Research paper

Assessment of the soil-protecting services of the forest ecosystem: a case study in Ilam catchment, Iran

Ali Mahdavi and Elham Motaharfard*

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Abstract. The natural forests of western Iran play a key role in delivering services and goods to local society. Nonetheless, this forest ecosystem, despite its importance, is threatened by natural factors and anthropogenic activities, resulting in decreasing soil quality and soil erosion. The present research aimed to assess the effects of the forest ecosystems on soil erosion control in Ilam catchment in southwest Iran. For this purpose, after estimating the soil loss in natural conditions (NC), we predicted the amount of soil erosion under two scenarios: (i) convert natural forest with 20% canopy cover to destructed forest with 0% canopy cover (SC.1), (ii) increase forest cover by 40% (SC.2). Our results indicate that the estimated mean soil erosion was within the range of 9.36 t ha^{-1} yr^{-1} in irrigated and garden use to about 256 t ha^{-1} yr^{-1} in bare soils under NC. We found that when converting natural forest to destructed forest, the mean annual soil erosion rate increased 105.75 t ha^{-1} yr^{-1}, 118.1 t ha^{-1} yr^{-1}, and 19.57 t ha^{-1} yr^{-1} in the dense forest, sparse forest, and Agri-Forest use, respectively. These results show the protective effect of the forest against soil erosion.

Key words: Zagros Mountains, forest, soil erosion, RUSLE model.

Authors' address: Department of Forest Sciences, Faculty of Agriculture and Natural Resources, University of Ilam, Ilam, Iran; *e-mail: emotaharfard@gmail.com

Introduction

Numerous studies have emphasized the forest ecosystems and their associated processes, fundamental protection of soil and water resources (Miura *et al.*, 2015; Chang *et al.*, 2019; Kooch *et al.*, 2020), and their important role in delivering a range of goods and services to human well-being societies (Kindler, 2016). For the country of Iran, the forest ecosystem is perhaps the most significant, due to already a rather low proportion of the country's area (less than 7.4%) being covered by forests. Approximately, 1.8 million hectares of forest land area cover the northern slopes of the Alborz Mountains in northern Iran (Kooch *et al.*, 2020) and the largest forest area (about 5 million ha) is located in the Zagros Mountains in western Iran (Ahmadi *et al.*, 2014). Forests in the Zagros basin have contributed to human well-being and are an important ecosystem in terms of the ecological balance of the region, production of by-products (Beygi Heidarlou *et al.*, 2019), major natural filters reducing dust (Moradi *et al.*, 2017), water (source for approximately 45% of the water supply in Iran) and soil restoration (Jazirehi & Rostaghi, 2003; Beygi Heidarlou *et al.*, 2019). Nonetheless, the extreme-

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ly strong relationship between the people and the forest (Ghazanfari *et al.*, 2004), and tree logging have impacted these valuable forests (Sadeghi *et al.*, 2017), degrading soil quality (Zarafshar *et al.*, 2020). Additionally, changes in land use due to development strategies exposing erosion-sensitive geological formations consisting largely of shale and marl and poor vegetation cover in the Zagros Mountains have resulted in making millions of tons of sediment available annually for erosion and transport (Tangestani, 2006). Soil is one of the most important natural resources the loss of which incredibly threatens physical resources, such as agricultural, grassland, forest, and environmental resources (Kayet *et al.*, 2018). Soil erosion is considered one of the most critical forms of soil degradation, causing environmental concerns in many parts of the world (Bozali, 2020). The soil is generally eroded by natural factors (e.g. wind, snow, rain, hail, waves, and surface waters) and anthropogenic activities (e.g. unsuitable land use practices) (Calitri *et al.*, 2020; Bozali, 2020); however, some of these factors may vary over time (Calitri *et al.*, 2020). This results in changes in soil structure and alters rooting depth, reduces agricultural and forestry productivity, increases greenhouse gas emissions, water pollution, and decreases soil quality (Noori *et al.*, 2016; Borrelli *et al.*, 2017; Calitri *et al.*, 2020; Benaud *et al.*, 2020). An effective way to protect soils is the use of permanent forest vegetation, and the soil protection function of forest ecosystems seems very effective (Wiśniewski & Märker, 2019). In maintaining such an important ecosystem service, it is essential to determine the spatial pattern of soil protection zones and implement specific forest management strategies in those areas. Studies about soil erosion in forests are lacking in most areas worldwide (Calitri *et al.*, 2020). The researchers still lack well-grounded knowledge about the impacts that forest management activities have on soil functions (Borrelli *et al.*, 2016). Consequently, understanding the effectiveness of forests in soil erosion control is essential for a better design and implementation of vegetation restoration programs (Liu *et al.*, 2020). Our study aimed at quantifying the effects of forest ecosystems on soil erosion and loss control. To achieve this goal, we incorporated GIS and RUSLE into the calculation of soil loss on about 132 km^2 of the catchment in southwest Iran.

