

The impact of land use change on runoff generation in an urbanizing watershed in the north of Iran

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Abstract Determining how land clearing and other land use changes will affect the amount of runoff is among the most important issues related to the watershed management. In this study, the L-THIA GIS model was applied to calculate the height and volume of runoff as well as the contribution of each land use type to producing runoff in a watershed under intense development pressure in the north of Iran. Different land use scenarios were also simulated using the CLUE-s model based on varying demands of each of the land use types. In this study, three different periods of 1986, 2000, and 2011 for the base period and 5 land use change scenarios for year 2030 were prepared. The results showed that the CLUE-s model is a suitable model to simulate future land use changes through the use of a ROC curve. The simulated runoff heights and runoff volumes were 132.55–165.31 mm and 119.295–148.779 m³/cell in base and future periods, respectively. The simulation of runoff under different land use scenarios showed that the amount of runoff in all the scenarios is more than the base period so that in a 44-year period (1986–2030) (assuming that the current rate of demand for land is constant), the total volume of runoff

will increase by 54 % due to land use changes. The amount of runoff is also affected by the amount of land use demand, so that the amount of runoff reduces with the decrease in demand. The increased runoff, rise in urbanization as well as indiscriminate cutting of forests are the most important factors that contribute to increased runoff in the study area, and the development of new residential areas causes the most significant increases in runoff. This study has shown that the hydrologic effects of land use changes can be reduced with an exact physical design of area land use through controlling the demand of each land use.

Keywords Land use change · CLUE-s · L-THIA · Runoff · Iran

Introduction

Land use refers to the manner of human-based activities on the natural characteristics of the land surface to achieve the products or service (Dan et al. 2015). The impact of land use change on hydrology and water resource is a major global research issue (Foley et al. 2005). Runoff water and its resulting impacts have become more important and increased along with local economic development (Coutu and Vega 2007). The influence of land use on runoff generation is very complicated. It depends on a number of factors including the size, average slope, and baseline land use characteristics of the watershed (Petchprayoon et al. 2010). Land use has an effect on interception, surface retention, evapotranspiration, and resistance to overland flow (Olivera and Maidment 1999). As forests have lower surface albedo, higher leaf surface area, higher surface aerodynamic roughness, and deeper roots than other types

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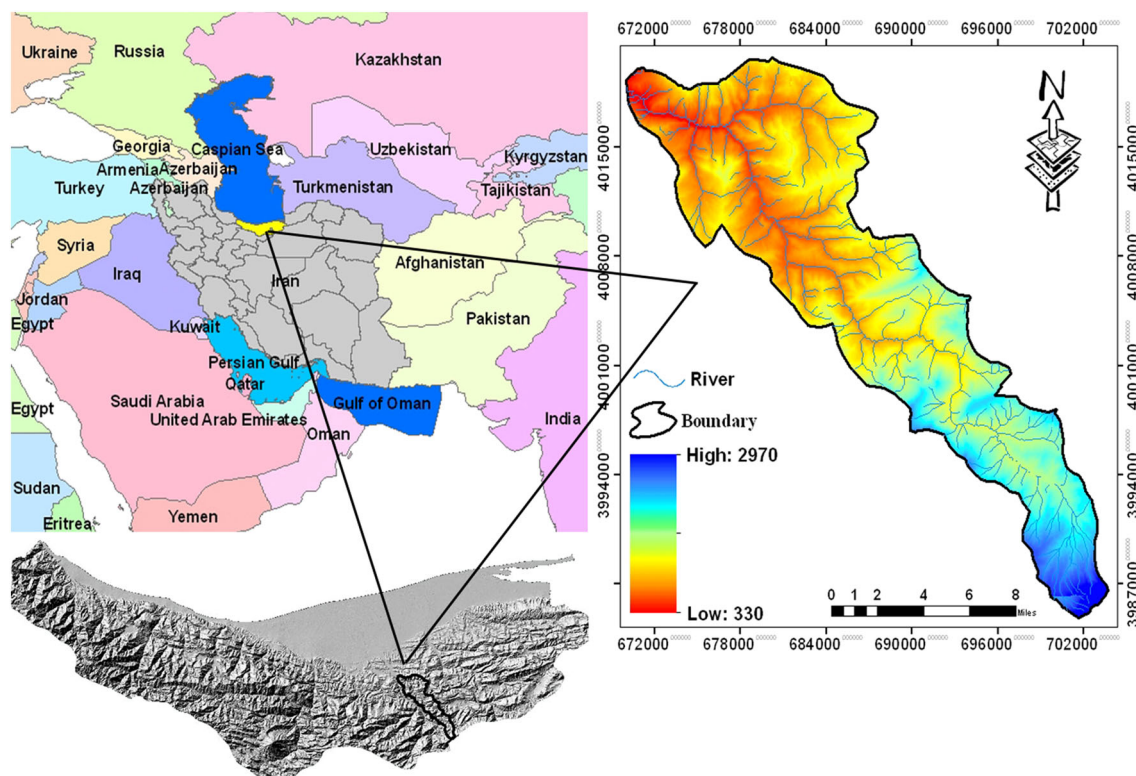


