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Investigation of likely effects of land use planning on reduction of soil erosion rate in river basins: Case study of the Gharesoo River Basin

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ABSTRACT

We investigated the effects of land use planning on reduction of soil erosion rate in the Gharesoo River Basin, Golestan Province, Iran. For this, the Revised Universal Soil Loss Equation (RUSLE) was used in conjunction with Geographic Information System (GIS) to model potential soil erosion. The average potential soil erosion in the river basin was 18.65 $t\,ha^{-1}\,yr^{-1}$, with a standard deviation of 33.88 $t\,ha^{-1}\,yr^{-1}$. The severe and very severe erosion classes comprised 8% and 4% of the river basin, respectively. We found that all areas with severe and very severe erosion were located in agricultural land. Assessing the impacts of land use and slope confirmed importance of interaction between these factors in increasing soil erosion, especially in agricultural areas with steep slopes. We applied a land use planning to control and reduce soil erosion rate, with a specific focus on agricultural areas. For this purpose, the Multi-Criteria Evaluation (MCE) and Multi-Objective Land Allocation (MOLA) were implemented for agriculture, urban and industrial development, and afforestation. We used the output land use map from MOLA in the RUSLE model. The results showed a significant reduction of average potential soil erosion equal to 25.6% (from 18.65 $t\,ha^{-1}\,yr^{-1}$ to 13.86 $t\,ha^{-1}\,yr^{-1}$) when the MOLA land use plan was followed. Also, the area impacted by severe and very severe erosion classes were reduced by 25.50% and 42.59%, respectively. The results of this research emphasized that implementation of land use planning in the Gharesoo River Basin is helpful in controlling soil erosion. The method presented in this study can be a basis for sustainable and comprehensive management of river basins.

1. Introduction

One of the major global scale problems nowadays is the rapidly increasing food demand due to rapid population growth, which is followed by increasing conversion of forest land into croplands. Increasing agricultural lands regardless of control techniques, together with urban development and forest harvest are fundamental factors of soil erosion (Ustun, 2008). Soil erosion by water is one of the most important types of erosion and about one-third of the arable land around the world has been affected by soil erosion over the past 40 years. Soil erosion causes losing valuable top soil which is the most productive part of the soil profile for agriculture, water pollution, and reduces the ability of soil to mitigate the greenhouse effect (Sun et al., 2014).

Soil erosion occurs naturally when the force of wind, raindrops or runoff on the soil surface is higher than the cohesive forces that bind the soil together. Vegetation cover protects the soil from the effects of these erosive forces (May and Place, 2005). Human activities such as irrational land conversion and poor management activities destroy vegetation cover and increase the possibility of soil erosion. Also, soil parameters and topography strongly affect the soil erosion, but they are relatively stable and are not easily changeable and manageable. Therefore, the rainstorms, irrational land uses, and vegetation destruction have been considered as the main factors of soil erosion (Mohammad and Adam, 2010; Sun et al., 2014).

Several models have been developed to predict and estimate soil erosion by water, including Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997), Water Erosion Prediction Project

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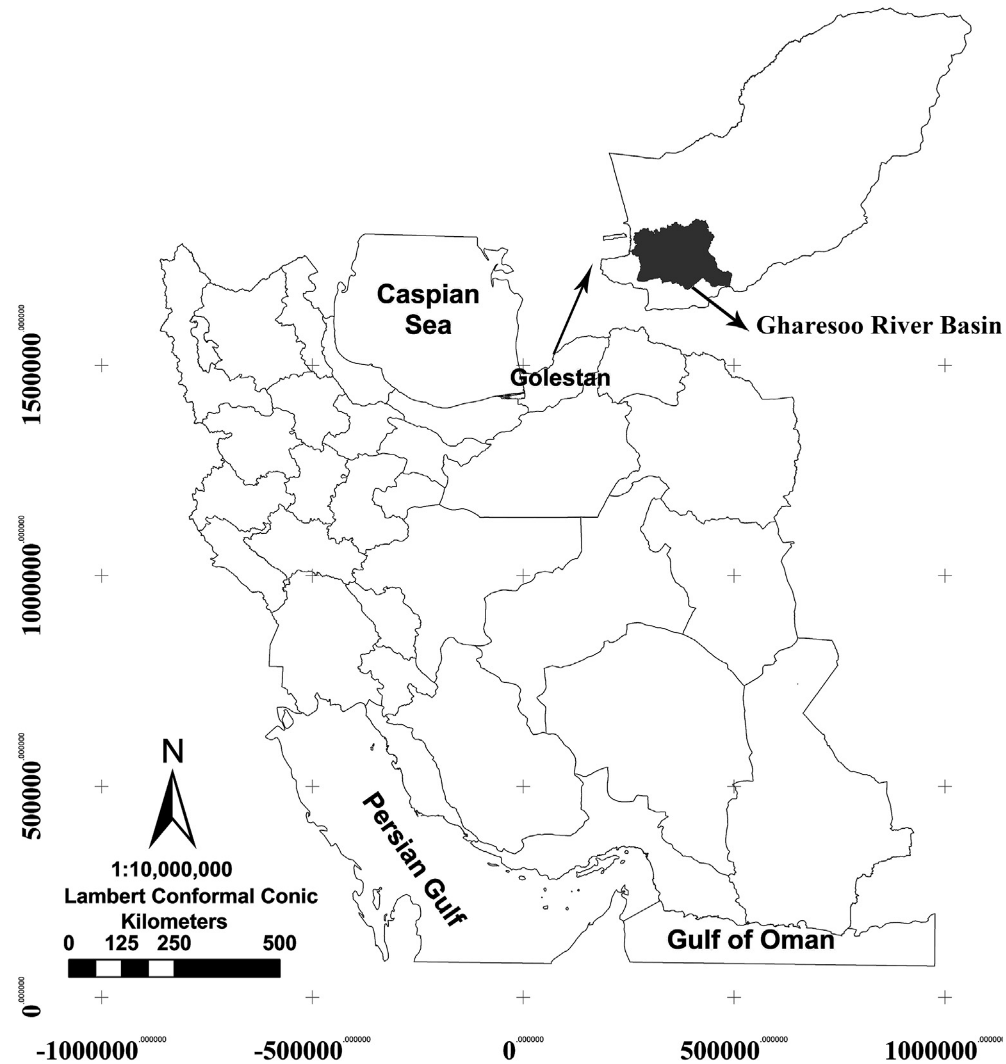

Fig. 1. Location of the Gharesoo River Basin in Golestan Province of Iran.

(WEPP) (Laflen et al., 1991), Soil Loss Estimation Model for Southern Africa (SLEMSA), Areal Non-Point Source Watershed Environment Response Simulation (ANSWERS), Erosion Potential Method (EPM), Modified Pacific Southwest Inter-Agency Committee (MPsiac), Chemicals Runoff and Erosion From Agricultural Management Systems (CREAMS) (Knisel, 1980), and Soil and Water Assessment Tool (SWAT) (May and Place, 2005).

RUSLE is a universally accepted method that can be used as an appropriate model for estimating potential soil erosion in vast areas with different types of land use and land cover such as agricultural land, forest and rangeland (Sun et al., 2014). RUSLE predicts potential soil loss due to water erosion as a function of rainfall erosivity, topography, soil erodibility, land use and land cover management, and control practices (Meshesha et al., 2012; Sun et al., 2014). The combination of RUSLE with Geographical information system (GIS) increases the predictive power of this model (May and Place, 2005). Considering that RUSLE factors are calculated by spatial data, GIS techniques provide useful tools to modify and map them. These techniques facilitate evaluation of soil erosion in large areas and in more detail (Karimi, 2011).

RUSLE have been used in a wide range of studies in the world to model spatial distribution of soil erosion (Prasannakumar et al., 2012; Alexakis et al., 2013; Sun et al., 2014; Rezaei et al., 2014; Kamangar et al., 2015) and investigate the effects of controlling measures on soil erosion rate (Meshesha et al., 2012; Andriyanto et al., 2015; Haregeweyn et al., 2017;). Meshesha et al. (2012) used RUSLE in Central Rift Valley of Ethiopia and found that the conversion of land during 23 years increased the rate of erosion by 80%, especially in croplands. Sun et al. (2014) concluded that soil erosion is significantly related to land use and topography in the Loess Plateau in China.

Reliability and validity of RUSLE have been confirmed in several studies. For example, Meshesha et al. (2012) illustrated that the overall accuracy of estimated erosion using RUSLE was 71.1% in Central Rift Valley. Also, Sun et al. (2014) found a significant relationship ($P < 0.01$) between erosion rate determined by field measurements and the estimates by the RUSLE. In addition, Andriyanto et al. (2015) showed a close relationship ($R^2 = 0.56$) between RUSLE results and field measurements.

In the present study, RUSLE was used in conjunction with GIS to model the spatial distribution of potential soil erosion by water in the Gharesoo River Basin, Golestan Province, Iran. The Gharesoo River Basin has been subject to multiple human pressures such as overexploitation of forest for fuel wood, clear-cutting of forest for agriculture, and rapid urban and industrial development without attention to the ecological suitability of land. So, implementation of mitigation measures is a necessity to control the risks arising from human activities, such as soil erosion. One way to investigate the possible outcomes of management and mitigation measures on soil erosion is through land use planning (Andriyanto et al., 2015; Haregeweyn et al., 2017). Andriyanto et al. (2015) illustrated that the soil erosion rate based on current situation and after sustainable land use planning in Kalikonto

Table 1
GIS data layers and sources used in the analysis.

