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ORIGINAL PAPER

Investigating effects of land use change scenarios on soil erosion using CLUE-s and RUSLE models

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Abstract Predicting soil erosion change is an important strategy in watershed management. The objective of this research was to evaluate land use change effects on soil erosion in the north of Iran using five land use scenarios. Three land use maps were created for a period of 25 years (1986–2010) to investigate land use transition and to simulate land use for the year 2030. Additionally, the RUSLE model was used to estimate erosion and the effect of land use change. The results showed that CLUE-s is suitable for modeling future land use transition using ROC curve. The median soil loss in the basis period was 104.52 t ha^{-1}-years^{-1}. Results indicate that the range of soil loss change is 2–32% in simulated period and soil loss value was higher than basis period in all scenarios. Thirty percent decrease in demand scenario has the lowest soil loss in simulated period, and the soil loss value under this scenario will be only 2% more than the basis period. Thus, the soil conversion effects resulted from the demand of each land use.

Keywords Land use change · Soil loss · CLUE-s · RUSLE

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Introduction

Forest cover reduction can lead to change runoff and erosion (Calder 2007). Many researches explained that land use change has direct consequences on erosion (Alkharabsheh et al. 2013; Anh et al. 2014; Sun et al. 2014; Li et al. 2014; Ferreira et al. 2015; Wang et al. 2016). Iran is located in a semiarid to arid area with annual rainfall of 240 mm. However, the north of Iran has a very good climate (rainfall about 800 mm) and a wide land cover of forest areas with fertile soils for agriculture. Therefore, it has received the attention of many non-indigenous people from other parts of Iran since the last 20 years. Gradually, the price of land in north of Iran has increased and so many landowners sold their land, so that agricultural areas were converted to settlement areas. In the study area, the forests were converted to rangeland areas and then have become settlement areas. Therefore, it is expected that these wide changes will result in environmental problems in the study area. Some researchers also reported effects of land use change on environmental problems. Leh et al. (2011), Quan et al. (2011) and Wijitkosum (2012) explained that conversion of natural resources to agriculture and residential area was led to increase in erosion. Plangoen et al. (2013) investigated effects of land use on the erosion, and simulation of erosion in the year 2040 using RUSLE showed that erosion and sediment will increase because of land use changes. Zare et al. (2016a) investigated effects of land use on runoff generation in the Kasilian watershed. Results showed that degradation of natural resources increased runoff generation.

The aim of this study is investigating the impact of land use changes on the erosion in Kasilian watershed located in the north of Iran. Simulating land use change is very important to predict soil erosion in future. In addition to understanding past changes on a land, providing an insightful perspective about what would happen is also important in sustainable planning

Springer

1906

Int. J. Environ. Sci. Technol. (2017) 14:1905–1918

and management (Deng et al. 2008). Furthermore, when analyzing the development of a land and its effects, it would be helpful to prepare a plan for the land use based on its capabilities and land use models (Li and Yeh 2002). Modeling land use changes informs managers of future soil erosion conditions. Nonetheless, simulating changes in land use is very complex and difficult (Verburg et al. 2002). CLUE[1] is a suitable model to land use modeling and scenario design in the future (Chen et al. 2009; Luo et al. 2010; Xu et al. 2013; Zhang et al. 2013; Zare et al. 2016a). The spatial techniques including remote sensing and GIS are useful tools for land use management (Krivtsov 2004; Rahman et al. 2009). RS is a useful tool to image classification and create accurate land use map. Also, driving force maps applied to land use simulation and RUSLE parameters will be prepared using GIS. It should be noted that soil degradation and erosion is a complex process with many driving forces. To achieve an acceptable result for soil erosion evaluation and simulation, spatial techniques were used, and a useful method was applied by RUSLE[2] model. At first land use map of years 1986 and 2011 was prepared, in the following, CLUE-s was applied to simulate the land use map for year 2030 and input it to the RUSLE model to assess erosion of watershed.

Materials and methods

Study area

The Kasilian watershed is located on the near Caspian Sea, IRAN. The area is 342.86 Km^2, and elevation ranges from 286 and 3288 m above sea level. It lies between the latitudes 35°1′ to 36°32′N and between longitudes 53°1′ to 53°26′E (Fig. 1). The climate of Kasilian is Mediterranean, characterized by semi-humid and cold, and its average precipitation equals 733.3 mm. The average annual temperature is 14 °C with the range of 10–18 °C. The main land use type is forest (82.2%), and remainder of the study is 14% rangeland, 2.4% settlement and 1.4% agriculture. In recent years, a lot of natural resources were destroyed to settlement and agriculture areas.

Methods

At first, provided data from rainfall gauges stations were calculated for the years 1981–2010. These data were prepared from Mazandaran Regional Water Company for six stations (4 stations in the watershed and 2 stations out of the watershed) including Darzikola, Sangdeh, Shirgah, Kaleh, Rigcheshmeh and Tallar stations. Daily rainfall data were entered to extract the rainfall erosivity factor in RUSLE. Then, satellite imagery

in three different time periods was prepared to land use classification using maximum likelihood for the basis period. After preparing the data, land use map of year 2030 was simulated. In addition, four land use change scenarios were defined. Then, C-factor was prepared for the basis (1986, 2000, 2011) and simulation (2030) periods.

Satellite data

In this study, spring and summer images of Landsat Thematic Mapper-5 were used. The Landsat images were used because of suitable spatial resolution of about 30 m (Mohammady et al. 2013). The images were acquired on June 11, 1986, September 07, 2000, and September 06, 2011. Also, aerial photographs, topographic images, false color composite images and knowledge of authors about the study area were employed to land use modeling. Radiometric correction was used during a two-step process (Chander et al. 2009). Based on primary pre-processing and field survey, four land use classes were identified including forest, agricultural, grassland and residential area. Land use classification was carried out using maximum likelihood method (Mohammady et al. 2015). Accuracy assessment of the classification was done using Kappa coefficient.

RUSLE model

RUSLE has been employed to calculate soil erosion (Renard et al. 1997). Using the RUSLE, the annual rate of soil loss can be calculated. It is the suitable method to calculate soil erosion in Kasilian watershed. The RUSLE shows that how climate, soil, land use and topography affect the rill and inter-rill erosion (Renard et al. 1997). Pixel size of 30 m was determined for the maps in the study area (Prasannakumar et al. 2013 ; Farhan and Nawaiseh 2015). Equation of RUSLE empirical model is (Renard et al. 1997):

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

where A is the soil loss (t ha^{-1} years^{-1}), and the other parameters are described below. After preparing maps of these parameters, based on Eq. 1 mentioned maps were multiplied in the ArcGIS 9.3 software.