Materials and Methods

Study area description

The Ilam catchment with 12 sub-catchments served as the study area and is located in the north of Ilam Province (46 °18´ 36´´ – 46° 30´ 44´´ East longitudes, 33° 34´ 07´´– 33° 41´ 10´´ North latitudes) in southwest Iran (Figure 1). The catchment occupies an area of 131.848 km^2 with an altitude that varies from about 1139 to 2461 m a.s.l. The climate in the Ilam catchment is semi-arid with a mean annual temperature of 18 °C and a mean annual precipitation of 571.6 mm with a dry season between May and August. The soil in the study area is brown soil, which are Entisoils and Inceptisoils. On average, more than 50% of the study area is covered by broad-leaf deciduous forests dominated by Persian oak (*Quercus brantii* Lindl.). The remaining lands are occupied by arable land (22%), residential areas (21%), pasture (2.7%), and bare lands (0.13%). The landscape of the area is characterized by plains, hilly and mountainous areas. Hilly is the dominant geomorphological feature over the area (40.24%), while plains make up a very small proportion. Comprehensive field observations and geomorphological facies revealed the existence of 5 types (sheet, rill, gully, rock fall, and channel erosion) of soil erosion in the study area.

Experimental design

Bearing in mind the fact that the vegetation changes have resulted in a significant shift

