1}); K – the soil erodibility factor (MJ^{-1}·ha^{-1}·mm^{-1}); L – the slope length, S – slope steepness factor; C – the cover and management factor; P – the conservation support-practices factor. LS, C and P values – dimensionless.

All these factors were mapped in raster data model; thus, the predicted average annual soil loss was obtained at depending on spatial resolution (pixel level). Since, the GIS based RUSLE model predicts potential soil loss at pixel level it can extract information on spatial heterogeneity as well as distribution of soil erosion in detail (Millward et al. 1999). The data description is given in Table 1.

Rainfall and runoff erosivity factor (R)

The R factor used to calculate the total annual erosion due to the rainfall. The intensity of rainfall is the biggest element that affects the Factor (R) as the higher intensity will cause the highest erosion in the respective area and vice-versa (Shaikh et al. 2018; Jain et al. 2001). The R factor was calculated using the monthly rainfall using Yu and Rosewell (1996)

$$R\text{-factor} = 0.0483 \times P^{1.61} \qquad (2)$$

where: P – in mm, R – in MJ·mm·ha^{-1}·h^{-1}·y^{-1}.

Table 1. The list of datasets used in the study for soil loss estimation in the Mitrovika city

Sr. No	Data/models	Resolution	Availability
1	DEM	30 m	https://dwtkns.com/srtm30m/
2	Soil	906 m	–
3	Land use/land cover	90 m	www.land.copernicus.eu
4	Rainfall	0.25 °	www.worldclim.org
5	QGIS/SAGA GIS	https://www.qgis.org/en/site/forusers/download.html	

The annual rainfall (P) ranges from year 1979 to 2013 as an input in the RUSLE for calculating the R-factor.

Soil-erodibility factor (K)

Lane et al. (1992) defines the K factor as the ability of soil particles to sustain themselves from the removal and to be carried out by water flow due to rainfall. The sand, silt, clay percentage and porosity, permeability and organic matter content are effective soil properties which influence K-factor. Sharpley and Williams (1990) suggested the formula of the K factor using the soil properties and sand, silt, clay and organic carbon were used for calculating the K factor.

Slope length and steepness factor (LS) (Topographic factor)

The slope length factor (L) and steepness factors (S) which constitute LS factor and depict the influence of topography on the soil erosion (Moore et al. 2016). The flow accumulation and slope factor is essential substances for calculating the topographic factor and the flow accumulation and slope were calculated using the digital elevation model (90 m). The topographic factor or LS factor was calculated based on Desmet and Govers (1996) in SAGA GIS. The LS-factor was calculated based on Digital Elevation Model (DEM) of SRTM 30 m spatial resolution.

Cover-management factor (C)

The crop pattern and the applied management practices in that area along with the erosion of soil can be easily analyzed using the C-factor. Wischmeier and Smith (1978) defined the factor C as the ratio of soil loss when management practices are involved and when there is no involvement. The value of C-factor was assigned from the Tables 5, 10, and 11 in Wischmeier and Smith (1978).

Support practice factor (P)

The P-factor like the C-factor also reflect the loss of soil from a basin but here in the case of factor P, there are controlling supportive practices like contouring along the slop or strip cropping, terracing are involved to reduce/control the erosion rate (Uddin et al. 2016). These supportive practices change the drainage structure or reduce the runoff potential by decreasing the water velocity to control the loss of soil and reduce erosivity in the catchment (Pradhran et al., 2018). The P-factor was also defined as the ratio of soil loss with a specific practice to the corresponding loss without any supporting practices (Prasannakumar et al., 2012; Renard et al., 1997). The P-factor ranges between 0 to 1, where uppermost value indicates the zone of no conservation practices and vice-versa (Pradhran et al. 2018). Here the value of P was selected using the LULC map and from the published sources (Jain et. al., 2001; Yansui et al., 2015; Renard et al., 1997).