Calculation of RUSLE parameters

Rainfall erosivity (R)

$$R = \frac{1}{n} \sum_{i=1}^{n} \left[\sum_{k=1}^{m} KE(I_{30}) \right] \tag{2}$$

where KE is the total kinetic energy (MJ ha^{-1}, I_{30} is the

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[1] Conversion of Land Use and its Effects.

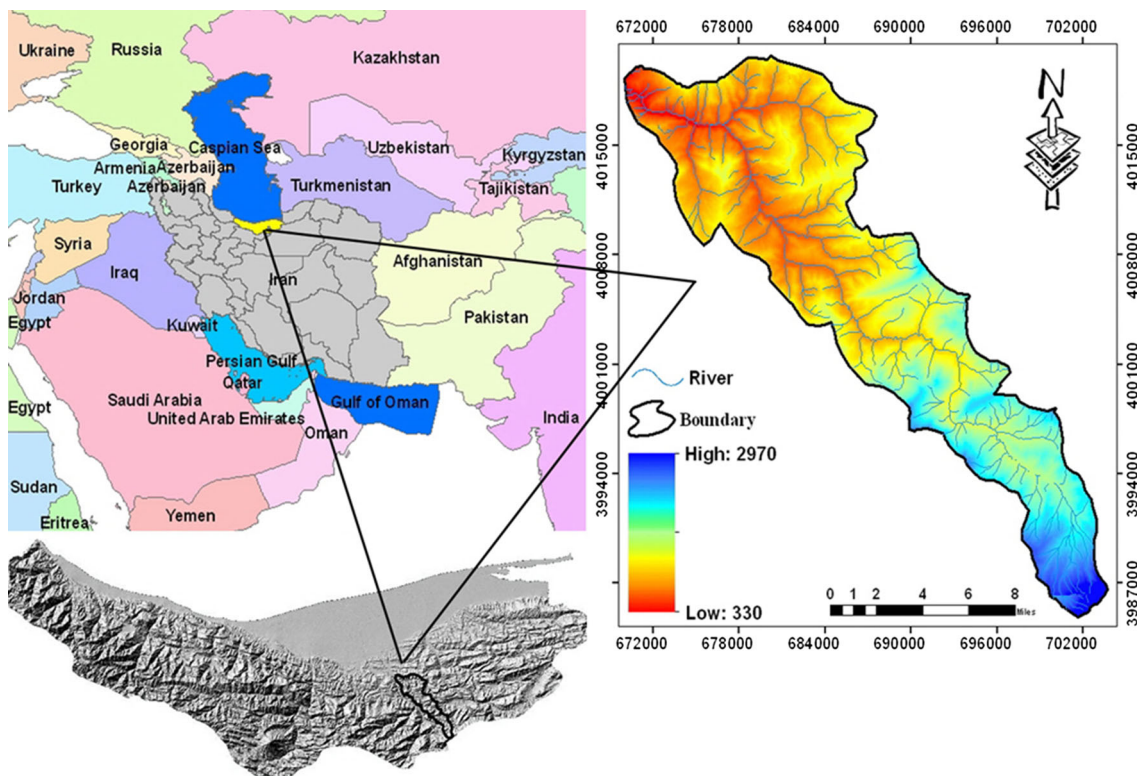[2] Revised Universal Soil Loss Equation.

Fig. 1 Location of Kasilian watershed in Iran

maximum intensity of 30-minute rainfall (mm h^{-1} (Renard and Freid 1994).

$$KE = (11.98 + 8.73 \log_{10} I). \tag{3}$$

One of the major watershed limitations in Iran is the lack of appropriate and at the same time with full statistics rainfall register stations. The rainfall register stations are not enough, so calculating the rainfall erosivity is difficult. The monthly and annual average rainfall was used to calculate R-factor by Renard and Freid (1994) equation resulted from Wischmeier studies. Of course, there are some stations with the details data, and these data were used to calculate I30. There is relationship between I30 and some rain parameters such as Fournier index, 24-hour rainfall and the annual rainfall values. Fournier index and R-factor obtained for all rain gauge stations using Eq. (4).

$$F = \frac{\sum_{i=1}^{12} Pi^2}{\sum_{i=1}^{12} P} \tag{4}$$

where P_i is the average rainfall (mm), I is month and p is the annual average rainfall (mm). In the next step, finally among Fournier index, 24-hour rainfall and the annual rainfall the best factor (annual rainfall values) that was able to make a relationship with rainfall erosivity index was fitted on the other stations. The rainfall erosivity map was prepared by interpolation method.

Soil erodibility factor (K)

K value was extracted from soil type (Wischmeier 1971) and following equation (Auerwwald et al. 2014):

(1) $K_1 = 2.77 \times 10^{-5}$
$\times \left(f_{si+vfsa} \times (100 - f_{cl})\right)^{1.14}$ for $f_{si+vfsa} < 70\%$
$K_1 = 1.77 \times 10^{-5} \times \left(f_{si+vfsa} \times (100 - f_{cl})\right)^{1.14}$
$+ 0.0024 \times f_{si+vfsa} + 0.16$ for $f_{si+vfsa} > 70\%$

(2) $K_2 = (12 - f_{OM})/10$ for $f_{OM} < 4\%$
$K_2 = 0.8$ for $f_{OM} > 4\%$

(3) $K_3 = K_1 \times K_2 + 0.043 \times (A - 2)$
$+ 0.033 \times (P - 3)$ for $K_1 \times K_2 > 0.2$
$K_3 = 0.091 - 0.34 \times K_1 \times K_2 + 1.79 \times (K_1 \times K_2)^2$
$+ 0.24 \times K_1 \times K_2 \times A + 0.033 \times (P - 3)$
for $K_1 \times K_2 < 0.2$

(4) $K = K_3$ for $f_{rf} < 1.5\%$
$K = K_3 \times \left(1.1 \times \exp(-0.024 \times f_{rf}) - 0.06\right)$
for $f_{rf} > 1.5\%$

$$\tag{5}$$

where $f_{si+vfsa}$: mass fraction (in%) of silt plus very fine sand Si + vfSa in the fine earth fraction, f_{cl}: mass fraction (in%)

1908

Int. J. Environ. Sci. Technol. (2017) 14:1905–1918

of clay (<2 μm) in the fine earth fraction, f_{OM}: mass fraction (in%) of organic matter in the fine earth fraction, A: soil structure index and C: permeability index (Wischmeier 1971).