Layer and data name (units)	Source	Processing/comments
Bare land (%)	Golestan Province land use planning report (GUASNR, 2013), in which images of MODIS were used with a spatial resolution of 250 m.	All data were used as criteria in suitability analysis using MCE.
Vegetation density	Golestan Province land use planning report (GUASNR, 2013), in which images of MODIS were used with a spatial resolution of 250 m.	
Geology	Golestan Province land use planning report (GUASNR, 2013), that was derived from 1:100000 and 1:250000 maps from Geological Survey & Mineral Explorations of Iran.	
Geomorphology	Golestan Province land use planning report (GUASNR, 2013), that was derived from land capability map and aerial imagery.	
Soil texture	Atlas of soil contaminants of Golestan Province (2010)	
Hydrologic soil groups		
Soil pH	Atlas of soil contaminants of Golestan Province (2010), including 74 sampling points.	All data were used as criteria in suitability analysis using MCE. Soil sand, silt, clay, and organic carbon were used to calculate RUSLE K-factor. IDW* interpolation method was used to produce a continuous raster layer from point data.
Cation exchange capacity (meq/100 g soil)		
Soil clay (%)		
Soil organic carbon (%)		
Soil sand (%)		
Soil silt (%)		
Soil electric conductivity (ds/m)		
Evapotranspiration (mm)	Meteorological Organization, 2013, including dataset of 19 meteorological stations.	All data were used as criteria in suitability analysis using MCE. The rainfall dataset of 10 years (2003 − 2013) was used to calculate RUSLE R-factor. IDW interpolation method was used to produce a continuous raster layer from point data.
Temperature (C°)		
Rainfall (mm)		
Humidity (%)		
Freezing degree days		
Sunny hours during the year		
Wind speed (m/S)		
Spring	Golestan regional water authority, 2013.	All data were used as criteria in suitability analysis using MCE. Distance layer was created using GIS.
Aqueduct		
Well		
Dam		
Restricted area of water harvesting		
Foothills and mountains	Extracted from geomorphology layer.	
Surface water resources	Extracted from land use layer.	
Ground water quality	Golestan regional water authority, 2013.	All data were used as criteria in suitability analysis using MCE. IDW interpolation method was used to produce a continuous raster layer from point data.
Ground water depth (m)		
Land use	Golestan Province land use planning report (GUASNR, 2013), in which Landsat images with a spatial resolution of 30 m were also used.	Layer Was used as criteria in suitability analysis using MCE. Also, was used to calculate RUSLE C-factor.
Digital elevation model (DEM) (m)	Golestan Province land use planning report (GUASNR, 2013), that was derived from ASTGTM** with a spatial resolution of 30 m.	All data were used as criteria in suitability analysis using MCE. Also, DEM and slope were used to calculate RUSLE LS-factor.
Slope (%)	Extracted from DEM layer.	
Aspect (qualitative categories)		
Residential areas	Extracted from land use layer.	All data were used as criteria in suitability analysis using MCE. Distance layer was created using GIS.
Roads		
Industrial area		
Fire risk	Golestan Province land use planning report (GUASNR, 2013). All layers have a spatial resolution of 30 m.	Was used as criteria in suitability analysis using MCE.
Flood potential		
Hydrocarbonic soil pollution		
Landslide susceptibility		

* Inverse Distance Weighted (IDW).
** The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM).

Watershed is $72\,t\,ha^{-1}\,yr^{-1}$ and $62\,t\,ha^{-1}\,yr^{-1}$, respectively. Also, Haregeweyn et al. (2017) found that after land use planning the total soil loss in the Upper Blue Nile River basin reduced by 52%.

Making decision about the use of land is urgent in areas that have been affected by human destruction and increasing population pressure. Land use planning can be defined as allocation of land to various uses according to the inherent ecological suitability of land (Makhdoum, 2007). Land development considering ecological suitability of land would help to control hazards caused by human activities and reduce the negative impacts of development on environment. Sustainable development should improve the quality of human life within the caring capacity of supporting ecosystems (De Wit and Verheye, 2003).

The goal of this study was to investigate the applicability of land use planning on reduction of soil erosion rate in the Gharesoo River Basin. The specific objectives were to (1) model spatial distribution of soil erosion using RUSLE model, (2) assess the impacts of land use and slope on soil erosion rate, and (3) evaluate the impacts of land use planning on soil erosion rate.

2. Materials and methods

2.1. Study area

The Study was conducted in the Gharesoo River Basin in Golestan Province, northern Iran, which is located approximately between 54°02′E and 54°44′E and between 36°37′N and 37°00′N (Fig. 1). The river basin covers approximately 161,528 ha, located in northern slopes

Table 2
Values of MFI and R-factor for each metrological station.

Stations	Longitude E	Latitude N	Elevation (m respect mean sea level)	Annual rainfall (mm)	MFI	R-factor
Aghghabr	54° 23′ 19″	37° 20′ 40″	−60	407.65	58.88	80.90
Aghghala	54° 27′ 42″	37° 01′ 00″	−04	390.70	54.48	6.93
Aghzabir	54° 34′ 12″	37° 04′ 38″	5	366.08	53.93	6.80
Alang	54° 09′ 00″	36° 47′ 45″	12	591.80	80.60	157.24
Eslamtape	54° 21′ 21″	36° 56′ 33″	−11	471.99	66.71	105.41
Ghalandarayesh	54° 10′ 56″	36° 45′ 23″	169	656.19	84.72	174.69
Gomishan	54° 04′ 16″	37° 03′ 47″	−19	463.01	68.66	112.02
Gorgan	54° 26′ 29″	36° 50′ 30″	145	679.97	84.87	175.32
Gorjimahale	54° 13′ 23″	36° 49′ 14″	3	532.15	72.06	124.09
Hajiabad	54° 20′ 09″	36° 38′ 06″	2112	294.11	40.65	4.03
Hedarabd	54° 32′ 36″	36° 56′ 39″	6	460.445	61.22	87.85
Jafarabad	54° 41′ 34″	36° 50′ 45″	245	740.00	91.25	204.22
Jelin	54° 33′ 33″	36° 51′ 37″	135	601.35	78.95	150.53
Kordkoy	54° 07′ 47″	36° 46′ 33″	95	680.4	84.62	174.23
Naman	54° 14′ 48″	36° 46′ 44″	103	707.53	87.41	186.56
Nochaman	54° 18′ 25″	36° 45′ 55″	300	646.18	82.12	163.56
Panjpeikar	54° 09′ 35″	36° 56′ 51″	−14	408.06	62.61	92.15
Siminshahr	54° 13′ 50″	37° 01′ 04″	−13	402.44	60.87	86.80
Varsan	54° 19′ 44″	36° 50′ 20″	82	503.40	66.71	105.38

Table 3
Values of RUSLE C factor for different land use classes in the Golestan Province (Karimi, 2011).

Land use	C factor
Forest	0.003
Barren	0.36
Agriculture	0.26
Rangeland	0.013
Developed	0.003
Water	0

of the Alborz Mountains and is close to the south eastern coast of the Caspian Sea. Dense and semi-dense forest areas and rangelands cover approximately 39% and 5% of the river basin in the south, respectively. In the northern part, agricultural lands dominate the landscape and cover 48% of the river basin. The altitude varies from 99 m below mean sea level in the north to about 3213 m in the southeast. The Gharesoo River Basin has been divided into 19 metrological stations. In Table 2 a few characteristics of the metrological stations are listed which are longitude and latitude of the stations and their elevation. The climate is humid, with average annual rainfall of 552 mm and mean annual temperature of 15 °C. The minimum temperature occurs in winter, with a seasonal average of 6 °C, and the maximum temperature occurs in summer, with a seasonal average of 24 °C. The highest amount of rainfall occurs in autumn, with an average annual of 180 mm, and the least rainfall occurs in summer, with an average annual of 72 mm. The dominant soil texture is clay-loam which covers approximately 50% of the river basin in the south. Silty-clay and silty-loam soils are dominant in the northern parts of river basin. Geologically, the Gharesoo River Basin is part of the Alborz Zone and consists of Miocene sediments including calcareous sandstone, sandy limestone with marl and conglomerate. This river basin has been subject to multiple human pressures such as overexploitation of forest for fuel wood, clear-cutting of forest for agriculture, road construction, and rapid urban and industrial development. During the years 1984–2013, the area of forest land has been decreased by 12%. About 5% of forest has been converted to agriculture and 6% to rangeland. Also 1% of forest has been changed into residential and industrial areas. The area of residential and industrial areas has nearly tripled over the same years (GUASNR, 2013).

2.2. Data collection

A list of data and layers used in the analysis is provided in Table 1. Also, some information on data quality, sources, and processing is presented. Because the data layers originated from different organizations, all data were rasterized to a 30 m grid and transformed to similar reference system.

2.3. Estimation of potential soil erosion using the RUSLE model

We used RUSLE in conjunction with GIS to model the spatial distribution of potential soil erosion by water. RUSLE estimates soil erosion rate using the following equation (Sun et al., 2014):

$$A = R \times K \times L \times S \times C \times P \tag{1}$$

where A is annual soil erosion ($t\,ha^{-1}\,yr^{-1}$), R is the rainfall erosivity factor ($MJ\,mm\,ha^{-1}\,h^{-1}\,yr^{-1}$), K is the soil erodibility factor ($t\,ha\,h\,ha^{-1}\,MJ^{-1}\,mm^{-1}$), L is the slope length factor, S is the slope steepness factor, C is the land cover and land use factor, and P is the conservation practices. L, S, C, and P factors are dimensionless.