Hypsometric analysis

The hypsometry is the area altitude which simply relates to the measurement of land elevation and aims to develop a dimensionless ration of cross section area of basin to its elevation (Dowling et al., 1998). Strahler (1952) stated that the hypsometric analysis could be useful to indentify the erosion status at different level throughout their evolution. The hypsometric integral (HI) and hypsometric curve (HC) are the two special indicators of the hypsometry which serves as indice of watershed condition (Ritter et al. 2002). The HC and HI have generated using DEM of 30 m form STRM and an free open source GIS Software QGIS using the Calhypso extension for the hypsometry at basin and sub-basin level. The basic method behind the calculation of hypsometric integral (HI) is given by Pike and Wilson (1971) which is simply an elevation-relief ratio. The following relationship is as given and expressed below in Eq. 3:

$$HI = \frac{(Elev_{mean} - Elev_{min})}{(Elev_{max} - Elev_{min})} \quad (3)$$

where: $Elev_{mean}$ – weighted mean elevation of the watershed; $Elev_{max}$ – maximum elevation within the watershed; $Elev_{min}$ – minimum elevation within the watershed.

RESULTS AND DISCUSSIONS

The estimation and identification of soil erosion activity and it hot spot area is more significant for better management of hydrological processes and for the remedial measure purposes in the study region. The spatial distribution of rainfall in the study area was shown in Figure 2. The empirical method RULSE was used here for estimation of soil erosion in the Mitrovica region.

The most influencing factor for the soil erosion is rainfall-erosivity factor, which depend upon the intensity of rainfall. The erosivity factor was calculated using the rainfall from 1979 to 2014 and the outcomes showed the range of the R-factor from 1594.67 to 1911.85 MJ·mm·ha^{-1}·h^{-1}·y^{-1} in study area. The upper and middle portions were occupied by the higher to medium value of R-factor while the lower value of R-factor was shown by the lower portion of the study area. The mean value of the erosivity factor is 1753.67 MJ·mm·ha^{-1}·h^{-1}·y^{-1}. The R factor here consequently has followed the rainfall distribution pattern as the higher amount of rainfall was received by the upper and middle portion of the city (Fig. 2), while the lower rainfall is received by the lower most portion of the city. The upper and middle portion of the city shows the high to middle value of R factor in the city.

The K factor is soil erodibility factor which represents both susceptibility of soil to erosion and the rate of runoff. The K factor in the study area ranges from 0.017 to 0.022. The lower portion of the study area was occupied by the higher value of k-factor and upper portion showed the medium K factor (Fig. 4). The meddle portion was occupied by the low value of K-factor.

The LS factor ranges from 0.03 to a maximum value of 15.97 with mean value of 4.71 in the study region (Fig. 5). The lower most parts was occupied by the low value of the LS factor, while upper and middle portion showed the medium to high value of the LS factor.

It is wildly known that agricultural and management practices help to control the rates of soil loss where vegetation cover protects the area from the soil loss activity (Gyssels et al., 2005). In RUSLE, the C factor is the one that local or central policy makers and farmers can most readily influence in order to help reduce soil loss rates (Panagos et al., 2014). The C-factor was ranged from less than 0.003 to maximum value of 0.63 in the study area, where major upper portion of the city have attained a lower value of the C-factor (Fig. 6). The major lower portion of the city was occupied by the lower to medium C-factor value. The C factor represents