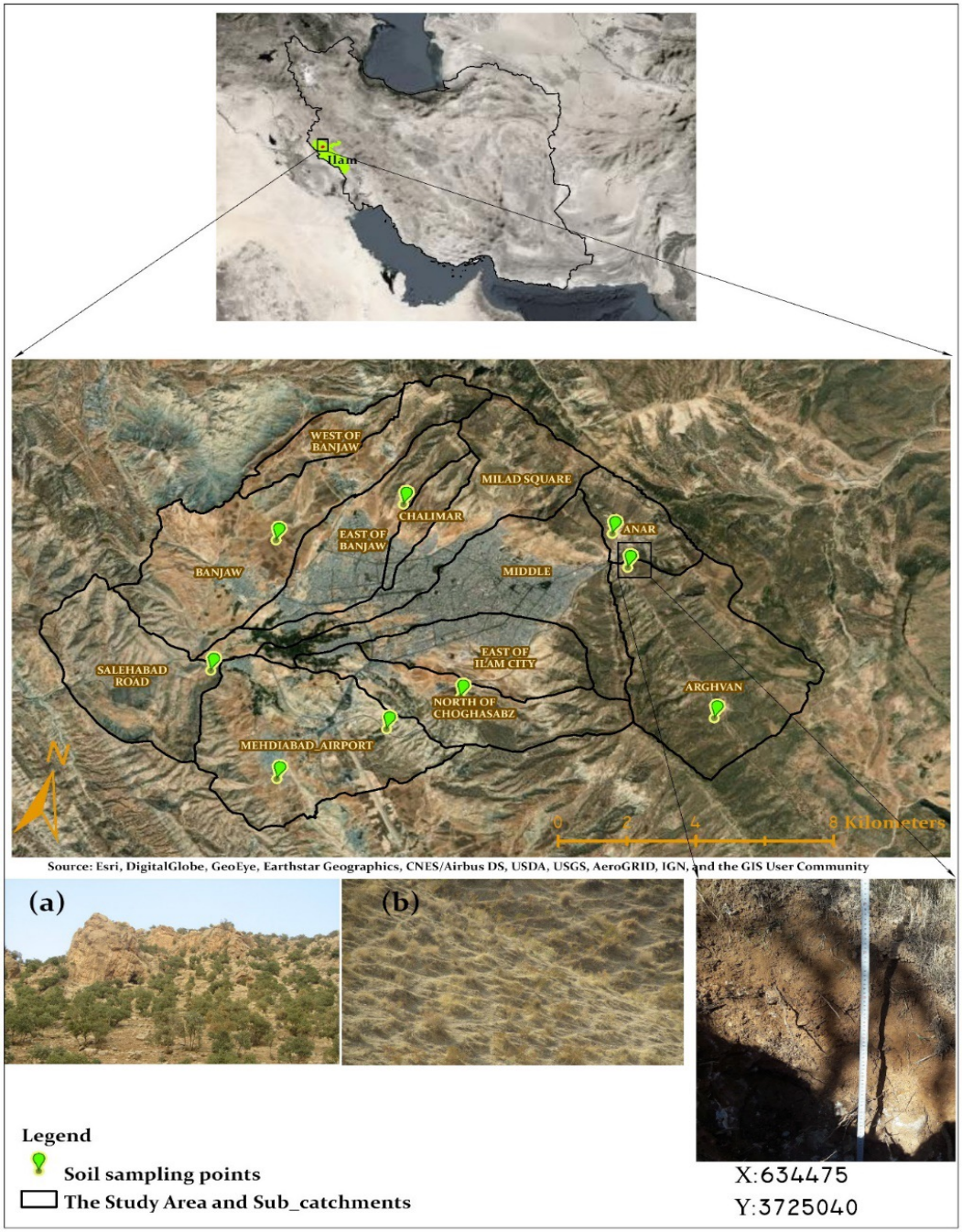


Figure 1. Location of the study area and pictures of the soil erosion types in the catchment (a) sheet erosion in the Southwest of the catchment and rock fall movements.

in the rates of the sediment yield, soil loss, and the values related to runoff, ground cover, and land use, eventually leading to increased erosion and sedimentation (Mobareghee, 2011). Therefore, as a first step towards understanding the effect of the forest in the conservation of soil resources, the estimated amount of soil loss in natural conditions (NC) in Ilam catchment needed to be determined. Then, we needed to define two scenarios that could illustrate the role of the forest ecosystem in protecting the soil and reducing erosion. Indeed, we sought to: (i) estimate the amount of soil loss with the assumption of converting natural forest (with 20% canopy cover) to destructed forest (with 0% canopy cover) (SC.1) and (ii) estimate soil loss with the assumption of increasing forest cover by 40% (SC.2).

The RUSLE model and the soil loss estimation

In watershed management studies, knowing the erodibility of the soil, the state, and intensity of erosion, and the expected effect of conservation measures control is of paramount importance in the understanding of erosion (Najm *et al.*, 2013). Numerous models and methods can be used for the evaluation of vulnerability and soil erosion quantification with an arrangement of various mathematical and geospatial skills (Gholami *et al.*, 2021). However, the choice of models and methods for estimating soil erosion should be based on the efficiency model and its compatibility with the conditions of the watershed (Karimi Sangchini *et al.*, 2009). Unfortunately, it would not have been possible to direct soil loss measurements in the study area. Using this method requires lenghty observations of sediment runoff and adequate equipment. The RUSLE model (Renard *et al.*, 1997) was applied, not only due to fewer data requirements but also due to the possibility of coupling RUSLE with GIS software (Jiang *et al.*, 2015). Therefore, the RUSLE model was chosen. Using the RUSLE model, average annual soil loss can be estimated by a runoff for any number of scenarios involving erosion control practices and under each of the identified land use types (Pradeep *et al.*, 2015; Obiahu & Elias, 2020). The following equation is presented as the primary equation of the RUSLE model:

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

Where:
A is the computed annual soil loss ($t\ ha^{-1}\ y^{-1}$),
R is the rainfall erosivity factor ($MJ\ mm\ ha^{-1}\ hr^{-1}\ yr^{-1}$),
K is the soil erodibility factor ($t\ hr.\ MJ^{-1}\ mm^{-1}$),
LS is the slope length and slope steepness factor (dimensionless),
C is the cover management factor (dimensionless),
P is the conservation practice factor (dimensionless).