2.3.1. Rainfall erosivity factor (R)

Rainfall is a driving force of erosion and its distribution pattern and erosivity have direct relationship with soil erosion (Sun et al., 2014). In the RUSLE model, R factor is calculated based on storm energy (E, $MJ\,m^{-2}$) and the maximum 30-min rainfall intensity (I_{30}, $mm\,hr^{-1}$). However, in regions where data for storm energy are not available, alternative methods and indices that effectively estimate the erosivity, can be used (Meshesha et al., 2012). In the present study, no adequate storm energy data were available, so the Modified Fournier Index (MFI) was used for calculation of the R factor. The MFI is well correlated with the rainfall erosivity (Kouli et al., 2009), considers the rainfall seasonal distribution (Alexakis et al., 2013), and its required data are readily available. Accordingly, The MFI was used to calculate R factor based on monthly rainfall dataset. The MFI was calculated based on the following equation (Renard and Freimund, 1994):

$$MFI = \frac{1}{N}\sum_{j=1}^{N}\sum_{i=1}^{12}\frac{Pij^2}{Pj} \tag{2}$$

where P_{ij} is the mean monthly rainfall (mm) in month i of year j, Pj is the mean annual rainfall (mm) in year j, and N is the number of years. Then, the R factor was estimated using the following equation (Renard and Freimund, 1994):

$$\begin{aligned} R &= (0.07397MFI^{1.847})/17.02 && MFI < 55 \\ R &= (95.77–6.081MFI + 0.477MFI^2)/17.02 && MFI \geq 55 \end{aligned} \tag{3}$$

Values of MFI and R-factor for each metrological station is provided

Table 4
The standardization methods and weights of criteria for agriculture suitability analysis.

Criteria	Standardization methods	Break points	Criteria weights	Final criteria	Final criteria weights
Bare land (%) (Modis-derived IGCP)	Linear ↓	0, 100	0.437	Vegetation	0.073
Vegetation density (Modis-derived NDVI)	Linear ↑	0–9975	0.563		
Geology (qualitative categories)	WE	–	0.500	Geology	0.063
Geomorphology (qualitative categories)	WE	–	0.500		
Soil texture (qualitative categories)	WE	–	0.082	Soil	0.201
Hydrologic soil groups (qualitative categories)	Linear ↑	A, D	0.044		
Soil pH	Linear S	4, 7, 7, 8	0.032		
Cation exchange capacity (meq/100 g soil)	Linear ↑	0, 59	0.023		
Percentage of clay in soil	Linear S	4, 40, 50, 67	0.018		
Soil organic matter (%)	Linear ↑	0, 5.5	0.052		
Percentage of sand in soil	Linear S	5, 30, 40, 82	0.014		
Soil electric conductivity (ds/m)	Linear ↓	0, 246	0.134		
Soil productivity	Linear ↑	0, 255	0.100		
Soil depth	Linear ↑	0, 256	0.279		
Soil erosion sensitivity (ton/pixel/year)	Linear ↓	0, 523	0.223		
Evapotranspiration	Linear ↓	0, 180	0.029	Meteorology	0.153
Temperature (C°)	Linear S	1, 14, 17, 20	0.161		
Rainfall (mm)	Linear ↑	100, 836	0.357		
Humidity (%)	Linear ↑	0, 83	0.242		
Freezing degree days	Linear ↓	0, 25	0.102		
Sunny hours during the year	Linear ↑	0, 2704	0.067		
Wind speed	Linear ↓	0, 5	0.044		
Distance to springs (m)	Linear ↓	< 30 = 0 (Con), 30, 500	0.022	Water resources	0.226
Distance to aqueducts (m)	Linear ↓	< 30 = 0 (Con), 30, 500	0.029		
Distance to surface water resources (m)	Linear ↓	< 60 = 0 (Con), 60, 5000	0.116		
Distance to well (m)	Linear ↓	< 30 = 0 (Con), 30, 1500	0.108		
Distance to dam (m)	Linear ↓	< 300 = 0 (Con), 300, 10,000	0.039		
Ground water depth (shallow) (m)	Linear S	3, 10, 20, 25	0.137		
Ground water depth (deep) (m)	Linear ↓	25, 200	0.100		
Ground water quality (Water Quality Index)	Linear ↑	0, 111	0.135		
Distance to foothills and mountains (m)	Linear ↓	0, 70,763	0.299		
Restricted area of water harvesting	WE	Restricted = 0, Unrestricted = 255	0.016		
Elevation (m)	Linear S	−144, 100, 300, 3000	0.171	Land use and physical land	0.251
Slope (%)	Linear ↓	0, 15	0.422		
Aspect (qualitative categories)	WE	P & N = 1, E & W = 0.6, S = 0.4	0.029		
Distance to residential areas (m)	Linear ↓	< 100 = 0 (Con), 100, 5000	0.054		
Distance to main roads (m)	Linear ↓	< 60 = 0 (Con), 500, 5000	0.192		
Distance to secondary roads (m)	Linear ↓	< 30 = 0 (Con), 500, 5000	0.094		
Distance to industrial area (m)	Linear ↓	< 180 = 0 (Con), 180, 15,000	0.038		
Fire risk	Linear ↓	0, 220	0.101	Natural hazard	0.034
Flood potential	Linear ↓	0, 255	0.423		
Earthquake risk	Linear ↓	0, 255	0.072		
Hydrocarbonic soil pollution	Linear ↓	0, 240	0.253		
Landslide susceptibility	Linear ↓	0, 255	0.151		

↑ = monotonically increasing, ↓ = monotonically decreasing, S = symmetric, WE = weighting categories by experts, Con = constraint, P = plain, N = north, E = east, W = west, S = south.

in Table 2.

2.3.2. Soil erodibility factor (K)

Soil is the eroded object and soil erodibility factor (K) represents average long-term soil response to the erosive power of rainfall and is defined as the ratio of soil loss per unit of erosion index for a specific soil (Alexakis et al., 2013; Meshesha et al., 2012). The K factor is related to factors such as soil texture, organic matter, permeability and other characteristics of the soil type. In the present study, the K factor was calculated using the following equation (Sun et al., 2014):

$$K = \left\{0.2 + 0.3\exp\left[-0.0256\mathrm{SAN}\frac{(1 - SIL)}{100}\right]\right\}\left(\frac{SIL}{CLA + SIL}\right)^{0.3} \times\left(1.0 - \frac{0.25C}{C + \exp(3.72 - 2.95C)}\right)\left(1.0 - \frac{0.7SNI}{SNI + \exp(-5.51 + 22.9SNI)}\right) \tag{4}$$

where SAN is the sand fraction (%), SIL is silt fraction (%) and CLA is clay fraction (%), C is the soil organic carbon content (%), and SNI is equal to 1-SAN/100.

2.3.3. Topographic factor (LS)

Topographic factor expresses the effect of slope length (L) and slope steepness (S) on the rate of soil erosion. As slope length and steepness increases the overland flow velocity increases, that leads to greater rate of soil erosion (Alexakis et al., 2013; Sun et al., 2014). In this study, the LS factor was calculated using the equation proposed by Renard et al. (1997):

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

where λ is the slope length (m) and m is an adjustable slope length exponent, calculated using the following equation:

$$\mathrm{m} = \frac{\beta}{1 + \beta} \quad \beta = \frac{\sin\theta/0.0896}{3.0(sin\theta)^{0.8} + 0.56} \tag{6}$$

where θ is slope angle.

$$\begin{aligned} &\mathrm{S} = 10.8\ \sin\ \theta + 0.03 && \mathrm{s} < 9\% \\ &\mathrm{S} = 16.8\ \sin\ \theta - 0.50 && \mathrm{s} \geq 9\% \end{aligned} \tag{7}$$

In the above equations θ is slope angle and s is percent slope.

Table 5
The standardization methods and weights of criteria for urban development suitability analysis.