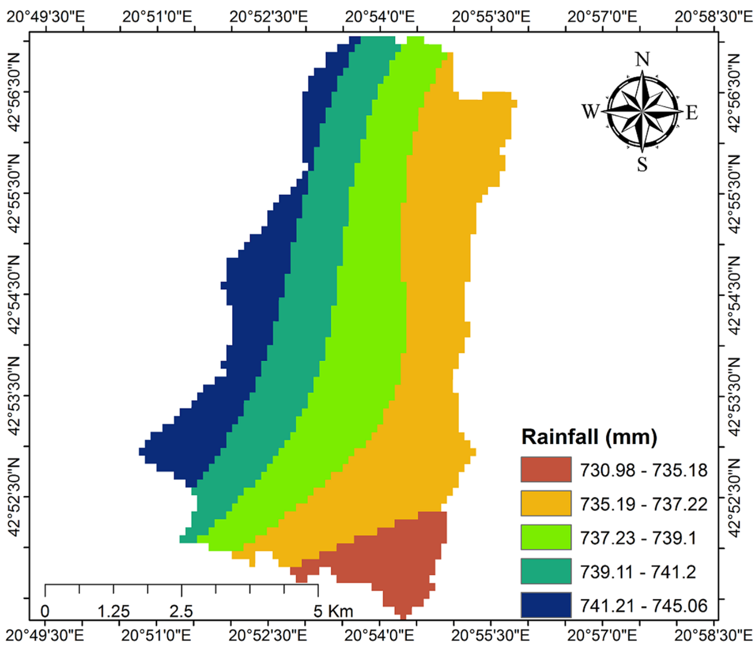

Fig. 2. The spatial distribution of rainfall in the Mitrovica city

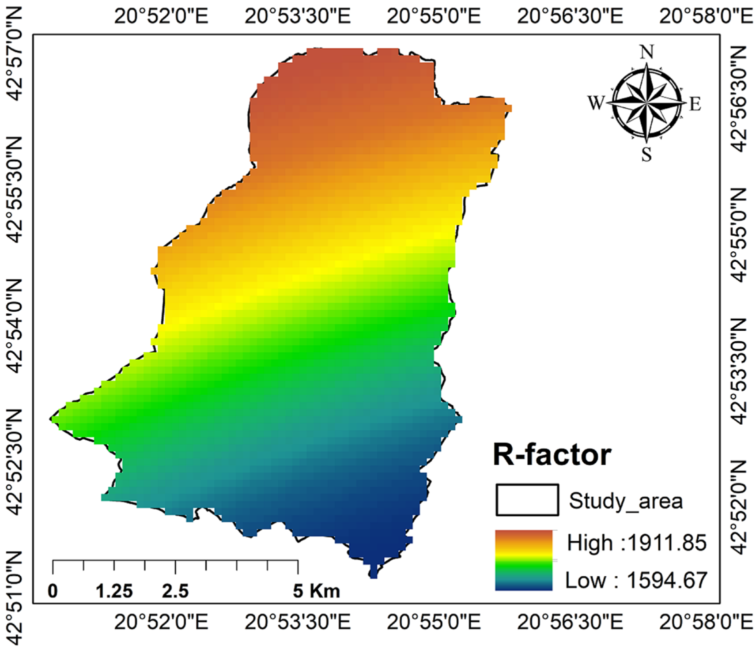

Fig. 3. The spatial ranges of rainfall-runoff erosivity map (R factor), in the Mitrovica city

the effects of plants, soil cover, soil biomass, and soil disturbing activities on erosion and it demonstrates how land cover, crops and crop management cause soil loss to vary from those losses occurring in bare fallow areas (Kinnell, 2010). The C-factor was found in similar ranges in different studied over the Asia and European region (Kumar et al., 2022; Panagos et al., 2015; Kouli et al., 2009). Rellini et al. (2019) estimated the C factor ranges from 0.001 to 0.3 over the Portofino promontory, NW-Italy. Tropikë, and Valbon, (2022) analysed of soil erosion risk in Hogoshti river basin of Kosova.

The P factor reflects the impacts of different support operation on soil erosion. The value of *P* factor ranges from 0 to 1, the value approaching to 0 indicates good conservation practice and the value approaching to 1 indicates poor or absent conservation practice. The upper portion of the fall in the higher value of the P factor, where broad leaf forest occupied by 14.87 km^2 area. The lower portion showed the low to

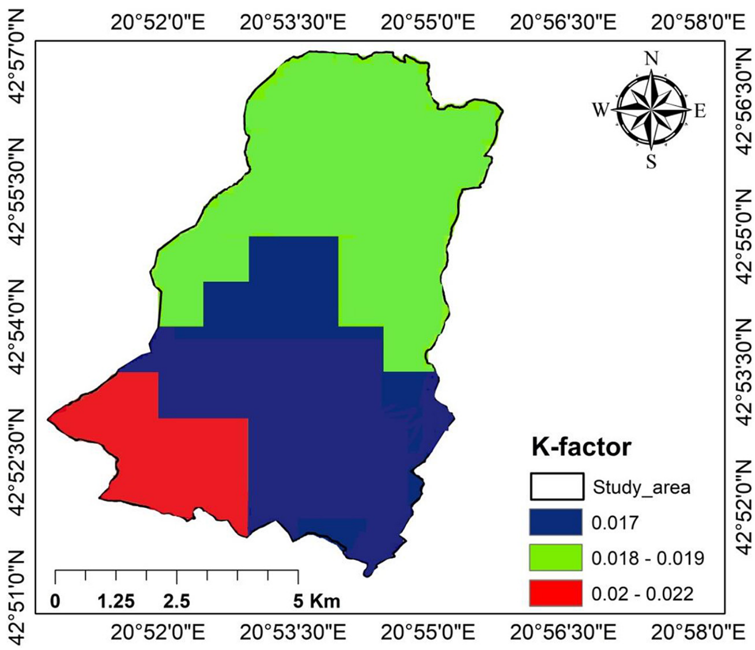

Fig. 4. The spatial ranges of soil erodibility factor map (K-factor), in the Mitrovica city