Slope length and steepness factor (LS)

To calculate LS, at first DEM was created using ArcGIS 9.3, and then, slope angle was prepared using DEM. More concerns are expressed over the L factor, due to the fact that slope length involves human judgment. (Ranzi et al. 2012). In this study, the formula of Moore and Burch (1986), adopted also by Pilotti and Bacchi (1997), was used.

$$L = 1.4[A_s/22.13]^{0.4} \tag{6}$$

$$S = [\mathrm{Sin}\beta/0.0896]^{1.3} \tag{7}$$

where A_s is the area of plot per unit width and β is slope angle.

P-factor

There is no significant support practice in the study area so; P-factor is considered 1 for study area.

Table 1 Attribute value of C-factor

Land use class	C Value
Forest	0.004
Rangeland	0.5
Agriculture	0.18
Settlement	1

C-factor

The plant cover factor C represents the relation between erosion on the bare soil and erosion under cultivation and is based on vegetation cover, production level and cropping techniques (Tirkey et al. 2013; Zare et al. 2016b). In this study, C-factor values were assigned to each corresponding land use classes, the values of which have been assigned from already available experimental value as tabulated in earlier studies USDA-SCS (1972). The C-factor value is given in Table 1.

CLUE-s model

CLUE model was developed for modeling land use changes (Veldkamp and Fresco 1996). The new version is CLUE-s with two sections: analysis of driving forces using logistic method, followed by land use change modeling using the rules of land transfer, restrictions, policy and demand (Xu et al. 2013). The allocation procedure is summarized in Fig. 2. A topographic map with 1:25,000 scale was used to create a DEM; slope and aspect maps were created from DEM using ArcGIS 9.3 software. Also, drainage network and road maps were extracted from topographic maps and distance from these phenomena was calculated in GIS. Digital map of soil textures and geology was prepared from the natural resources head office of Mazandaran Province.

Land use change drivers

CLUE-s uses logistic regression between the land use and contributive variables (Eq. 8).

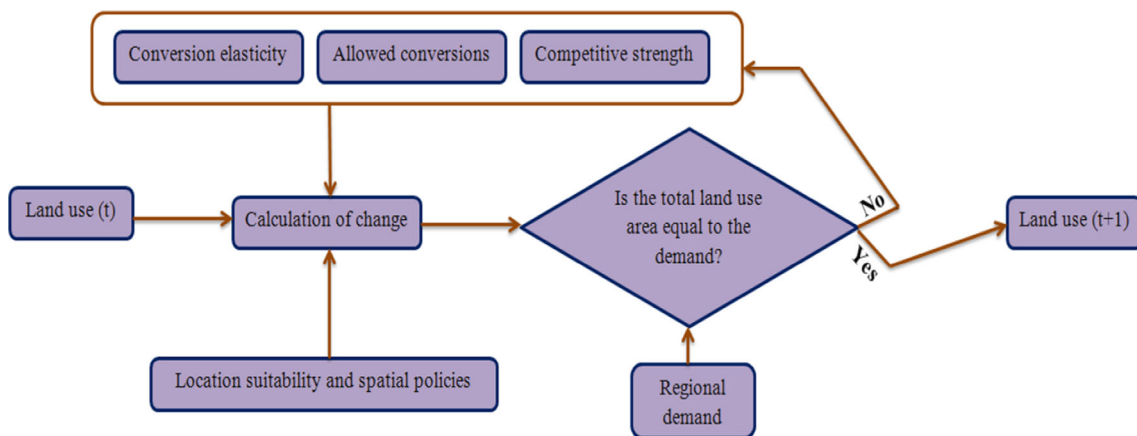$$\mathrm{Log}\left(\frac{P_i}{1 - P_i}\right) = \beta0 + \beta1X1 + \beta2X2 + \cdots + BnXn \tag{8}$$

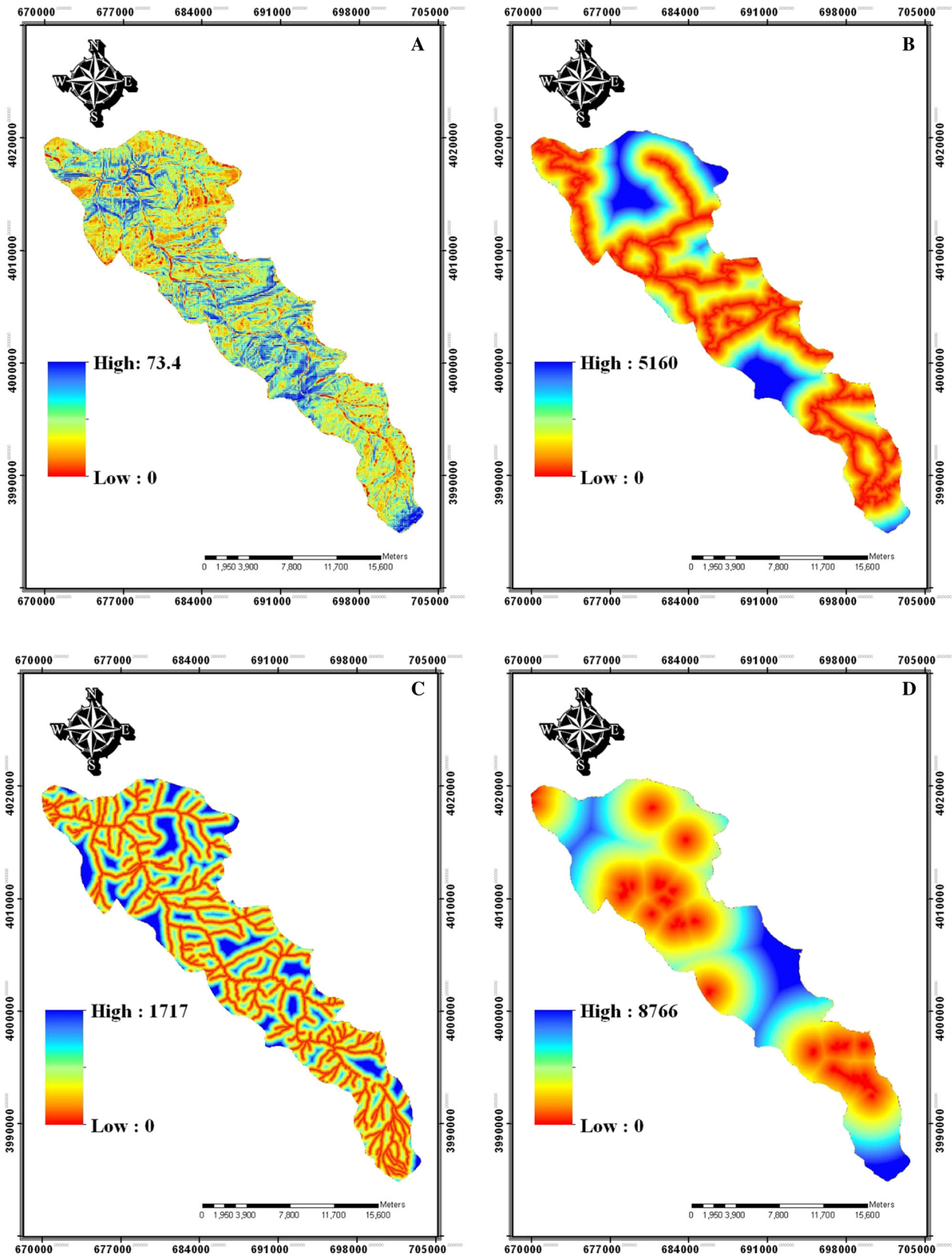**Fig. 2** Flowchart of the CLUE-s model

Fig. 3 Driving factor maps: slope **a**, distance from road, **b** distance from river, **c** distance from settlement, **d** in the study area