Criteria	Standardization methods	Break points	Criteria weights	Final criteria	Final criteria weights
Bare land (%) (Modis-derived IGCP)	Linear S	0, 150, 200, 255	0.430	Vegetation	0.030
Vegetation density (Modis-derived NDVI)	Linear ↑	2000, 9000, > 9000 = 0 (Con)	0.570		
Geology (qualitative categories)	WE	–	0.500	Geology	0.120
Geomorphology (qualitative categories)	WE	–	0.500		
Soil texture (qualitative categories)	WE	–	0.120	Soil	0.120
Hydrologic soil groups (qualitative categories)	Linear ↑	A, D	0.080		
Soil pH	Linear S	4, 7, 7, 8	0.031		
Cation exchange capacity (meq/100 g soil)	Linear ↑	0, 59	0.021		
Percentage of clay in soil	Linear S	4, 40, 50, 67	0.030		
Soil organic matter (%)	Linear ↑	0, 4.5, > 4.5 = 0 (Con)	0.050		
Percentage of sand in soil	Linear S	5, 30,50, 82	0.050		
Soil electric conductivity (ds/m)	Linear ↓	0, 246	0.100		
Soil productivity	Linear ↑	0, 255	0.118		
Soil depth	Linear ↑	0, 256	0.200		
Soil erosion sensitivity (ton/pixel/year)	Linear ↓	0, 523	0.200		
Evapotranspiration	Linear ↓	0, 160	0.100	Meteorology	0.080
Temperature (C°)	Linear S	1, 14, 17, 20	0.230		
Rainfall (mm)	Linear ↑	250, 836	0.150		
Humidity (%)	Linear S	0, 50, 60, 78	0.220		
Freezing degree days	Linear ↓	0, 25	0.100		
Sunny hours during the year	Linear ↑	0, 2704	0.100		
Wind speed	Linear S	0, 2, 3, 5	0.100		
Distance to springs (m)	Linear ↓	< 30 = 0 (Con), 30, 2000	0.021	Water resources	0.270
Distance to aqueducts (m)	Linear ↓	< 30 = 0 (Con), 30, 2000	0.027		
Distance to surface water resources (m)	Linear ↓	< 60 = 0 (Con), 60, 5000	0.200		
Distance to well (m)	Linear ↓	< 30 = 0 (Con), 30, 1500	0.106		
Distance to dam (m)	Linear ↓	< 300 = 0 (Con), 300, 10,000	0.100		
Ground water depth (shallow) (m)	Linear S	3, 10, 20, 24	0.070		
Ground water depth (deep) (m)	Linear ↓	3, 10, 20, 24	0.039		
Ground water quality (Water Quality Index)	Linear ↑	0, 111	0.149		
Distance to foothills and mountains (m)	Linear ↓	0, 35,000	0.249		
Ground water electric conductivity	Linear ↓	0, 2966	0.039		
Elevation (m)	Linear S	400, 1200, 1800, 2000	0.140	Land use and physical land	0.230
Slope (%)	Linear ↓	0, 9	0.291		
Aspect (qualitative categories)	WE	P & N = 1, E = 0.6 W = 0.2, S = 0.4	0.116		
Distance to residential areas (m)	Linear S	3000, 5000, 20,000, > 20,000	0.116		
Distance to main roads (m)	Linear ↓	< 60 = 0 (Con), 1000, 3000	0.093		
Distance to secondary roads (m)	Linear ↓	< 30 = 0 (Con), 500, 5000	0.058		
Distance to industrial area (m)	Linear S	300,10,000, 20,000, > 20,000	0.093		
Distance to mines (m)	Linear S	1000, 7000, 20,000, > 2000	0.093		
Flood potential	Linear ↓	0, 240	0.400	Natural hazard	0.150
Earthquake risk	Linear ↓	0, 200	0.300		
Hydrocarbonic soil pollution	Linear ↓	0, 240	0.100		
Landslide susceptibility	Linear ↓	0, 240	0.200		

↑ = monotonically increasing, ↓ = monotonically decreasing, S = symmetric, WE = weighting categories by experts, Con = constraint, P = plain, N = north, E = east, W = west, S = south.

2.3.4. Land cover and land use factor (C)

The land cover factor (C) represents the effect of a given vegetation and the cover on the amount of soil erosion (Haregeweyn et al., 2017; Meshesha et al., 2012). In this study, we used land use maps of 2013 and assigned a C-factor to each type of land use. The C factor values for each land use class were obtained from data provided by Karimi (2011) for Golestan Province (Table 3).

2.3.5. Conservation practices factor (P)

Conservation practices factor (P) reflects the effects of support practices, such as terracing and contour tillage, to reduce the rate of soil erosion. Areas without any support practice are assigned with a P factor equal to 1 (Alexakis et al., 2013; Meshesha et al., 2012). In the Gharesoo River Basin currently no significant conservation practices are implemented. There is no terracing farmland, as commonly used conservation practice, in the river basin. Other practices such as agroforestry and contour farming may be implemented on very small scattered parcels, that cannot be incorporated in the model. So, in this study the P factor was set to 1 and as such, it had no effect on the calculations in RUSLE equation (Eq. (1)).

2.3.6. Model input parameters

In the present study, RUSLE was used in conjunction with GIS. All RUSLE factors that were explained in the previous sections should be in raster grid layer with similar reference system and resolution. The DEM and land use type raster layers were used to calculate LS and C factor, respectively. To calculate LS, slope length and slope percent (Eqs. (5)–(7)) were extracted using Surface Analysis module in GIS based on DEM layer as input. The equations were implemented using Raster Calculator module, and the LS factor layer was produced. To create C factor layer, the appropriate value (Table 3) was assigned to each land use type using Raster Reclassification module in GIS, based on land use layer as input. Both DEM and land use layers had 30 m grid (Table 1), so the LS and C factor layers had a resolution of 30 m.

The monthly rainfall data required for calculating R factor were in Excel spreadsheet format. First we calculated MFI and R factor for all stations using Eqs. (2) and (3) in Excel (Table 2). Then, we made a point vector layer using geographical position of stations and assigned them

Table 6
The standardization methods and weights of criteria for industrial development suitability analysis.

Criteria	Standardization methods	Break points	Criteria weights	Final criteria	Final criteria weights
Bare land (%) (Modis-derived IGCP)	Linear S	0, 150, 200, 255	0.430	Vegetation	0.030
Vegetation density (Modis-derived NDVI)	Linear ↑	2000, 9000, > 9000 = 0 (Con)	0.570		
Geology (qualitative categories)	WE	–	0.500	Geology	0.120
Geomorphology (qualitative categories)	WE	–	0.500		
Soil texture (qualitative categories)	WE	–	0.120	Soil	0.120
Hydrologic soil groups (qualitative categories)	Linear ↑	A, D	0.080		
Soil pH	Linear S	4, 7, 7, 8	0.031		
Cation exchange capacity (meq/100 g soil)	Linear ↑	0, 59	0.021		
Percentage of clay in soil	Linear S	4, 40, 50, 67	0.030		
Soil organic matter (%)	Linear ↑	0, 4.5, > 4.5 = 0 (Con)	0.050		
Percentage of sand in soil	Linear S	5, 30,50, 82	0.050		
Soil electric conductivity (ds/m)	Linear ↓	0, 246	0.100		
Soil productivity	Linear ↑	0, 255	0.118		
Soil depth	Linear ↑	0, 256	0.200		
Soil erosion sensitivity (ton/pixel/year)	Linear ↓	0, 523	0.200		
Evapotranspiration	Linear ↓	0, 160	0.100	Meteorology	0.080
Temperature (C°)	Linear S	1, 14, 18, 20	0.230		
Rainfall (mm)	Linear ↑	220, 836	0.150		
Humidity (%)	Linear S	0, 50,78, 83	0.220		
Freezing degree days	Linear ↓	0, 25	0.100		
Sunny hours during the year	Linear ↑	0, 2704	0.100		
Wind speed	Linear S	0, 2, 3, 5	0.100		
Distance to springs (m)	Linear ↓	< 30 = 0 (Con), 30, 1500	0.020	Water resources	0.270
Distance to aqueducts (m)	Linear ↓	< 30 = 0 (Con), 30, 2000	0.027		
Distance to surface water resources (m)	Linear ↓	< 60 = 0 (Con), 60, 3000	0.198		
Distance to well (m)	Linear ↓	< 30 = 0 (Con), 30, 1500	0.106		
Distance to dam (m)	Linear ↓	< 300 = 0 (Con), 300, 10,000	0.049		
Ground water depth (shallow) (m)	Linear S	5, 15, 20, 24	0.109		
Ground water depth (deep) (m)	Linear ↓	3, 10, 20, 24	0.109		
Ground water quality (Water Quality Index)	Linear ↑	0, 111	0.099		
Distance to foothills and mountains (m)	Linear ↓	0, 45,000	0.245		
Ground water electric conductivity	Linear ↓	0, 2966	0.038		
Elevation (m)	Linear S	400, 1200, 1800, 2000	0.140	Land use and physical land	0.230
Slope (%)	Linear ↓	0, 9	0.291		
Aspect (qualitative categories)	WE	P & N = 1, E = 0.6 W = 0.2, S = 0.4	0.116		
Distance to residential areas (m)	Linear S	3000, 5000, 20,000, > 20,000	0.116		
Distance to main roads (m)	Linear ↓	< 60 = 0 (Con), 1000, 3000	0.093		
Distance to secondary roads (m)	Linear ↓	< 30 = 0 (Con), 500, 5000	0.058		
Distance to industrial area (m)	Linear S	300,10,000, 20,000, > 20,000	0.093		
Distance to mines (m)	Linear S	1000, 7000, 20,000, > 2000	0.093		
Flood potential	Linear ↓	0, 240	0.400	Natural hazard	0.150
Earthquake risk	Linear ↓	0, 200	0.300		
Hydrocarbonic soil pollution	Linear ↓	0, 240	0.100		
Landslide susceptibility	Linear ↓	0, 240	0.200		

↑ = monotonically increasing, ↓ = monotonically decreasing, S = symmetric, WE = weighting categories by experts, Con = constraint, P = plain, N = north, E = east, W = west, S = south.

their R factor value. These values then were interpolated to a raster grid layer using IDW interpolation module in GIS. IDW is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The parameters required for calculating K factor (Eq. (4)) were available as a point vector layer. We calculated K factor for all points in attribute table of vector layer, using formulating equation in Field Calculator module. Finally, IDW interpolation module in GIS was used to produce a raster grid layer from point data. Both K and R factor were rasterized to a 30 m grid to make them similar with other two layers.

In the end, to produce soil erosion layer, RUSLE Eq. (1) was implemented using Raster Calculator module in GIS. To do that, all aforementioned factor layers were multiplied.

2.4. Assessing impacts of land use and slope on erosion rate

Land use and slope are two major factors that control soil erosion. Assessing impacts of different types of land use and slope classes on soil erosion rate can help identify erosion hotspots and select appropriate conservation practices (Meshesha et al., 2012). We assessed the importance of land use and slope on spatial distribution of soil erosion using cross-tabulation technique in GIS.