Fig. 1 Location of Kasilian watershed in Iran

of vegetation, with each characteristic tending to contribute to an increase in evapotranspiration and a decrease in stream flow (Costa et al. 2003; Farley et al. 2005), a reduction in forest cover can increase runoff. Conversely, the cultivation of tree plantations has often caused reductions in runoff (Calder 2007) in a watershed.

Urban growth is one of the main threats to natural resources and environmental degradation. Increasing the impervious area due to the construction of houses, streets, and culverts may reduce infiltration and shorten the time of concentration. Generally, urbanization will increase peak discharge, runoff volume, floods, occurrence of socioeconomic problems, and decrease in water quality (Weng 2001). Land development and urbanization in the north of Iran have substantially increased over the last two decades. In the late twentieth century, the forest area has been reduced and converted to rangelands and residential areas.

Regional changes in runoff due to land use changes are generally investigated using models that can simulate runoff and non-point source (NPS) pollutant loads at regional/watershed scales such as AGNPS (Young et al. 1987) and SWAT (Arnold et al. 1998). Additionally, the Long-term Hydrologic Impact Assessment (L-THIA) model has been developed by Purdue University and U.S. Environmental Protection Agency as a tool to assess how land use and land use change could affect annual average

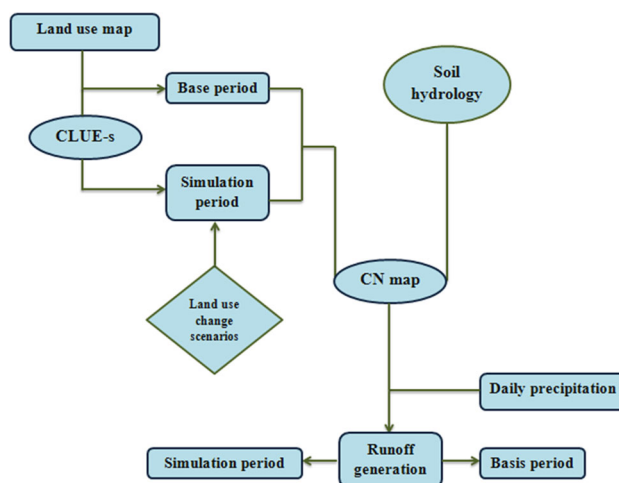


Fig. 2 Research flowchart

runoff in a watershed. Due to the effects of land use change on runoff, extensive studies have been performed in this field (Bronstert et al. 2002; Coutu and Vega 2007; Viilers and Donnell 2013; Sanyal et al. 2014; Lin et al. 2015; Sajikumar and Remya 2015; Yuan et al. 2015; Zhang et al. 2015). However, in these studies, the future effects of land use changes on runoff have been unclear. The simulation of land use changes is very complex, since environmental systems have a nonlinear nature (Verburg et al. 2002). In

recent years, a large number of operational models have been produced that can be used to predict or explore possible land use change trajectories (Verburg et al. 2006). The models can support the exploration of future land use changes under different scenarios, and scenario analysis via land use models can support land use planning and policy.

The Conversion of Land Use and its Effects at Small regional extent (CLUE-s) model was specifically developed for the spatially explicit simulation of land use change based on the empirical analysis of location suitability combined with the dynamic simulation of competition and interactions between the spatial and temporal dynamics of land use systems (Verburg et al. 2002; Verburg 2010). The CLUE-s model is able to provide different scenarios of land use changes on the basis of land management features in the future. Land use change and its effects are very important in Iran, especially in the northern regions. This is because due to the favorable climatic conditions of the region, its beautiful scenery, and its proximity to the Tehran-North highway, the Kasilian watershed has always been exposed to intense development which has caused the degradation of natural resources and the conversion of forests into other land uses.

In this study, the trend of land use change in this watershed was prepared from past to present and with regard to the kind of land use change in different scenarios, land use simulated maps were prepared using CLUE-s model for this watershed. Since small changes in land use may have large effects on the hydrology of a watershed, in this study, generated runoff for base and future periods was simulated and was estimated based on different scenarios. Then, the effect of each land use change was considered depending on the height and the volume of runoff that was generated during rainfall events.