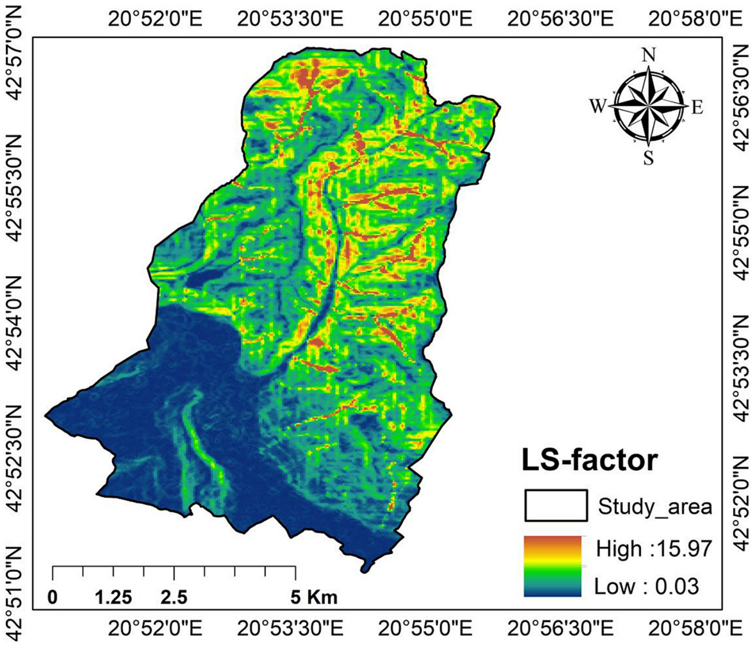

Fig. 5. The spatial ranges of topographic factor maps (LS factor), in Mitrovica city. The upper and middle section of city is generally dominated by the medium to high LS factor value

medium value of P factor where the discontinuous urban fabric occupied the large proportion (Fig. 7). The study showed the average value of P factor in the study area as 0.69. Panagos et al. (2015) have shown the effect of p-factor on reduction of soil erosion by water at European scale. They have estimate the mean P factor for Europe as 0.97 by considering the three support practices such as contour farming, stone walls and grass margins to reduce the overall soil erosion risk by 3%.

The hypsometric analyses help to generate the disequilibria and landscape evolution, and there are two types of hypsometric curves according to the geomorphic age of the Mitrovica. Convex upward and S-shape describe the youth and mature stage respectively, while concave upward demonstrates the old stage (Strahler,

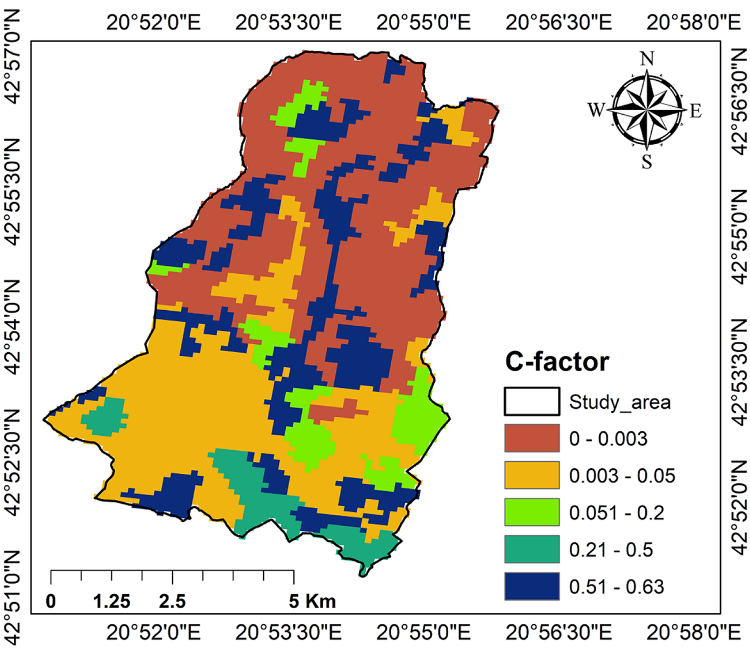

Fig. 6. The spatial variation cover management factor map (*C*-factor) in the Mitrovica city