2.5. Analysis of impacts of optimized land use planning

The land use planning was implemented to control future development of four uses, including agriculture, urban and industrial development, and afforestation. It is assumed that no land use change is permitted in the natural forest areas and rangelands. Land use planning was implemented in two phases, including land evaluation and land use allocation. In the land evaluation phase, Multi-Criteria Evaluation (MCE) was used to evaluate suitability of land for different uses. In the land use allocation phase, the Multi-Objective Land Allocation (MOLA) was used to allocate optimum uses to the land units based on results of MCE (Riveria and Maseda, 2006).

2.5.1. Land evaluation through MCE

The suitability of the land for different uses is affected by different

Table 7
The standardization methods and weights of criteria for afforestation suitability analysis.

Criteria	Standardization methods	Break points	Criteria weights	Final criteria	Final criteria weights
Bare land (%) (Modis-derived IGCP)	Linear ↓	0, 100	0.437	Vegetation	0.080
Vegetation density (Modis-derived NDVI)	Linear ↑	0–9975	0.563		
Geology (qualitative categories)	WE	–	0.500	Geology	0.050
Geomorphology (qualitative categories)	WE	–	0.500		
Soil texture (qualitative categories)	WE	–	0.134	Soil	0.190
Hydrologic soil groups (qualitative categories)	Linear ↑	A, D	0.044		
Soil pH	Linear S	4, 7, 7, 8	0.032		
Cation exchange capacity (meq/100 g soil)	Linear ↑	0, 59	0.023		
Percentage of clay in soil	Linear S	4, 40, 50, 67	0.018		
Soil organic matter (%)	Linear ↑	0, 5.5	0.052		
Percentage of sand in soil	Linear S	5, 30, 40, 82	0.014		
Soil electric conductivity (ds/m)	Linear ↓	0, 246	0.082		
Soil productivity	Linear ↑	0, 255	0.100		
Soil depth	Linear ↑	0, 256	0.279		
Soil erosion sensitivity (ton/pixel/year)	Linear ↓	0, 523	0.223		
Evapotranspiration	Linear ↓	0, 180	0.044	Meteorology	0.180
Temperature (C°)	Linear S	1, 14, 18, 20	0.161		
Rainfall (mm)	Linear ↑	100, 836	0.357		
Humidity (%)	Linear ↑	0, 83	0.241		
Freezing degree days	Linear ↓	0, 25	0.066		
Sunny hours during the year	Linear ↑	0, 2704	0.102		
Wind speed	Linear ↓	0, 5	0.029		
Distance to springs (m)	Linear ↓	< 30 = 0 (Con), 30, 500	0.032	Water resources	0.090
Distance to aqueducts (m)	Linear ↓	< 30 = 0 (Con), 30, 500	0.038		
Distance to surface water resources (m)	Linear ↓	< 60 = 0 (Con), 60, 5000	0.260		
Distance to well (m)	Linear ↓	< 30 = 0 (Con), 30, 1500	0.118		
Distance to dam (m)	Linear ↓	< 100 = 0 (Con), 100, 10,000	0.049		
Ground water depth (m)	Linear S	3, 10, 20, > 25	0.147		
Ground water quality (Water Quality Index)	Linear ↑	0, 111	0.057		
Distance to foothills and mountains (m)	Linear ↓	0, 70,763	0.299		
Elevation (m)	Linear S	−144, 500, 1000, 3000	0.166	Land use and physical land	0.240
Slope (%)	Linear ↓	0, 100	0.409		
Aspect (qualitative categories)	WE	P & N = 1, E & W = 0.6, S = 0.4	0.054		
Distance to residential areas (m)	Linear ↓	< 100 = 0 (Con), 100, 5000	0.052		
Distance to main roads (m)	Linear ↓	< 30 = 0 (Con), 1000, 5000	0.153		
Distance to secondary roads (m)	Linear ↓	< 30 = 0 (Con), 1000, 5000	0.128		
Distance to industrial area (m)	Linear ↓	< 100 = 0 (Con), 100, 15,000	0.038		
Fire risk	Linear ↓	0, 220	0.300	Natural hazard	0.170
Flood potential	Linear ↓	0, 255	0.200		
Hydrocarbonic soil pollution	Linear ↓	0, 240	0.200		
Landslide susceptibility	Linear ↓	0, 255	0.300		

↑ = monotonically increasing, ↓ = monotonically decreasing, S = symmetric, WE = weighting categories by experts, Con = constraint, P = plain, N = north, E = east, W = west, S = south.

Table 8
The preferred area and weights of land uses for implementation MOLA.

No	Land use	Area preferred (hectares)	Weight
1	Agriculture	31,734	0.235
2	Urban development	1269.36	0.26
3	Industrial development	964.53	0.26
4	Afforestation	13,520.97	0.245

environmental criteria. The first issue in MCE is how to combine the data from different criteria to form a single index of evaluation (Eastman, 2012). We used the Weighted Linear Combination (WLC) method, that is most commonly used technique for combination of continuous criteria (Voogd, 1982). In this method, each criterion is multiplied by a weight, then all weighted criteria are summed to yield a suitability layer. Also, constraint criteria, that are boolean layers containing cells with values of 0 and 1 showing unsuitable and suitable areas for given land use, respectively (Mahiny and Clarke, 2013), are multiplied to the results to mask out unsuitable areas and generate final suitability layer (Eq. (8)) (Eastman, 2012).

$$S = \sum w_i x_i * \prod C_j \quad (8)$$

where S is suitability layer, W_i is weight of factor i, X_i is criterion score of factor i, C_j is criterion score of constraint j, and Π is product. Because criteria are measured in different scales, they should be standardized before combination (Voogd, 1982). The simplest methods that we have also used in this study is linear scaling (Eq. (9)).

$$Xi = (R_i - R_{min})/(R_{max} - R_{min}) * \text{standard range} \quad (9)$$

where R is raw score of factor i, R_{min} is minimum raw score of factor i, R_{max} is maximum raw score of factor i, and standard range here is 0 to 255. The higher value of standardized scale (here 255) represent the most suitable score. In standardization method, criteria can be standardized in the range 0–1 or 0–255. Both ranges have been used in several studies. We decided to use 0–255 range because of several studies in our country, such as Hajehforooshnia et al. (2011), Mahiny and Clarke (2013), Sakieh et al. (2015) and its accordance with the 1 byte range used in computer codes.

To development of factor weights, we used Analytical Hierarchy Process (AHP), that is a pairwise comparisons developed by Saaty (1977). In the MCE methods using WLC the sum of weights should be equal to one (Eastman, 2012).

All the above steps were implemented for all four uses. Several environmental criteria for agriculture, urban and industrial

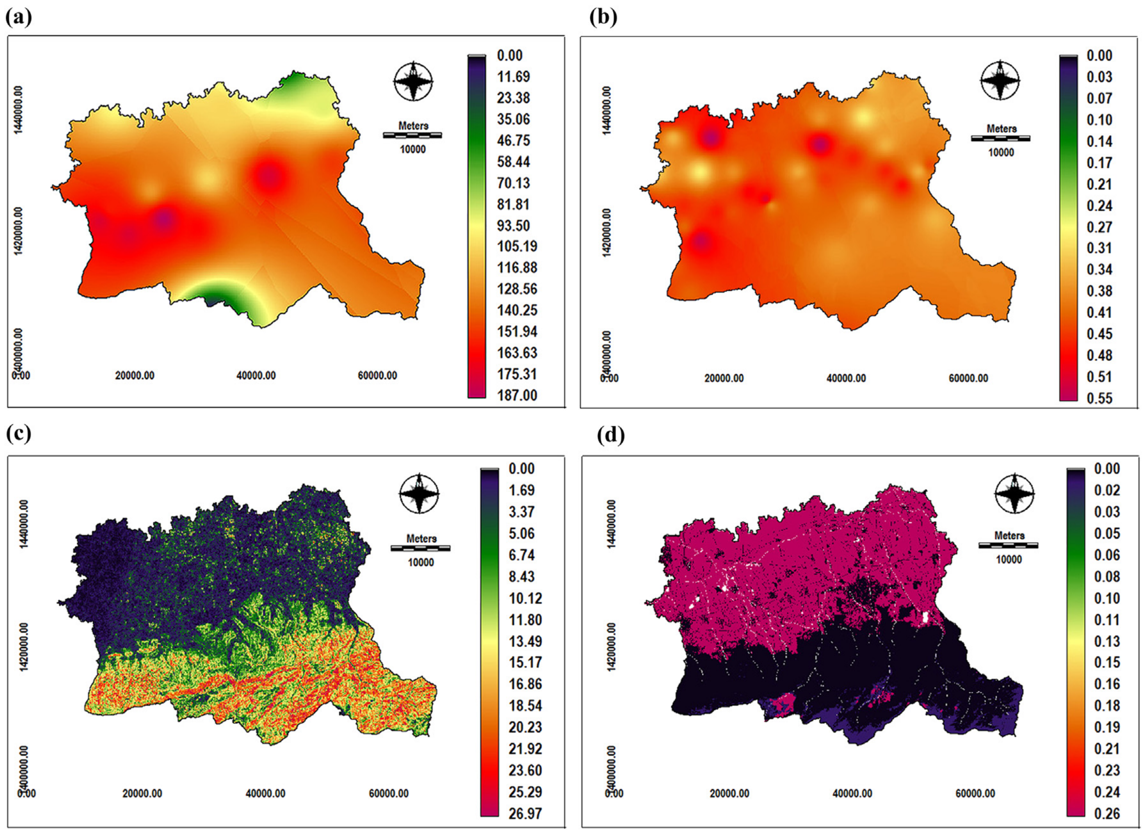

Fig. 2. Spatial distribution of RUSLE factors maps: (a) R factor (MJ mm ha^{-1} h^{-1} yr^{-1}), (b) K factor (ha h ha^{-1} MJ^{-1} mm^{-1}), (c) LS factor, (d) C factor.