Materials and methods

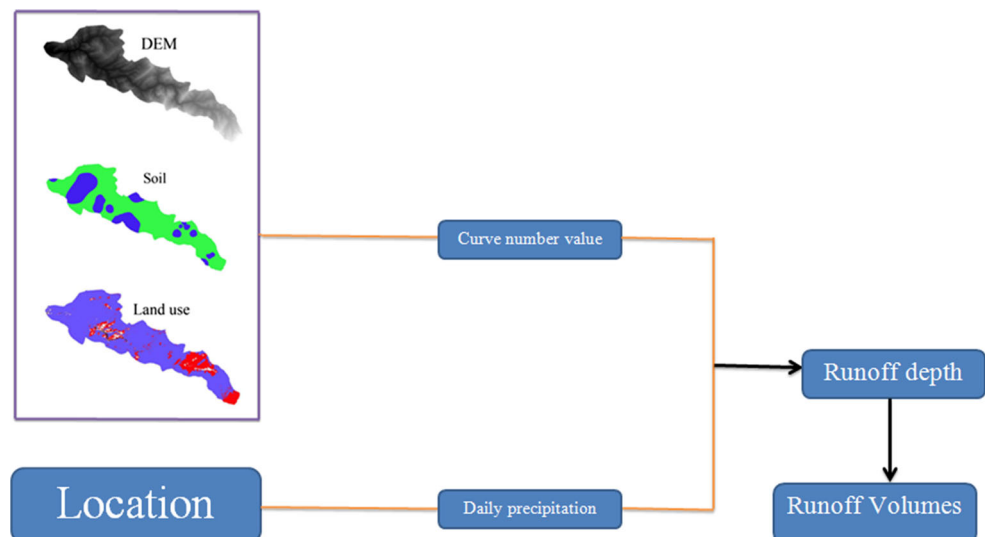
Study area

The Kasilian watershed is a sub-watershed of the Tallar catchment which is located in the central region in the north of Iran. The surface area of the watershed is 342.86 km², and its geographic coordinates are 53°01′–53°26′E and 35°01′–36°32′N (Fig. 1). The minimum and maximum heights of watershed are 286 and 3289 m above sea level, respectively. The average annual precipitation in the watershed is 733 mm, and the average annual temperature range in the region varies from 18 °C on the plain area to 10 °C in the mountains. In terms of Iranian geological classification, this watershed belongs to Central Alborz and its surface rocks belong to the first, second, and third eras. The majority of this watershed is covered with different forest species containing other land uses such as rangeland, residential development, and agricultural uses in addition to forest land use. The soil is primarily of podzolic, brown forest, and sedimentary types. In recent years, many rangelands and agricultural lands have been converted into residential areas due to favorable climatic conditions. Therefore, the price of agricultural land has increased and rangeland is occupied illegally. In this paper, land use types are divided into 4 classes including agriculture, forest, settlement, and rangeland.

Methods

In the present research, future land use change scenarios were simulated in order to evaluate their potential impacts on runoff generation in the Kasilian watershed, Iran. To

Fig. 3 Overview of L-THIA GIS



achieve this objective, the observed daily precipitation data covering 1981–2010 from 6 stations of Iran Water Resource Management Company (IWRMC) were used in this study. Land use maps of three different time periods (1986, 2000, and 2011) were prepared using information from satellite images that was processed using the maximum likelihood method. After preparing the data required for the CLUE-s model, land use simulation was restricted out to the year 2030. This is because the simulation of land use change over long-term periods will increase the probability of errors, so that models can only be used to explore scenarios for near-future (15–20 years) land use changes (Veldkamp and Fresco 1996; Kok and Winograd 2002). In addition to the simulation of the current distribution of land uses, four additional land use change scenarios were defined based on land use demand. Finally, by entering data from the land use simulation in L-THIA model, runoff generation was calculated both for the base period and for the simulated period. The modeling process is summarized in Fig. 2.