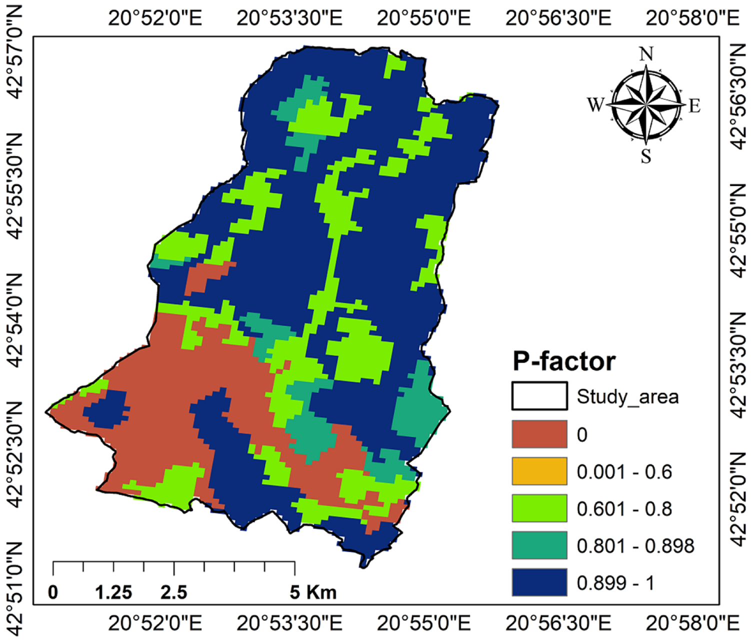

Fig. 7. The spatial ranges of support practice factor map (P-factor), in the Mitrovica city. The lower portion of the Mitrovica city shows the lower p-factor

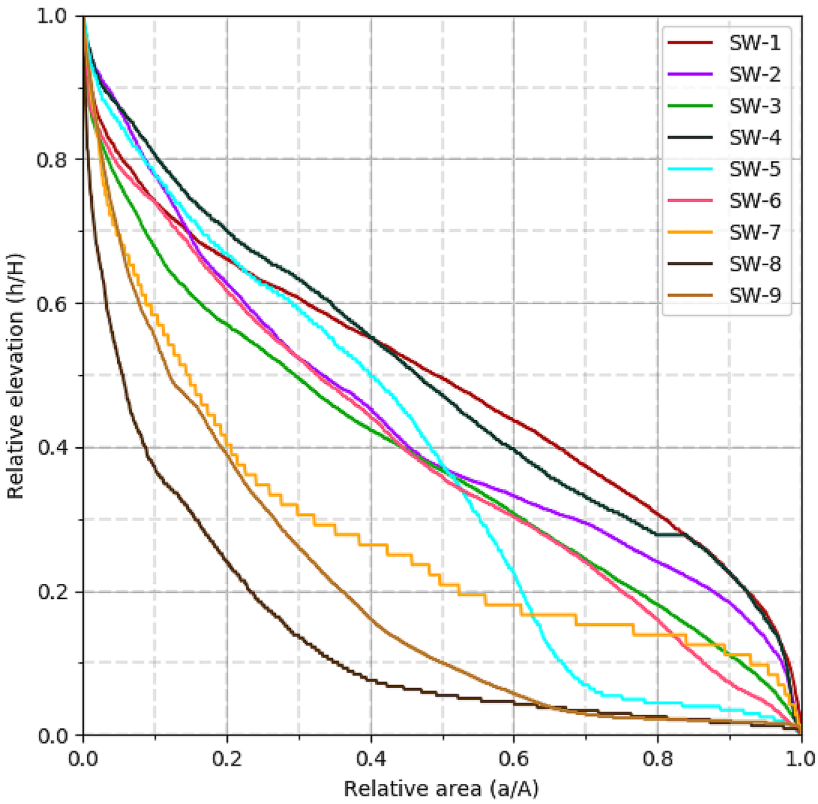

Fig. 8. The hypsometric curve of the Mitrovica city

1952). The hypsometric analysis of the study area was done performed for understanding the geomorphic stage for better management aspect due to soil erosion activity. The outcomes from hypsometry showed the concave upward and S-shape hypsometric curve which depicted geomorphic stage of study region from old to mature respectively (Fig. 8). The hypsometric integral showed the geomorphic stage using a range of value from 0 to 0.3 (old), 0.3 to 0.6 (mature) and greater than 0.6 (youth) at the sub-watershed level. Therefore, the whole area was divided at sub-watershed level (total 9) for detailed analysis and understanding of erosion prone zones. The hypsometric integral (HI) values were also categorized into three zones for easy identification of erosion area in the previous studies (Kumar and Singh, 2021). For our study region, the HI values ranges from (i) 0 to 0.3, which means that 30% of original rock mass still exist (old stage) and (ii) 0.3 to 0.6, which means these zones are in mature stage (Table 2).