Factor R

Rainfall erosivity is usually quantified by an EI30 index (the kinetic energy of the rain and rainfall intensity in 30 minutes). With regard to the inaccessibility to historical information on rainfall intensity in the study catchment, the monthly and annual average rainfall from 23 pluviometry stations in and around Ilam city between 1992 and 2016 were collected from Iran meteorological organization www.irimo.ir. As the next step, the monthly and annual average rainfall data were used to estimate the Fournier Index and R factor with Renard & Freimunds (1994) equations (Equations 2, 3, 4).

$$F = \frac{\sum_{i=1}^{12} pi^2}{\sum_{i=1}^{12} p}, \qquad (2)$$

$$\text{R-Factor} = \frac{(0.07397 \times F^{1.847})}{17.2} \qquad (3)$$

if F<55 mm ,

$$\text{R-Factor} = \frac{(95.77 - 6.081 \times F + 0.4770 \times F^2)}{17.2} \quad (4)$$

if $F \geq 55$ mm

Where:
Pi is the average rainfall (mm), i is the month and P is the annual average rainfall (mm), finally, the R factor map was generated with a raster through interpolation using the inverse distance weighting (IDW) method in ArcGIS Pro 1.2 environment (Figure 2b).

Factor k
The soil erodibility factor is a parameter that represents the resistance of the soil to rainfall erosive effects. The soil physical and chemical property data for the soil layer (0–60 cm), such as clay, sand, silt, and soil organic carbon contents and soil sampling at 9 points (Figure 1) were collected by the General Department of Natural Resources and Watershed Management of Ilam province in 2017. In this study, to determine K-values, we relied on this information to estimate soil erodibility. Then, the K factor map (Figure 2c) was generated using the IDW method.

Factor LS
The topographic factor is the ratio of soil loss from the actual field to that at a site with a 22.13-meter length and 9% slope on the same soil type (Wischmeier & Smith, 1978). The methods are available for the estimation of the LS factor. This study used the equations proposed by Moore & Wilson (1992) to extract the LS factor values (see Figure 2a).

$$L = \left(\frac{\lambda}{22.13}\right)^m, \quad (5)$$

$$m = \frac{\beta}{\beta + 1}, \quad (6)$$

$$\beta = \frac{\frac{\sin\theta}{0.0896}}{3 \times (\sin\theta)^{0.8} + 0.56} \quad (7)$$

where λ is the horizontal projection (m); m is a variable slope length exponent and θ is the slope angle.

Factor C
The C factor specifies the effects of the vegetation cover on controlling soil loss. Soil loss is very low in densely vegetated lands due to better protection of the soil surface by vegetation cover (Gashaw *et al.*, 2020). There are several methods, such as a land use map or a linear regression model to represent the relationship between the C values and spectral indices, to get the C factor. For this study, C factor values were determined from the land use map of the year 2017 in the Ilam catchment. This map encircles 11 different land uses (Figure 3). For each land use, C factor values were determined based on local conditions.

Factor P
P factor values range from 0 to 1, the value approaching 0 indicates a good man-made erosion resistance facility, and the value approaching 1 indicates a lack of such facility (Jiang *et al.*, 2015). As there are no sufficient protection interventions for land in the Ilam catchment, this factor was assigned with 1.

Results

Soil erosion rate at the catchment level (NC)
The factors of RUSLE were integrated into the ArcGIS Pro 1.2 environment to compute the average annual soil loss in the Ilam catchment. Figure 2 illustrates the spatial distribution of these factors (LS, R, and K factors). R values, ranging from 86 to 92 MJ mm^{-1} ha^{-1} h^{-1} yr^{-1}, and decreasing trend toward the western and northern of the catchment (Figure 2b). In the map of the spatial distribution of soil erodibility (Figure 2c), K values ranged from 0.41 to 0.55 t h MJ^{-1} mm^{-1}. LS values in Figure 2a ranged from 0.03 to 40.09. Statistical operations revealed that the annual soil loss