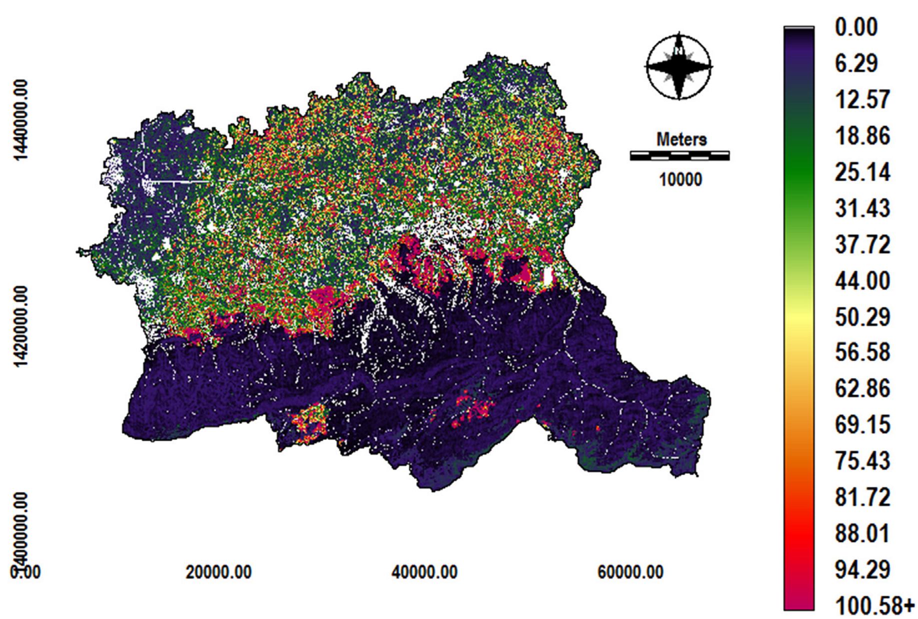

Fig. 3. Spatial distribution of annual potential soil erosion (t ha^{-1} yr^{-1}) estimated using RUSLE model.

Table 9
The average soil erosion for different land use classes.

Land use	Average soil erosion (t ha^{-1} yr^{-1})
Developed	0.40
Forest	2.21
Rangeland	6.90
Agriculture	36.15

development, and afforestation were considered. The standardization methods and weights of criteria for each use are provided in Tables 4–7. The decision about the criteria and their standardization and weights was made based on the ecological models for different land uses in Iran (Makhdoum, 2007), data availability, review of the relevant literature, and consulting with local experts and policy makers.

2.5.2. Land use allocation through MOLA

In the land use allocation phase, optimum uses are dedicated to the

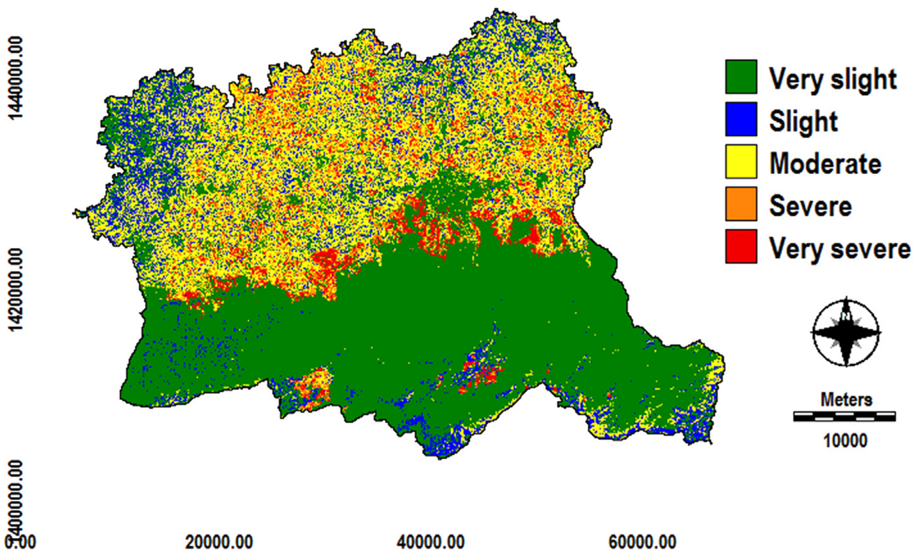

Fig. 4. Reclassified annual potential soil erosion map estimated using RUSLE model. Erosion (t ha^{-1} yr^{-1}): Very slight (0–5), Slight (5–10), Moderate (10–50), Severe (50–100) Very severe (> 100).

Table 10
The area of each category of erosion severity.

No	Erosion status	Soil erosion (t ha^{-1} yr^{-1})	Area (hectares)	Area (% of total)
1	Very slight	0–5	84,134.53	52.09
2	Slight	5–10	16,949.67	10.49
3	Moderate	10–50	41,511.42	25.70
4	Severe	50–100	12,547.52	7.77
5	Very severe	100–524	6384.65	3.95

land units according to the results of land evaluation. The ideal point is a method that allocates each spatial unit to a use with the highest suitability (most suitable use), excludes it from the other uses, and repeats the process to cover all units (Riveria and Maseda, 2006). The MOLA is a heuristic procedure based on the ideal point concept, proposed by Eastman et al. (1995). It determines a compromise solution that attempts to maximize the suitability of spatial units for each use with respect to their weights (Hajehforooshnia et al., 2011).

Before implementing MOLA, the suitability maps of uses were ranked in descending order according to their closeness to the ideal point. A weight based on AHP was assigned to each ranked map. In addition, the required area of four uses was determined. The weights and area for all four uses in this study is determined based on consulting with local experts and policy makers (Table 8).

3. Results

3.1. Estimation of potential soil erosion using the RUSLE model

Distribution of the four factors in RUSLE is shown in Fig. 2. The average R factor of the Gharesoo River Basin was 131 MJ mm ha^{-1} h^{-1} yr^{-1}, varying from 11 to 186 MJ mm ha^{-1} h^{-1} yr^{-1}. The soil erodibility factor (K) ranged from 0.1 to 0.55 t ha h ha^{-1} MJ^{-1} mm^{-1}, with the average of 0.4 t ha h ha^{-1} MJ^{-1} mm^{-1}. The areas with high K values were located in north-western and south-western parts of the river basin, where soil texture is silt-clay, silt-loam, and clay-loam. The mean values of topographic factor (LS) is 7.37, ranging from 0 in flat areas to 27 in mountainous and steep areas. The land cover factor (C) ranged from 0 to 0.26, and the average was 0.13.

The annual soil erosion was estimated using RUSLE model (Eq. (1)) based on the factors mentioned above. The soil erosion ranged from 0 to 523.42 t ha^{-1} yr^{-1} (Fig. 3). The average soil erosion in the river basin was 18.65 t ha^{-1} yr^{-1}, with a standard deviation of 33.88 t ha^{-1} yr^{-1}. The average soil erosion for different land use classes was calculated and are given in Table 9. The agricultural lands produced the maximum rate of soil erosion. The minimum soil erosion occurred in forest and developed areas. In the developed areas, mostly bare soil and vegetated areas have been converted to impervious surfaces, such as cement and concrete surfaces, so there is not much soil available to erosion by water.

To evaluate the spatial distribution of soil erosion, the rate of soil erosion was classified into five severity classes (Haregeweyn et al., 2017) (Fig. 4, Table 10). The upper and lower limits of each class were determined using Natural Breaks method. About 62% of the study area belonged to very slight and slight classes. The moderate, severe and very severe erosion classes contained 26%, 8% and 4% of the river basin, respectively.

3.2. Assessing the impacts of land use and slope on erosion rate

The results of cross-tabulation of slope and land use classes and average soil erosion are displayed in Table 11. The results confirmed

Table 11
Cross-tabulation of slope and land use classes and average soil erosion (t ha^{-1} yr^{-1}).

Slope classes (%) land use	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100	100–181
Developed	0.20	0.86	1.55	2.09	2.61	3.08	3.40	3.62	3.73	3.93	–
Forest	0.33	1.02	1.65	2.22	2.69	3.06	3.33	3.48	3.54	3.53	3.08
Rangeland	0.94	3.03	5.28	7.44	9.25	11.06	12.15	13.00	13.63	13.99	14.58
Agriculture	16.40	68.11	122.08	164.76	192.62	211.59	230.60	231.09	233.26	237.51	–

In this slope class there was not such land use in the region.