The RUSLE soil erosion parameters were used for quantization soil erosion rate in the study area. The soil erosion rate ranged from 0.05 to a maximum value of 112.61 ton/ha/year (Fig. 9). The mean value of soil erosion rate was 13.30 ton/ha/year in the study area. The outcomes from the study demonstrated that not very greater portion of the study area was affected by the soil loss activity as amount of erosion rate was quite lower in the major portion of the study area. The upper and middle portion was dominated by the high to medium soil erosion activity and in these regions; the rainfall amount was quite high as compared to others and therefore, the soil loss activity in these regions followed the rainfall pattern. The previous studied also showed that soil loss activity primarily affected by the soil rainfall pattern, especially the intensive rainfall of short duration have more potential to increase the rainfall erosivity and accelerate the soil loss (Kumar et al., 2021; Pal et al., 2021; Tsitsagi et al., 2018; Gupta and Kumar, 2017).

Table 2. The hypsometric integral showing the geomorphic stage of the study area from old to mature stage

Sub-watershed	Hypsometric integral	Geomorphic stage
1	0.489	Mature
2	0.430	Mature
3	0.382	Mature
4	0.490	Mature
5	0.375	Mature
6	0.389	Mature
7	0.282	Old
8	0.136	Old
9	0.202	Old

CONCLUSIONS

The thematic map of soil loss will be one of key products to control soil loss in Mitrovica region. Therefore, the current study has been applied the imperical model RUSLE to calculate the soil loss in the study area region. The hypsometric analysis was also performed to calculate the geomorphic age of the study area. Among the soil erosion parameter, the rainfall erosivity (R-factor) as 1594.67 to 1911.85 $MJmmha^{-1}h^{-1}y^{-1}$ in the study area. The LS-factor was maximum (15.97)

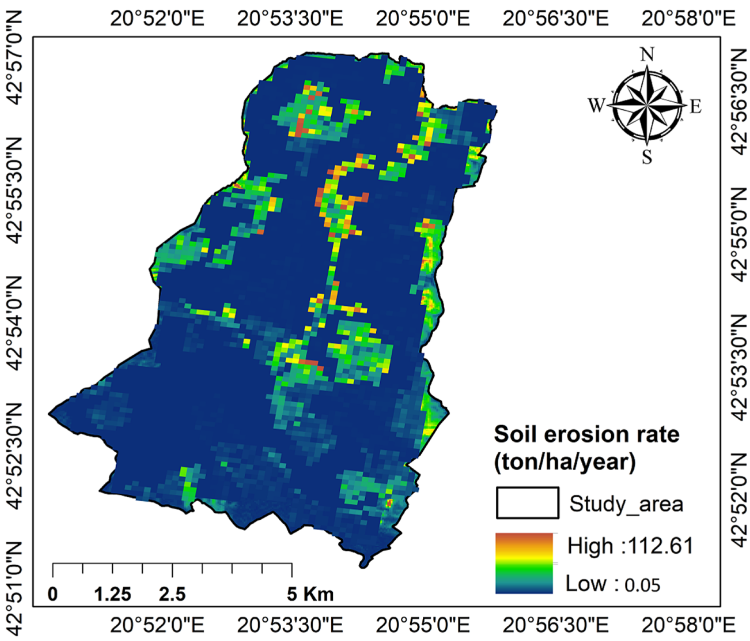

Fig. 9 The major erosion hot spot regions in the Mitrovica city

in the middle and upper portion of the city. The estimated annual soil loss using the five different soil erosion parameters through the RUSLE ranges from 0.03 to 112.61 ton/ha in the study area. The performed hypsometric analysis depicts that the geomorphic age of the Mitrovica region varies from old to mature. In general, the results from the present study can be used by local or central institution in Kosova, to reduce soil erosion due to high surface runoff and suggest to hydrologists for disaster monitoring and management, as well as policy or decision making.

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