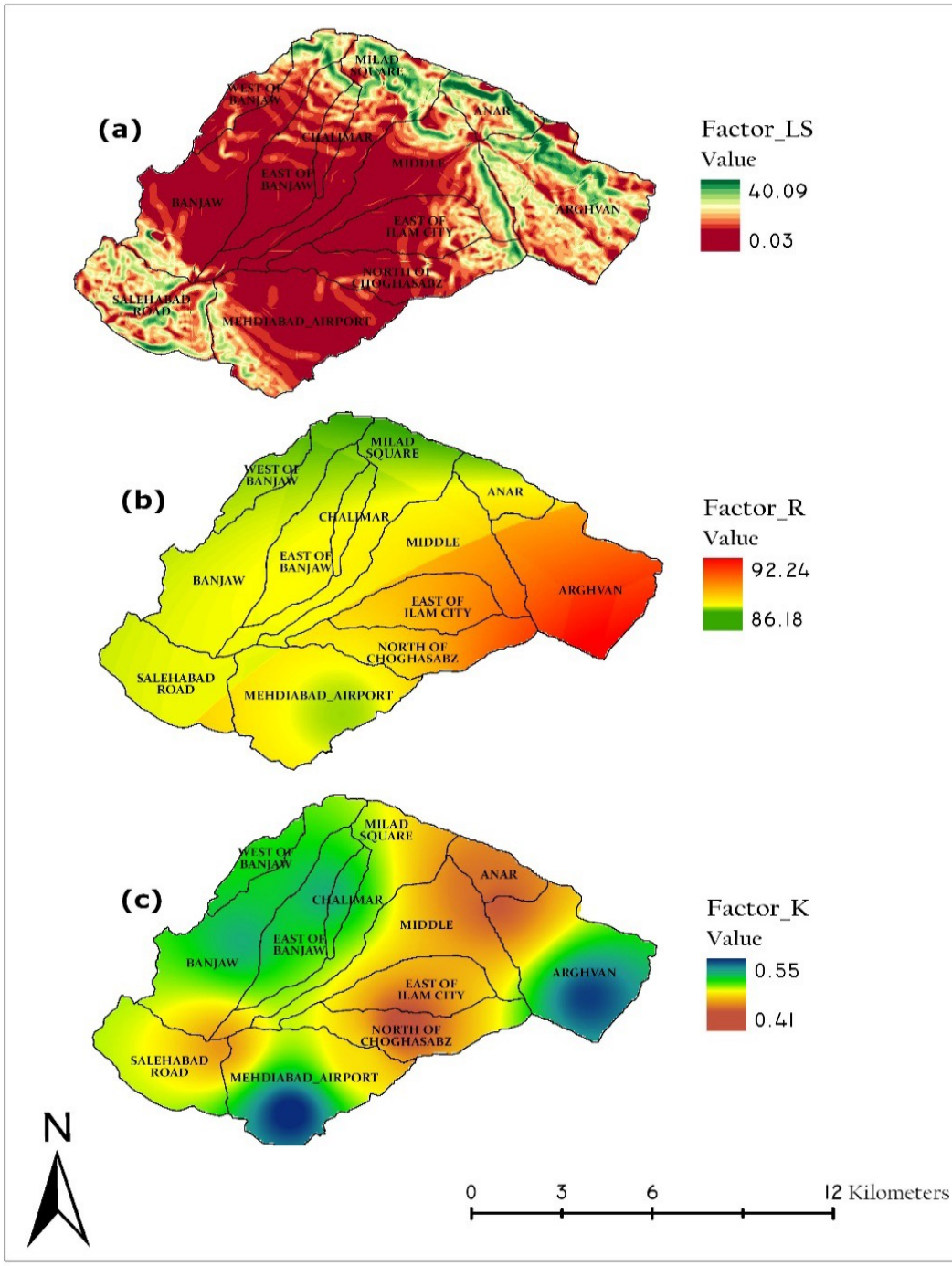


Figure 2. Factors used to calculate the annual soil loss in the RUSLE model.