1910

Int. J. Environ. Sci. Technol. (2017) 14:1905–1918

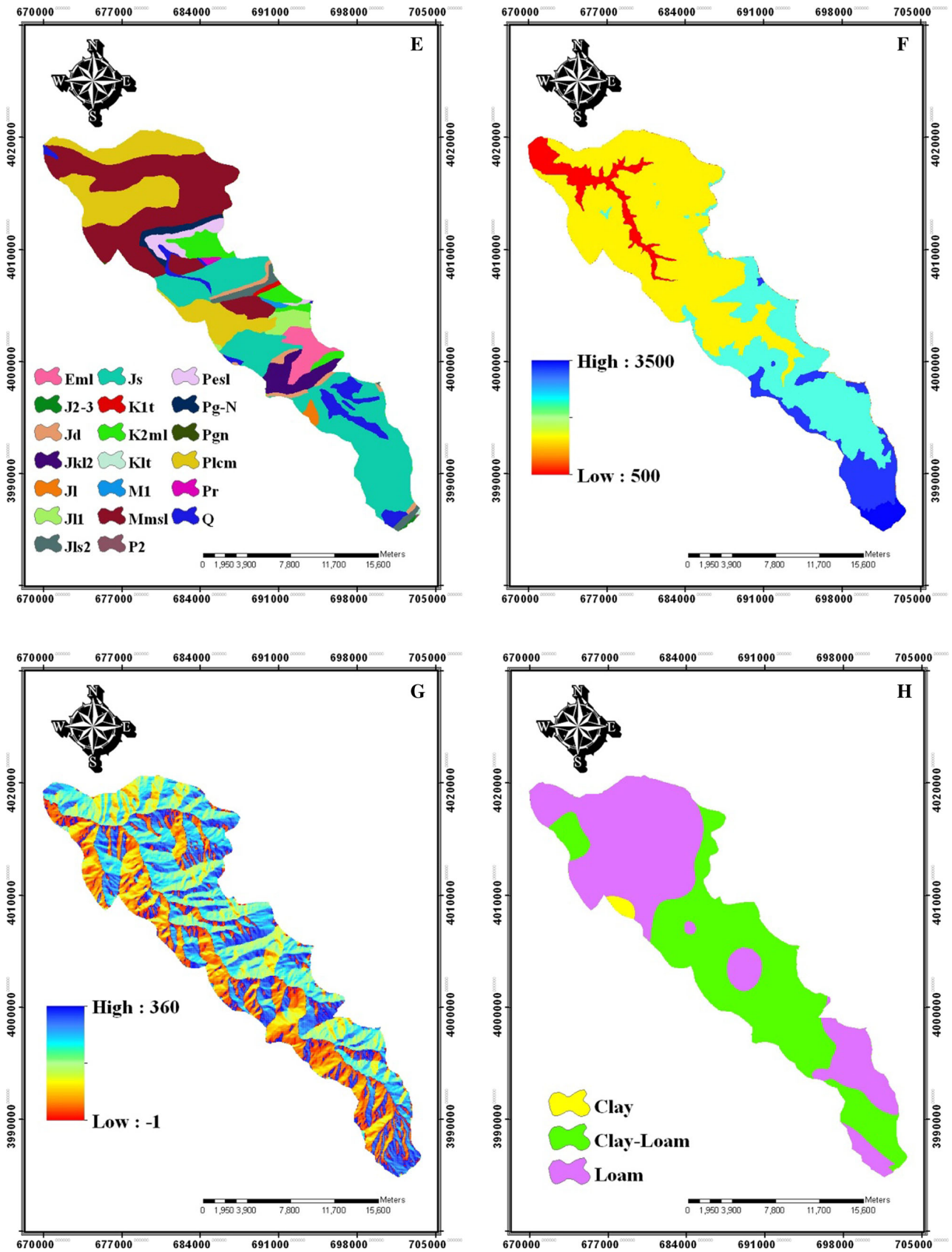Fig. 3 continued

Int. J. Environ. Sci. Technol. (2017) 14:1905–1918

1911

where P_i is the probability of a cell for the occurrence of the considered land use type and the Xs are the driver factors (Verburg et al. 2002; Chen et al. 2009). Driving factors in Kasilian watershed include altitude (m), soil erosion coefficient, soil texture, slope, distance from the river, distance from roads, distance from residential area, lithology, slope aspect and annual precipitation (Fig. 3). Receiver operating characteristic curve (ROC) was used to assess the logistic regressions.
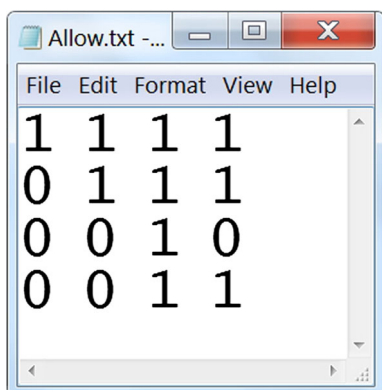

Fig. 4 Conversion matrix of the study area

Conversion matrix

This matrix is determined in the conversion of different land use (Luo et al. 2010). It is necessary to determine a weight 0 and 1 to show the elasticity to land use change (Verburg et al. 2002). Elasticity is defined based on observed behavior of historical land use characteristics or expert knowledge (Luo et al. 2010) (Fig. 4).

For example, 1 in the first row showed that other land use can convert to land use 1 (residential). Row 2 explain that land use 1 cannot convert to land use type 2, but it is possible that other 3 land uses convert to land use 2.