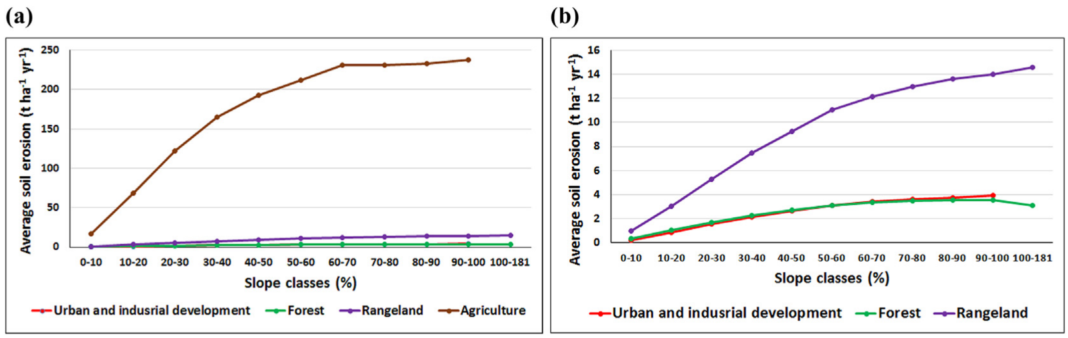

Fig. 5. Changes in average soil erosion according to land use and slope. In (b) agriculture has been removed to make a clear distinction between other land uses graphs.

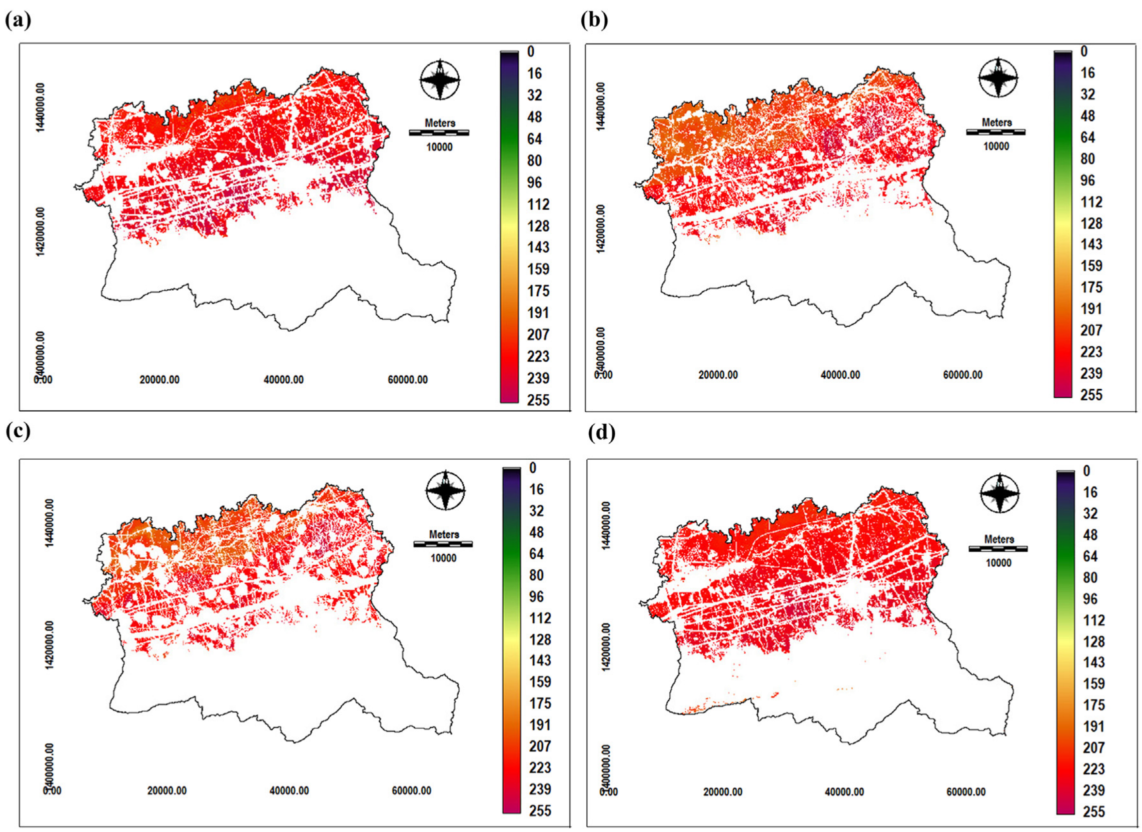

Fig. 6. Final suitability maps resulted from MCE: (a) Agriculture (b) Urban development (c) Industrial development (d) Afforestation suitability maps. Suitability increases as the value rise.

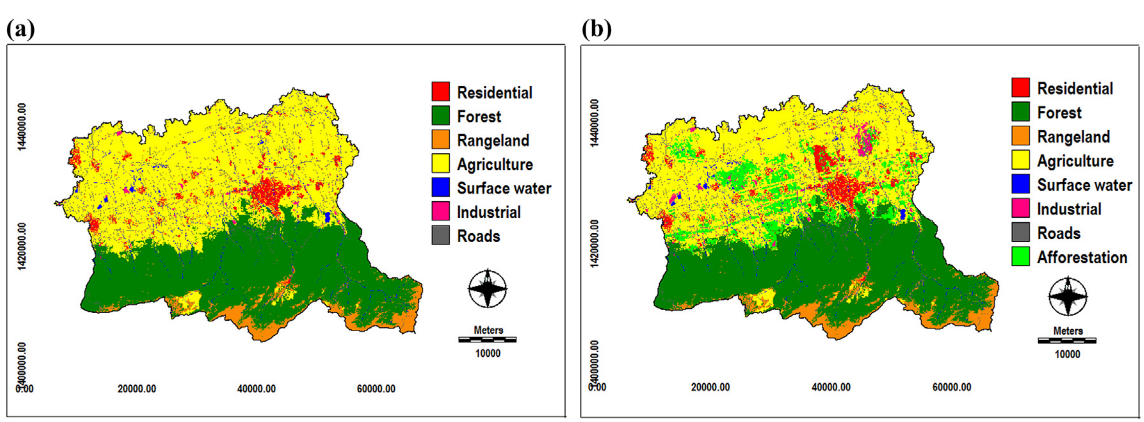

Fig. 7. (a) Current land use and (b) output land use map from MOLA.

Table 12
Land use conversion under optimized land use planning.

Current land use	Land use_MOLA	Land use conversion (hectares)	Land use conversion (%)
Agriculture	Residential	1214.95	1.56
Agriculture	Agriculture	63,529.31	81.65
Agriculture	Industrial	970.72	1.25
Agriculture	Afforestation	12,092.82	15.54

importance of interaction between these factors in increasing soil erosion, especially in agricultural areas with steep slopes. In the same slope classes, agriculture had the highest rate of soil erosion. Also, with increasing slope percent, soil erosion increased under the same land use type, especially in agricultural land.

The relation of slope and soil erosion in different land use classes is shown in Fig. 5. Compared to other land uses, the agriculture land use graph shows the sharp increase in soil erosion in steep slopes, that denotes the significant impact of slope on soil erosion in agricultural land. These areas should be given the high priority in rehabilitation measures.

3.3. Optimized land use planning

The final suitability maps for four uses are presented in Fig. 6. These maps were derived from overlaying their relevant factor maps using WLC. Then, they were input to the MOLA procedure. Finally, the results were used to modify the current land use map. Fig. 7 illustrates the current land use and that derived from MOLA. Some patches in agricultural land were dedicated to afforestation as a new class. The current land use and that of MOLA were compared in terms of land use conversion (Table 12). As we assumed, only current agricultural lands were changed. About 1.5%, 1.2% and 15.5% of the current agriculture were converted to residential, industrial and afforestation uses, respectively.

3.4. Analysis of impacts of land use planning on erosion rate

We used the output land use map from MOLA to estimate annual soil erosion using RUSLE model (Eq. (1)), as was described in detail in previous section. The results showed that, soil erosion ranged from 0 to 523.42 t ha^{-1} yr^{-1} (Fig. 8). The average soil erosion in the river basin was 13.86 t ha^{-1} yr^{-1}, with a standard deviation of 27.5 t ha^{-1} yr^{-1}. Accordingly, land use planning reduced the average soil erosion by 25.6% compared with the current situation (from 18.65 t ha^{-1} yr^{-1} to 13.86 t ha^{-1} yr^{-1}).

The map of soil erosion was classified into five severity classes, based on Natural Breaks method (Fig. 9). The Natural Breaks is a data clustering method that used the Jenks Natural Breaks algorithm to determine the best arrangement of values into different classes. Table 13 summarizes the area impacted by each severity class and the proportion of area that changed compared with the current situation. After land use planning, the area impacted by severe and very severe classes reduced by 25.50% and 42.59%, respectively.

4. Discussion

Soil erosion is a natural process that has become a major global environmental threat as a result of human activities such as irrational land conversion and vegetation degradation. In present study, estimation of soil erosion using RUSLE showed that the river basin could lose 18.65 t ha^{-1} yr^{-1} soil on average. Such losses remove valuable top soil which is the most productive part of the soil profile for agriculture. The results revealed that about 12% of the river basin belonged to severe and very severe erosion classes. All these areas were located on agricultural land.