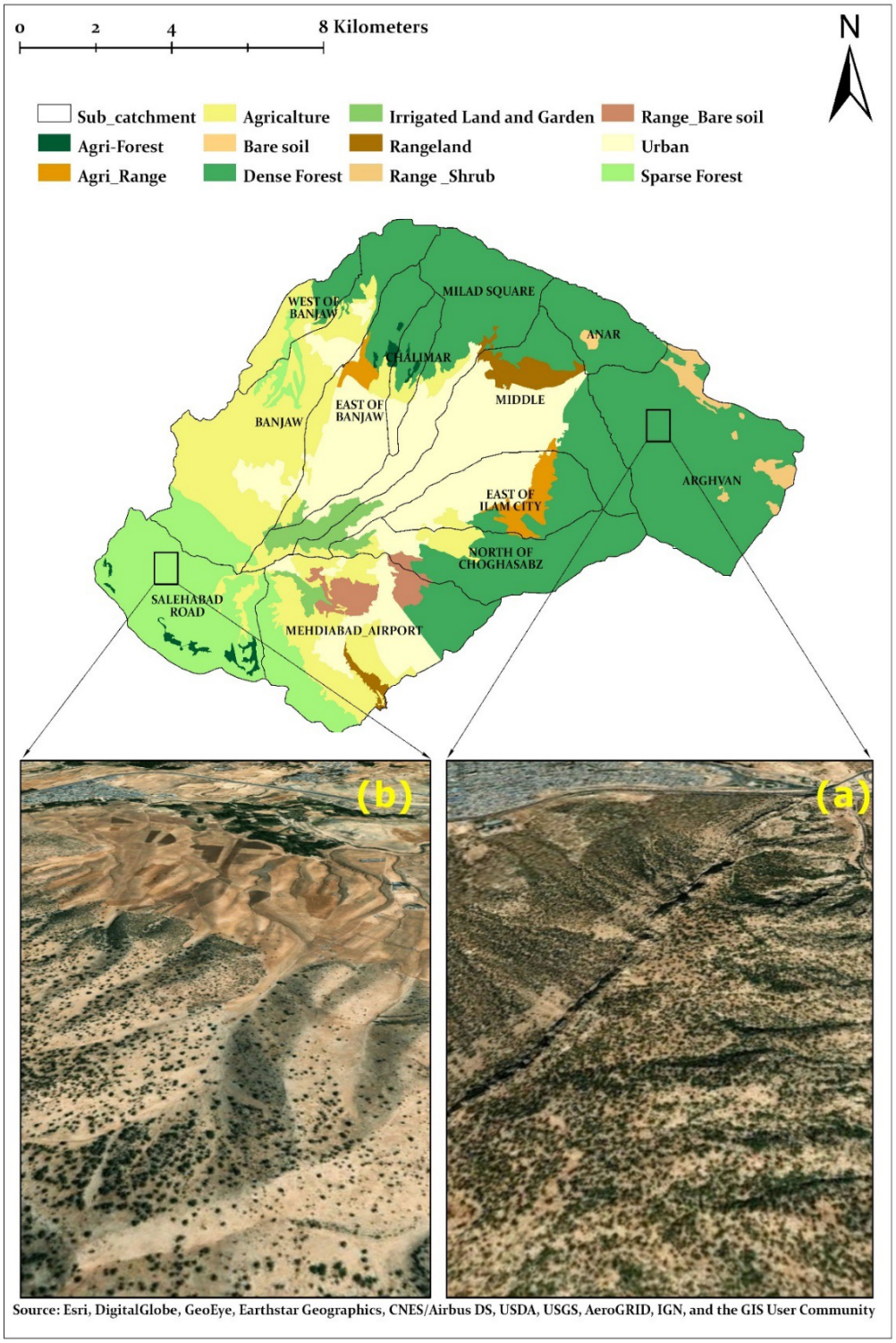


Figure 3. The Land use map of the study catchment and pictures of the (a) Dense Forest, (b) Sparse Forest.