Table 2 Pattern of change in the surface area of land use in different periods (in ha)

Land use type	1986	2000	2011
Forest	30,277.71	28,599.3	27,978.3
Rangeland	3030.93	4436.91	4629.87
Settlement	203.4	205.2	832.23
Agriculture	205.56	476.19	277.2

Fig. 5 Land use map in study area

1912

Int. J. Environ. Sci. Technol. (2017) 14:1905–1918

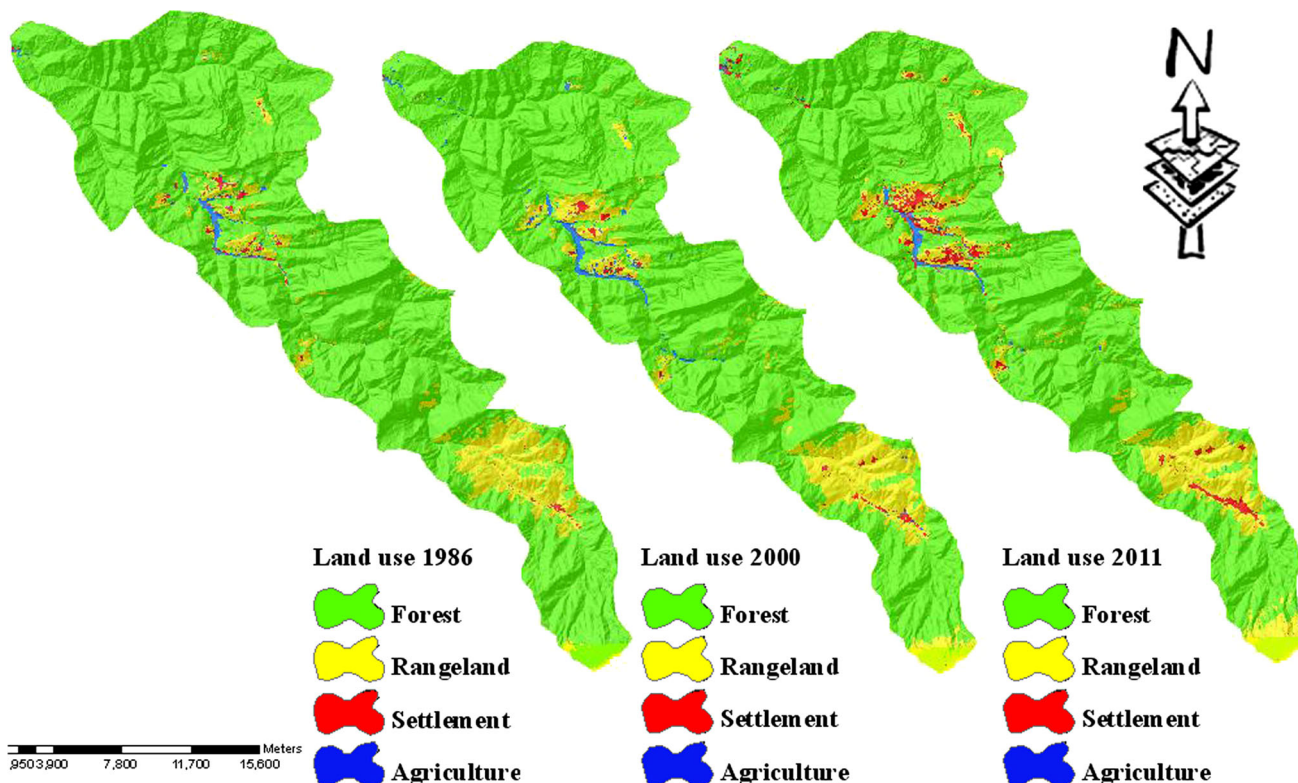## Land use demand

For demand calculation, several models are possible. The results of demand module will be specified on a yearly scale.

At first, the rate of change for each land use types from year 2000 to 2011 was calculated. To calculate yearly demand of each land use type, total change was divided to 11. The rate of demand will add to area of present land use type area to calculate land use area for the next year. This process will continue to the last year (2011–2030).

Table 3 Results of ROC curve

Land use	Area	Std. error[a]	Asymptotic sig.[b]
Forest	0.865	0.011	.000
Rangeland	0.873	0.012	.000
Residential	0.995	0.007	.000
Agriculture	0.98	0.004	.000