Several studies have illustrated that soil erosion is highly related to land use types (Meshesha et al., 2012; Sun et al., 2014; Zokaib and Naser, 2011). We found that soil erosion severity varies within different land use types. Agricultural lands produced the maximum rate of soil erosion, approximately an average soil erosion twice the amount of the average for the whole river basin. Like our result, Nacinovic et al. (2014) explained that the agricultural land use in the mountainous region of Rio de Janeiro produced the maximum rate of soil erosion compared with other land uses. Meshesha et al. (2012) estimated that more than half of the total soil loss in the Central Rift Valley of Ethiopia is produced from intensive cultivation areas. Sun et al. (2014) found that with slope gradient increased, soil erosion significantly increased under the same land use type. They estimated that the highest rate of soil erosion occurred in slope cropland. In our study, assessing the impacts of land use and slope confirmed importance of interaction between these factors in increasing soil erosion in agricultural areas with steep slopes. Most of severe and very severe erosion areas lay on

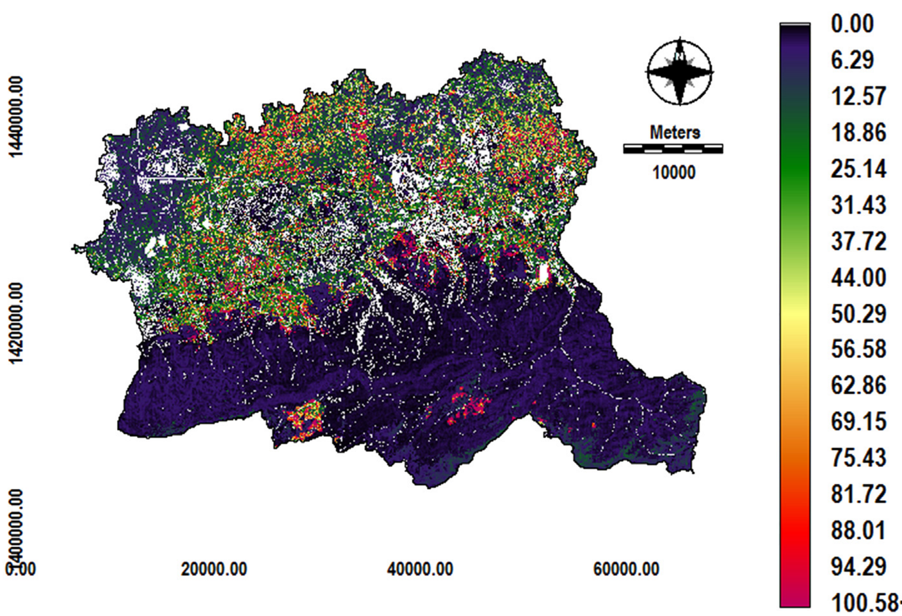

Fig. 8. Spatial distribution of annual potential soil erosion (t ha^{-1} yr^{-1}) estimated using RUSLE model after land use planning.

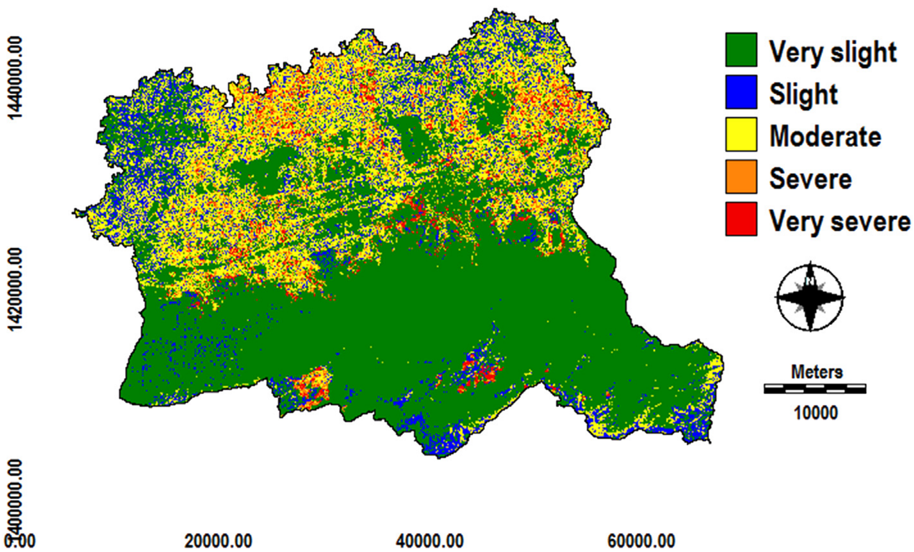

Fig. 9. Reclassified annual potential soil erosion map estimated using RUSLE model after land use planning. Erosion (t ha^{-1} yr^{-1}): Very slight (0–5), Slight (5–10), Moderate (10–50), Severe (50–100) Very severe (> 100).

Table 13
The area of each category of erosion severity based on current land use and MOLA.

No	Erosion status	Soil loss (t ha^{-1} yr^{-1})	Area based on current land use (hectares)	Area based on land use from MOLA (hectares)	Change in area (%)
1	Very slight	0–5	84,134.53	97,140.97	15.46
2	Slight	5–10	16,949.67	16,231.54	−4.24
3	Moderate	10–50	41,511.42	35,142.60	−15.34
4	Severe	50–100	12,547.52	9347.28	−25.50
5	Very severe	100–524	6384.65	3665.40	−42.59

agricultural land with a slope of 10% to 40%, while, according to the ecological models of Iran for agricultural land use, the maximum allowable slope is 8% for irrigation farming and 12% for rain-fed farming (Makhdoum, 2007). These results showed that land conversion regardless of ecological potential of land is the most important factor of soil erosion in the study area. The same result was found in Meshesha et al. (2012). They illustrated that conversion of forest into agriculture land is responsible for the high rate of soil erosion in the Central Rift Valley of Ethiopia, especially in steep slopes. Bhattacharyya et al. (2008) concluded that mixed forest had the highest soil loss tolerance limits, which indicates better capacity of structural and functional integrity to resist water erosion.

Our result of land use planning showed a significant reduction of average potential soil erosion equal to 25.6% (from 18.65 t ha^{-1} yr^{-1} to 13.86 t ha^{-1} yr^{-1}). Also, the area impacted by severe and very severe erosion classes were reduced by 25.50% and 42.59%, respectively. It is important to note that this amount of decrease in the area of these severity classes had an obvious impact on the average of soil erosion. In Ethiopia, Meshesha et al. (2012) found that rehabilitating degraded land and installing stone erosion-control structures in cropland would decrease the total soil erosion by 12.6% and 63.8%, respectively. Andriyanto et al. (2015) showed that sustainable land use planning in Kalikonto Watershed could decrease the soil erosion rate by 14%. Haregeweyn et al. (2017) concluded that treating all of the areas prone to moderate to very severe erosion could reduce the total soil loss in the Upper Blue Nile River basin by 52%. Tadesse et al. (2017) found that watershed management in Ethiopia, such as development of vegetation cover and changes in the cropping pattern, reduced soil erosion rate from 7.7 to 4.8 t ha^{-1} yr^{-1}and increased soil moisture availability, which resulted in the increased crop production and reduced sedimentation and flooding problems.

Environmental crises of today caused by the irrational use and land conversion, have made ecological evaluation and land use planning ever more essential. The results of this research emphasized that implementation of land use planning in the Gharesoo River Basin is a necessity to direct future changes and control soil erosion. Also, Meshesha et al. (2012) emphasized that continuing current conversion of forests and woodland into intensively cultivated land would increase the soil loss by 66%. Land is used for a wide range of uses including agriculture, urban and industrial development, mining, forestry, protection and etc. that are mostly in conflict. Decision making on land use options is an important and complex issue that requires a multi-disciplinary knowledge and a planning frame work for implementation and monitoring (Verheye, 1997). In our study, the ecological suitability of land for uses was evaluated considering several environmental criteria (about 45 criteria for each use) comprising groups such as vegetation cover, geology, soil, meteorology, water resources, land use/cover, and natural hazards. Also, the most suitable uses were dedicated to the best candidate pixels of lands to develop an optimized land use on river basin. This method not only reduced the soil erosion rate, but also it helped control other hazards caused by human activities.

The predicted spatial distribution of soil erosion in the present study can be a basis for more sustainable and comprehensive management of the Gharesoo River Basin. The areas with severe and very severe soil erosion have special priority for implementation of mitigation measures. Our approach has provided a practical framework which help decision makers and stakeholders to consider their own scenarios to control soil erosion. They can apply different scenarios with preferred weight and area in MOLA and investigate their impacts on reduction of soil erosion. However, beside of land use planning for future developments, other management practices such as terracing, agroforestry, and contour farming should be considered. In future studies, the impact of these practices on the rate of soil erosion in Gharesoo River Basin should be examined.

5. Conclusions

In the present study the goal was to investigate the applicability of land use planning on reduction of soil erosion rate in the Gharesoo River Basin. For this, the Revised Universal Soil Loss Equation (RUSLE) was used in conjunction with Geographic Information system (GIS) to model potential soil erosion in the Gharesoo River Basin. The results indicated the need to take immediate measures to control and reduce soil erosion. We found that all the areas with severe and very severe erosion were located in agricultural land, whereas the natural forest areas with dense vegetation cover produced much less soil erosion. So, agricultural lands should be considered as priority for implementation of mitigation measures such as terracing and vegetation rehabilitation, along with land use planning to reduce erosion and prevent its negative impacts on environment and economy. This can be particularly significant in agricultural areas with steep slopes, where the interaction between slope and land use increase the rate of soil erosion dramatically. Our method illustrated the applicability of land use planning on reduction of soil erosion rate in the Gharesoo River Basin. Land development considering ecological suitability helps reduce the negative impacts of development on environment.

Another important point to consider when controlling soil erosion is to protect natural vegetation cover such as forests. Forests provide high amount of canopy cover and thus play an important role in reduction of rainfall erosivity and subsequently reduction of soil loss. In the present study, as a conservation strategy, future development of human uses was restricted to agricultural land and natural forest areas and rangelands were kept unchanged. However, in future studies, it is better to use systematic conservation approaches to select suitable forest patches as protected areas and as such actively restrain unsustainable development. These approaches have high potential in the evaluation of different conservation scenarios and can be used as decision support tools for managers and planners with multiple goals.

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