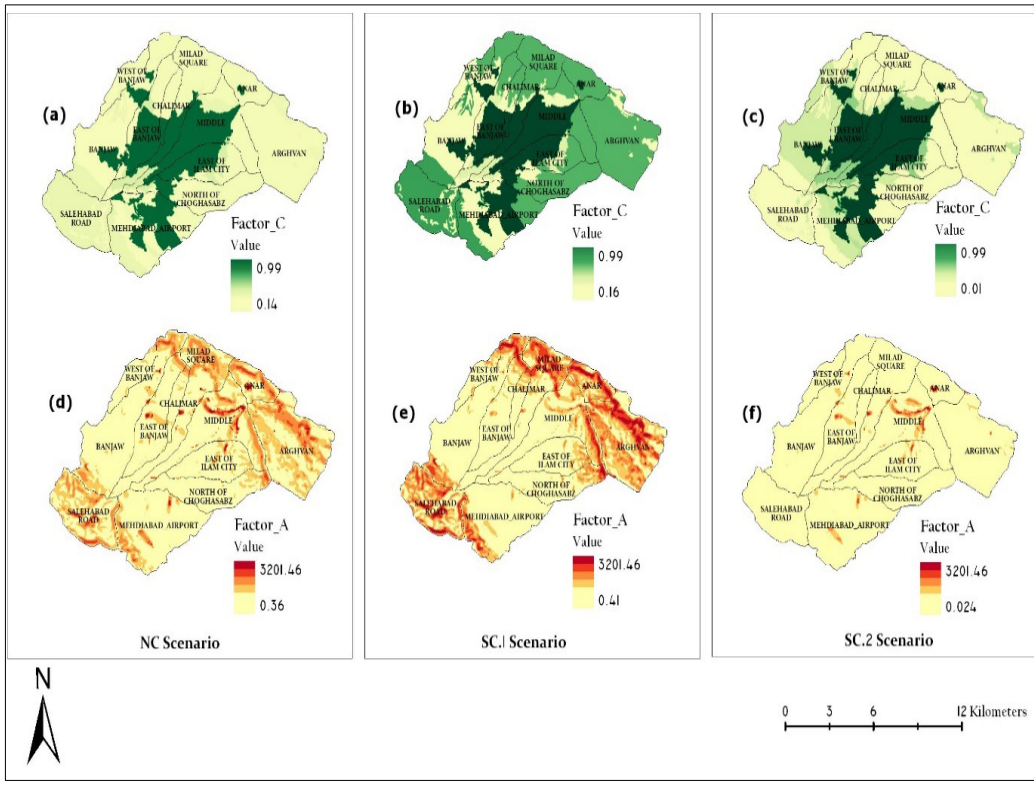


Figure 4. The C factor and levels of soil erosion maps for the defined scenarios on the Ilam catchment.

rate varies from 36 t ha^{-1} yr^{-1} to large over 3200 t ha^{-1} yr^{-1} (Figure 4d) which shows a larger spatial variation of soil loss over the catchment. Table 1 shows the comparison between the average of the annual soil erosion rate of different land use types on the Ilam catchment.

Table 1. Average annual soil erosion (t ha^{-1} year^{-1}) under natural conditions.

Land use type	NC				
	Area		Factor	Soil loss	
	(km^2)	(%)	C	Mean	Std
Dense Forest	52.974	40.18	0.17	78.61	53.17
Sparse Forest	17.083	12.96	0.2	95.41	48.85
Agri-Forest	0.854	0.65	0.14	46.79	27.61
Agri-Range	2.075	1.57	0.25	46.42	32.38
Agriculture	23.075	17.5	0.16	16.27	18.4
Bare soil	0.17	0.13	0.99	256.6	156.5
Rangeland	1.954	1.47	0.2	77.94	64.01
Range-Bare soil	2.138	1.62	0.55	39.02	36.74
Range-Shrub	1.476	1.12	0.19	62.01	55.7
Irrigated and Garden	2.833	2.15	0.18	9.36	12.49
Urban	27.212	20.64	0.99	63.54	63.88

Soil erosion rate with assumption changes in forest cover (SC.1 and SC.2)

The differences in the average of the soil erosion predictions using RUSLE under the SC.1 and SC.2 scenarios in the study catchment are summarized in Figure 4, Table 2, and Table 3. In the SC.1 scenario, the

mean annual soil erosion rate in the dense forest use was 184.36 t ha^{-1} yr^{-1} and in the sparse forest use and in the Agri-Forest use it was 213.51 and 66.35 t ha^{-1} yr^{-1}, respectively. Compared with the natural conditions (NC) the current mean values of SC.1 increased 105.75 t ha^{-1} yr^{-1} in the dense forest use, 118.1 t ha^{-1} yr^{-1} in the sparse forest use, and 19.57 t ha^{-1} yr^{-1} in the Agri-Forest use. In the SC.2 scenario, the mean annual soil loss with an increase in forest coverage reached 5.04 t ha^{-1} yr^{-1} in the dense forest use. In the same direction, for the sparse forest the use rate of 10.33 t ha^{-1} yr^{-1} was observed and reached 21.41 t ha^{-1} yr^{-1} in the Agri-Forest use.

Table 2. Average annual soil erosion (t ha^{-1} $year^{-1}$) under SC.1 scenarios.

Land use type	SC.1				
	Area		Factor	Soil loss	
	(km^2)	(%)	C	Mean	Std
Dense Forest	52.974	40.18	0.4	184.36	124.8
Sparse Forest	17.083	12.96	0.45	213.51	111.09
Agri-Forest	0.854	0.65	0.16	66.35	56.9

Table 3. Average annual soil erosion (t ha^{-1} $year^{-1}$) under SC.2 scenarios.