[a] Under the nonparametric assumption

[b] Null hypothesis: true area = 0.05
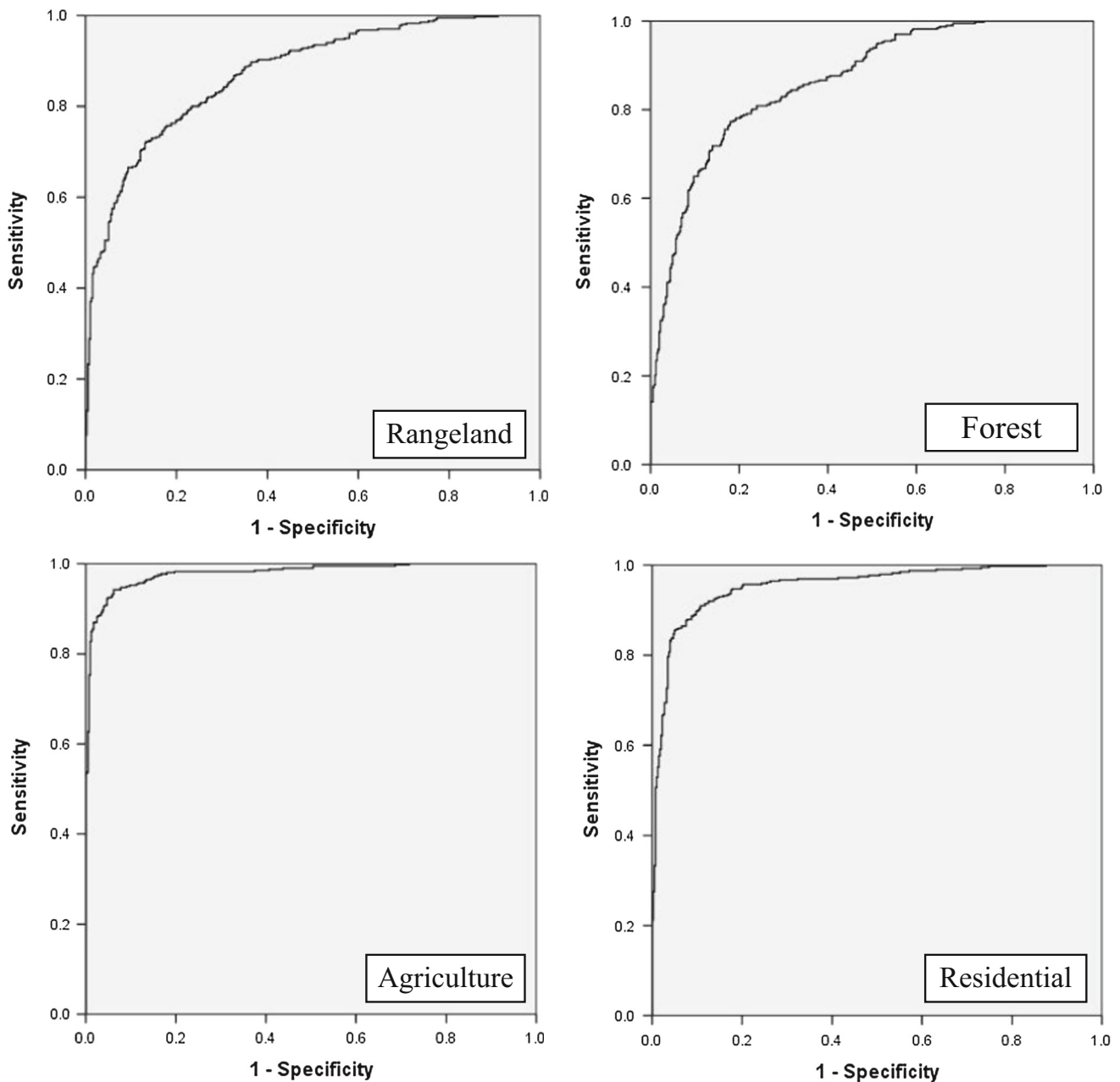

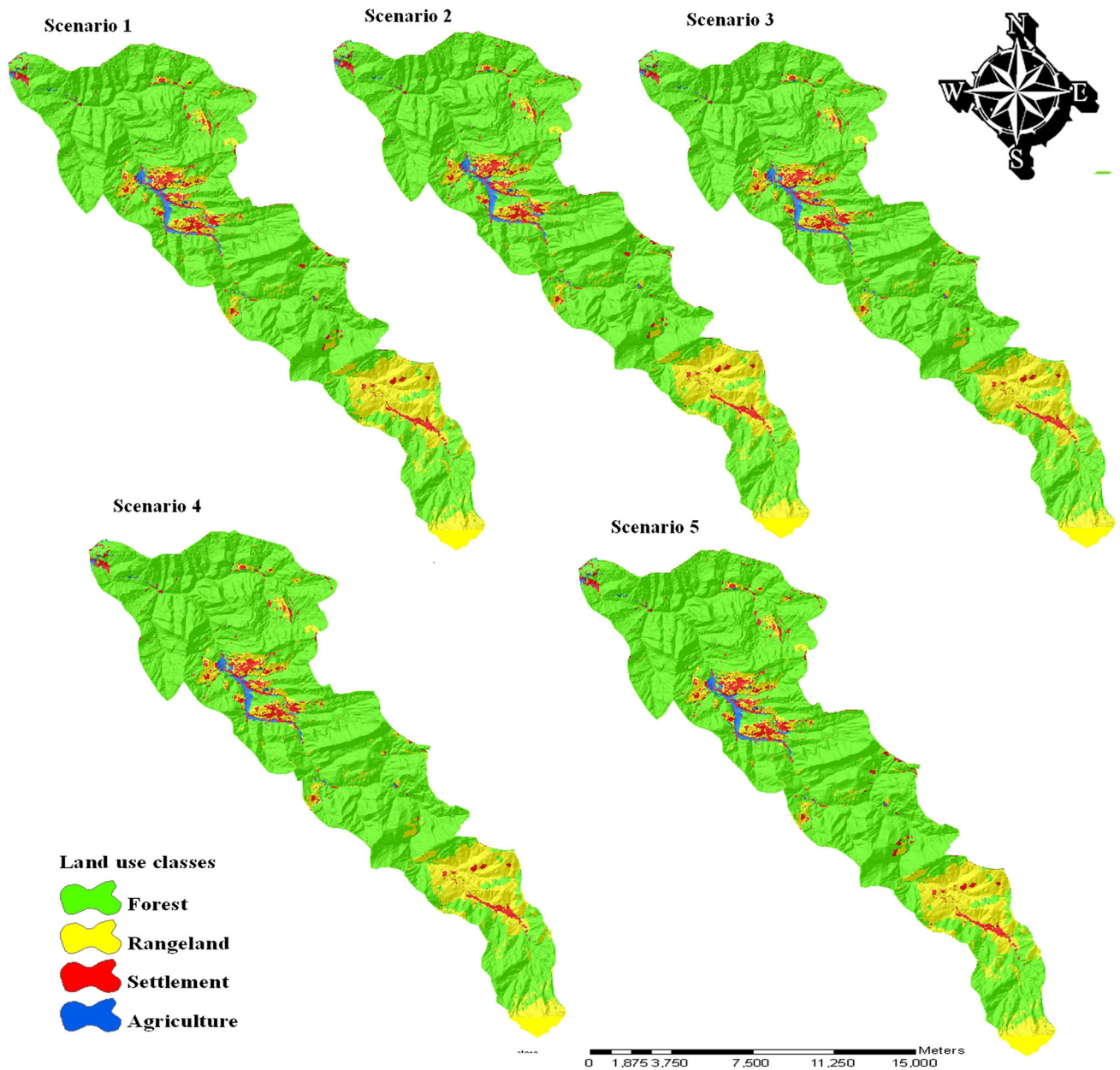**Fig. 6** ROC *curve* of land use in the study area

Fig. 7 Land use change scenarios by CLUE-s model

Land use change simulation

Total data and map of driving factors were placed in the CLUE-s folder, and simulation was done. After simulation in the CLUE-s folder, there are land use maps from 2012 to 2030.

Land use change scenarios

The first three scenarios were based on the reduction in land use degradation in the future, so the demand was calculated with 10, 20 and 30% decrease. Also, in the other scenario the new demand (% increase in demand) will be considered. The main objective of research was to determine effects of land

use on soil erosion. So we design these hypothetical scenarios to investigate how decrease or increase in land use change affects the erosion. In the different scenario, percent of natural resources degradation and conversion to agriculture and residential area was changed.

Result and discussion

Land use change in basis period

As said before using maximum likelihood method, land use maps for years 1986, 2000 and 2011 (Fig. 5) were obtained

for the study area in four classes including forest, agricultural, grassland and residential uses (Table 2). Accuracy assessment was done using Kappa coefficient that was 0.79, 0.82 and 0.87 for years 1986, 2000 and 2011, respectively.

The results showed that forest has been exposed to threats in the past 25 years such that its surface has decreased in this period, while surface area of residential and grassland use has increased. About 290 ha of change and land use, conversion was related to land use change from forest to grassland in the areas surrounding forests.