L-THIA model

The L-THIA model was used to calculate the average annual runoff for the study area. The L-THIA model uses the US Department of Agriculture (USDA) Natural Resources Conservation Service's curve number (CN) method with data inputs from daily rainfall, land use, and hydrologic soil group data to calculate direct runoff (Harbor 1994; Harbor et al. 1998; Wang et al. 2005; Sun et al. 2011). The simplicity of the model (e.g., no calibration requirement) makes it attractive to policymakers wishing to identify management issues of concern and to target resources to ameliorate any adverse impacts (Bhaduri et al. 2001; Perry and Nawaz 2008). Given that observed runoff data were unavailable for the watershed, model validation

could not be performed. This is not of concern since we are primarily interested in relative changes in runoff (Perry and Nawaz 2008). The CN method is an empirical set of relationship between rainfall, land use, and runoff height. CN values range from 25 to 98 and represent land surface conditions. They are a function of land use, hydrologic soil group, and antecedent moisture condition (USDA SCS 1986). The basic equation used in the CN method for standard or average condition is:

$$R = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (1)$$

$$S = \frac{1000}{CN} - 10 \quad (2)$$

where R runoff height, P precipitation height, S potential maximum retention and CN curve number. The detailed classifications are not readily taken into consideration in the L-THIA model for direct runoff calculation; therefore, there is a need to calibrate CN values for better match with the measured direct runoff (Lim et al. 2006). In this study, the annual runoff height was used as the sole indicator to perform the calibration of CN values. The manual trial-and-error method was used for the calibration based on default CN values provided by the L-THIA system and other research results in the area (Du et al. 2013). In the L-THIA, soils are classified into four hydrologic soil groups based on the runoff potential, as defined by USDA (1986). For the soils under impervious surfaces, soil type D was used because of being the recommended value for compacted urban soils (Purdue Research Foundation 2004). The soil types were not differentiated across the studied area and classified as type D due to the low permeability of the soils of East Leeds. For this purpose, 52 soil samples in different land use categories were collected from all over the area and the soil texture was measured using a hydrometer.