Land use type	SC.2				
	Area		Factor	Soil loss	
	(km^2)	(%)	C	Mean	Std
Dense Forest	52.974	40.18	0.01	5.04	8.2
Sparse Forest	17.083	12.96	0.02	10.33	7.7
Agri-Forest	0.854	0.65	0.08	21.41	14.1

Discussion

Soil erosion rate at the catchment level (NC)

The obtained mean annual soil erosion rate at NC is comparable with the results of Mohammadi *et al.* (2018) who estimated the soil loss rate in Iran based on the RUSLE model: the highest soil erosion rates observed in the western (Ilam, Lorestan, …) provinces of Iran. They noted that the higher LS and R values in these regions and the Zagros Mountains with steep topography are as important reasons for high soil erosion rates in these provinces. Complementarity means, that the combined effects of low vegetation coverage, dry soils, and heavy rainfalls have made these regions the most severely eroded areas in Iran (Kardavani, 2005). Our results indicate that the highest rate of soil erosion was for bare soils with an average of 256.59 t ha^{-1} yr^{-1} and the next forest lands (σ 85 t ha^{-1} yr^{-1}) are more vulnerable to erosion (Table 1). Importantly, we highlight the reasons that explained the vulnerability of this catchment to soil erosion: (1) The cover provided by these different land uses. Forests provided rarity canopy cover (about 20%) than other land uses (agriculture lands, rangeland, etc.); despite that, on average, one-half of the study catchment was covered by forests. Low canopy cover and vast bare soil reduced the interception and velocity of raindrops. This finding confirms previous results reported by Liu *et al.* (2020). These authors reported that with increasing optimum vegetation coverage, soil erosion control by vegetation coverage increases. This indicates that intermediate tree cover with a positive influence on the soil water budget will be maximized groundwater recharge (Ilstedt *et al.*, 2016). Instead, the susceptibility of soil to erosion and exposure of the soil particles to the direct impact of raindrops increased (Mohammad & Adam, 2010; Bozali, 2020). (2) The specific topographic conditions and slope of the region. More than 70% of the catchment consists of hilly mountainous areas with medium to high slopes. The slope gradient factor plays a vital role in the magnitude of soil erosion control (Aslam *et al.*, 2021; Liu *et al.*, 2020), and is an important structural component of the landscape in determining soil erosion intensity (Wang *et al.*, 2016). Land

cover changes associated with specific topography have an accelerating or retarding impact on soil loss (Sun *et al.*, 2014).

Soil erosion rate with assumption changes in forest cover (SC.1 and SC.2)

From Biddoccu *et al.* (2020) findings it was evident that among the factors used to determine the RUSLE value, the C factor seems to be an important one. Toy *et al.* (1999) noticed the strong influence of the C factor on the soil-loss rate because it represents surface conditions that often are easily managed for erosion control, and second, its values range from virtually 0 to slightly greater than 1. Thus, in this study, the variation in C values between a range of maximum C (zero ground cover) by 40% ground cover in forest use was considered to assess the effects of protecting the forest ecosystem on soil erosion control. Our study outputs supported previous research reporting that forest restoration and management can effectively reduce soil erosion (Teng *et al.*, 2019; Rodrigues *et al.*, 2020; Liu *et al.*, 2020). Ma *et al.* (2019) reported that the controlling effect of forests on soil erosion is the result of the combined different factors, such as canopy, litter, and root system. The forests have a dense and multistory canopy, intercepted rainfall, and improved soil, all of which greatly reduce soil erosion (Blanco-Canqui & Lal, 2010). In forests, rainfall before hitting the soil surface is intercepted by the canopy. The energy of raindrops is reduced to almost zero when they reach the soil. Not only are raindrops modified by tree and leaf traits within the forest canopy but also rainfall amounts are reduced by the vertical distribution of foliage and canopy roughness (Song *et al.*, 2019). Therefore, vegetation restoration can improve the effectiveness of land cover and reduce susceptibility to soil erosion (Sun *et al.*, 2014). Vegetation recovery is a promising strategy to control soil erosion and to improve other ecosystem services at a scale ranging from the catchment to a global level (Berendse *et al.*, 2015).

Conclusion

Reliable estimates of soil loss using the RUSLE and GIS-based approach (Kebede *et al.*, 2021) enabled the prediction of the soil erosion rate and illustrated the role of the forest ecosystem in protecting the soil under two scenarios at the catchment level in southwest Iran. The annual soil loss rate from the whole catchment varies from 25 t ha^{-1} yr^{-1} to considerably over 3200 t ha^{-1} yr^{-1}. However, bare soils with a mean of 256.59 t ha^{-1} yr^{-1} were highly susceptible to soil erosion. The changes in natural forest coverage under the defined scenarios showed clear differences in soil erosion rates. The assumption that destructed natural forests show the highest values of soil erosion while soil erosion control was best achieved by SC. 2 (assumption of increase in forest cover by 40%).

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