Lack of sufficient supervision from relevant organizations such as Natural Resources and Watershed Management Organization during the mentioned period and increased avarice by the local inhabitants to change forest to grassland in order to increase the amount of forage for the livestock have caused a very inappropriate situation in the land use change in the region. Under such conditions, a gradual decrease in forest change in an attempt to expand forage production (grassland) seems to be reasonable; therefore, grassland surface area has gradually increased to a considerable degree. When grasslands lose their initial potential (due to overuse by livestock), use of the lands with suitable topography will be susceptible to change to residential sites. Comparing land use maps of years 2000 and 2011 explained that about 20 ha of rangeland was converted to residential sites. Selling the grasslands owned by local people to non-local (non-native) inhabitants, and increased demand from these people to build country villas are among the other factors for this transition. These factors along with wood logging for domestic purposes such as firewood supply are other reasons for the decreased surface area of the forest. Increasing trend of the transition of dense forests into the semi-dense forests caused by wood logging from the dense forests, also verified. Nonetheless, since Kasilian watershed is one of the most famous basins in Iranian watershed management program, it has not experienced great land use change compared to other watersheds in the north. Results showed that, due to the specific topographic condition in the region, land use change from one class to the other was very hard. For instance, there was no considerable change in the surface area of the agricultural land use during the past 25 years. Specific properties of this watershed, including sharp slopes in most parts of the region and low productivity of farm lands, would not experience noticeable changes in its nature. Land use changes modeling suggested that, in case current conditions remained unchanged, 974 ha of forest surface would be converted into rangeland and settlement areas by 2011. If these changes occurred, and considering the special topographic properties of the region, phenomena such as soil erosion, landslide, high flooding potential (Verburg et al. 1999) and finally desertification would be highly probable in Kasilian watershed. The results of residential land

use category showed a slight increase in constructions of the area from 1986 to 2000, but the trend has been highly accelerated from 2000 to 2011, so that the area of residential land use increased three times over 25 years. Vega et al. (2012) reported 35% decrease in forest over an 8-year period in the area in Greece, and area of residential areas has increased 290%. Economic problems along with the increased price of land caused the transform of forests and pastures to the residential lands (Abdollahi 2006). However, these changes have also been reported in many countries. Wu et al. (2006) introduced the destruction of other resources and transformation to the residential lands in Beijing. Brinkmann et al. (2012) explained that conversion of forests to residential and agricultural areas is the most important change of land use in West Africa.

Scenarios of land use changes

ROC curves are shown for land use types in Fig. 6 and Table 3. The result shows AUC higher than 0.8 for total land use types which meant good accuracy in assessing the driving forces.
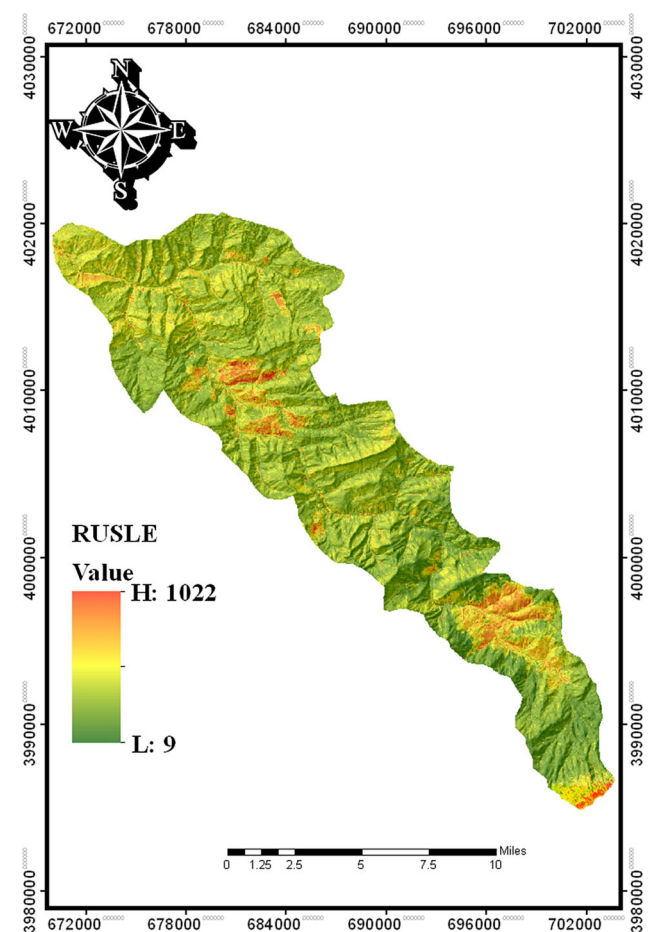

Fig. 8 Distribution of annual soil loss in the Kasilian watershed

Five land use scenarios were designed including land use demand based on past trends (the first scenario), changes in demand with 10, 20 and 30% reduction in degradation and changes with 10% increase in degradation (Fig. 7). According to the maps of 2030, if the change procedure is the same as the previous years, there would be a noticeable destruction in the forest of downstream in 2030 and the pastures would progress.

The results showed if the first scenario (no change in demand) is implemented, the area of forest land will decrease 552.33 ha until 2030. With decrease in demand for each land use, changes in land use area will be lower than changes in basis period. In the scenario with 10% increase in demand, forest land area will decrease 590 ha

and rangeland, settlement and agriculture area will increase 316, 269 and 4 ha respectively.

Actual soil loss

The minimum and maximum R value was 179 and 272 MJ mm ha^{-1} h^{-1} years^{-1}. K values was achieved using Eq. 5 and ranged from 0.32 to 0.44 t ha h MJ^{-1} ha^{-1} mm^{-1}. LS-factor was derived using topography map, and the highest value was 55.235. The minimum and maximum C value was considered for forest and residential area, respectively. P-factor was considered as 1 in total area. Figure 8 shows soil loss in the study area.
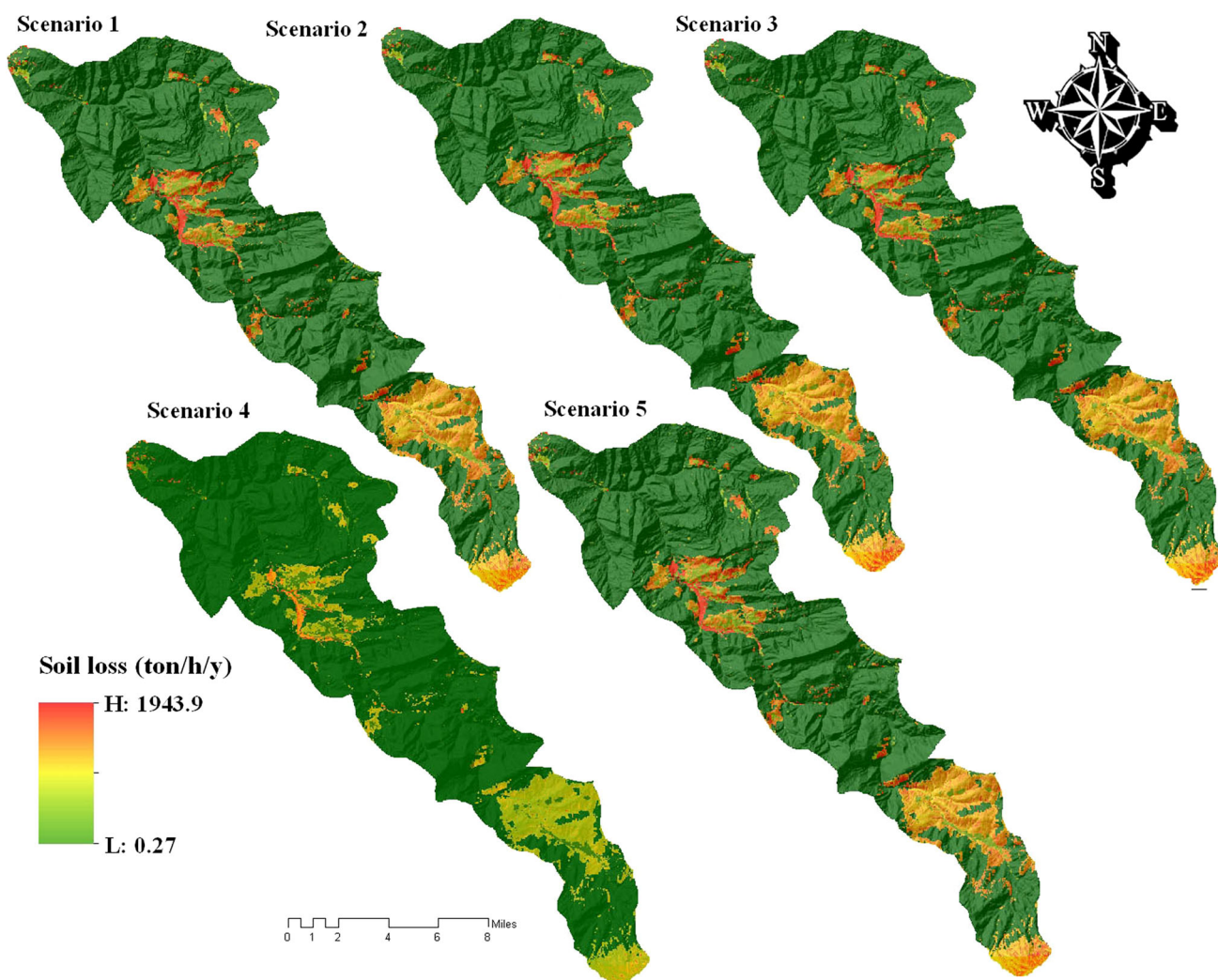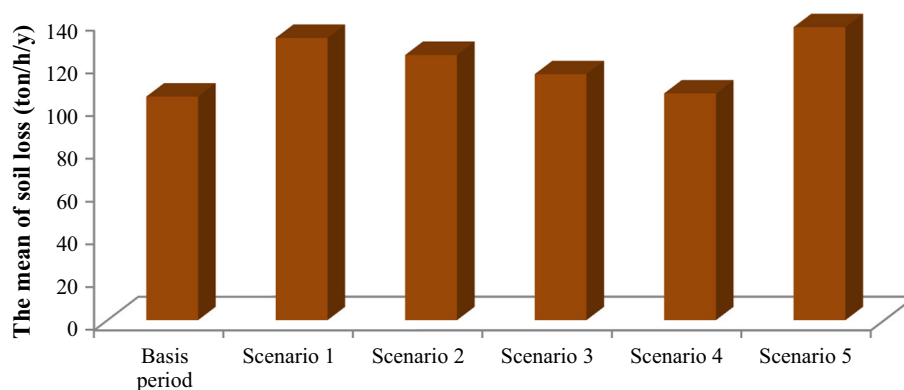

Fig. 9 Simulation of soil erosion risk for 2030

1916

Int. J. Environ. Sci. Technol. (2017) 14:1905–1918

Fig. 10 Mean of soil loss in basis and simulated period

Rain erosion rates are decreased from the northwest to the southeast of watershed. The increase in slope length results in the increased power water flow and leading to increase in erosion (Ranzi et al. 2012). Some researchers also have shown similar results such as Ranzi et al. (2012) and Prasannakumar et al. (2013) that have emphasized about effects of slope length on erosion. Vegetation cover is a very important obstacle against erosion, and conversion of natural resources to residential area will result in increase in erosion. Increase in the clay content will increase the adhesive between soil particles, and decrease in permeability and hydraulic conductivity causes increase in the shear stress and transition of soil. Soil erosion map in the study area showed that most of the area has low erosion level because most of the area covered with forests that prevent increase in erosion.

Degradation of natural resources especially dense forests will result in increase in erosion and soil transition (Zare et al. 2016b). The soil losses map shows that the soil losses in the study area is between 9 and 1022 ton/hectare/year and the highest value is related to pasture and the area with the poor vegetation cover.

Impact of land use change scenarios on soil loss

Future soil erosion and deposition at Kasilian watershed under five scenarios are displayed in Fig. 9.

The mean of soil loss in simulated period shows in all of the scenarios, soil loss value was higher than basis period. The range of soil erosion change is 2–32% in all scenarios. Thirty percent decrease in demand scenario has the least soil loss in simulated period in such a way that the soil loss value under this scenario will be only 2% more than the basis period. Among all land use change scenarios, this is the most restrictive scenarios and it has the most management processes. Therefore, the amount of soil loss is near the basis period. Ten percent increase in land use demand scenario has the greatest difference in the soil loss with the basis period, and the amount of soil loss will have increased 32% until by 2030 (Fig. 10). Also, Mullan et al. (2012) and Paroissien et al. (2015) have emphasized the importance of land use management in soil loss.

Conclusion

Increase and decrease in land use demand will change the soil loss. The results showed that scenario affects soil loss, but many scenarios did not have any effect on spatial soil erosion. Most of the changes occur in land use boundaries and monitoring in the process of watershed management and land use boundary can be effective in soil loss control. The results of this study have confirmed the role of monitoring processes under land use change scenarios. Among all RUSLE factors, climate and land use change have the most changes of all the other factors in future. In fact, climate change is a natural and unavoidable process and it is not under human control. Thus, if land use change can be controlled, despite future climate changes, soil loss will be controlled and even decreased to a large extent.

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