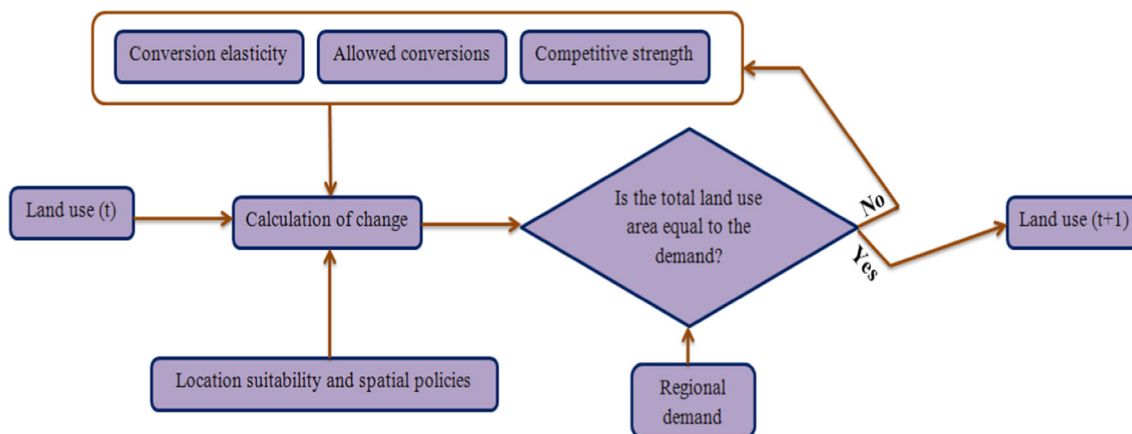


Fig. 4 Flowchart of the CLUE-s model

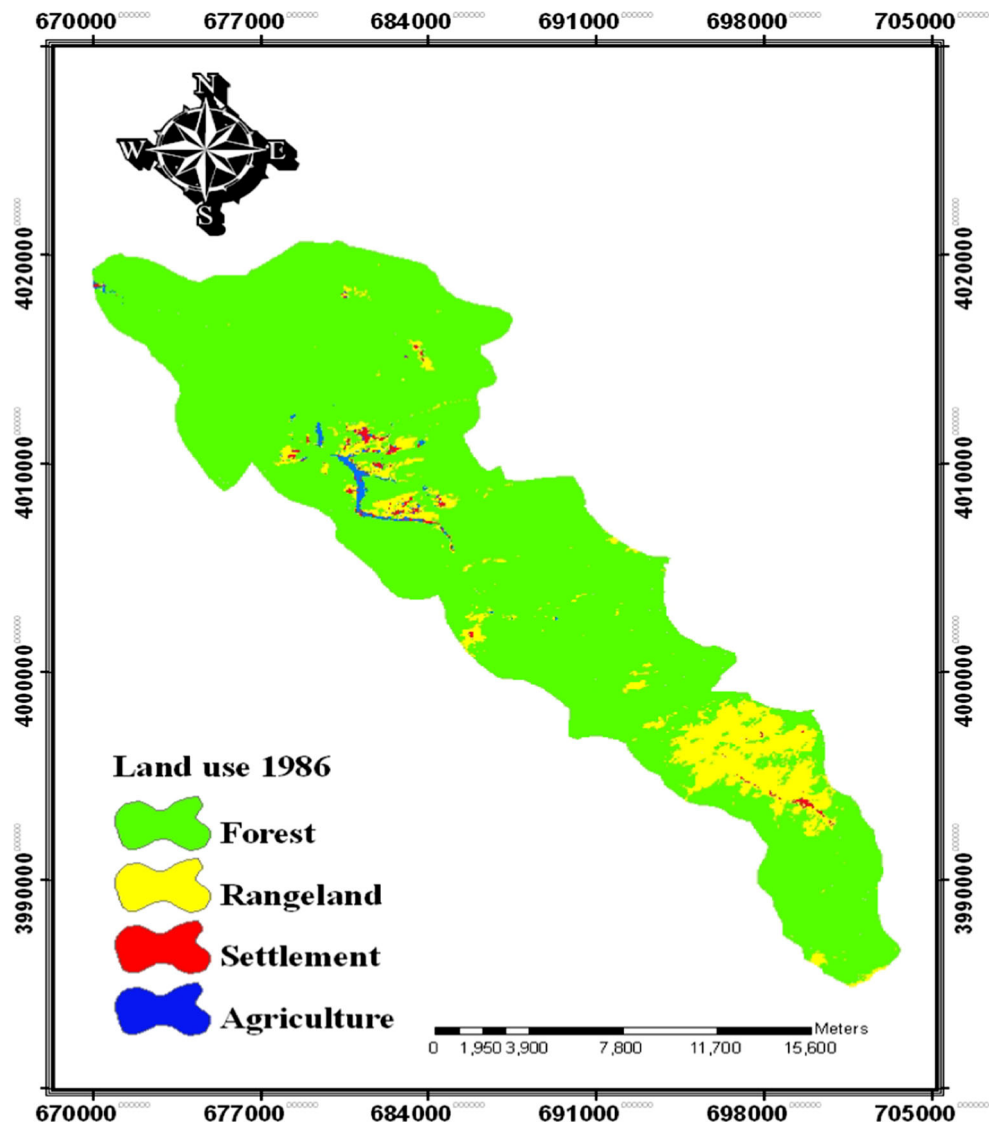
The L-THIA model works by two methods: L-THIA web-based and L-THIA GIS. In this study, the L-THIA GIS (<http://www.ecn.purdue.edu/runoff>) was used. This model determines CN based on land use and soil type in raster format, calculates daily runoff height based on SCS-CN method, and calculates daily runoff volume (cubic meter) multiplied by area (cell size × cell size) (Fig. 3). For the implementation of land use in the L-THIA model, 8 classes of land use are used. So, for the implementation model, the land use map of the study area should be re-classified on the basis of the model. Also, if the classes are some of the different classes of the model, they should be placed in a class that most closely resembles the characteristics of the class to be runoff (2005). After doing so, using the module land use classification in L-THIA GIS, land use is allocated to each of the classes of 1000 and 7000 codes. To prepare the rainfall data for the L-THIA, daily rainfall data from rain-gauge stations were used in the

study area over a period of 30 years (1981–2010). Then, after preliminary preparation, the data were transported to the L-THIA GIS format.

Satellite image preprocessing

In this study, three cloudless images from Landsat satellite (TM) in 1986, 2000, and 2011 were used as the primary data. The images of landsat series provide a useful data source for land use mapping and monitoring (Mohammady et al. 2013). Additional information was obtained from aerial photographs with the scale of 1:20,000 in 1968, collections of topographic images, false color composite images from Spot satellite, and particularly previous knowledge of authors about the studied region were employed as the complementary data for the analysis of processing steps and modeling the land use change. Since the first layer images from the Landsat satellite were

Fig. 5 Land use map of year 1986



automatically geo-referenced, we ignored the geometrical correction preprocessing (Arvidson 2002). Radiometric correction was also used as one of the most important preprocessing steps during a two-step process. In the first step, DN values of the image cells were converted into spectral radiance and, in the second step, the spectral radiance was converted into earth surface reflectance (Chander et al. 2009). Based on the primary preprocessing, field survey, and applying the first level classification by Anderson (1976), 4 land use classes were identified in the studied region, which included forest, agricultural, rangeland, and settlement uses. Training samples were prepared to train the maximum likelihood classification algorithm for the whole region (Arsanjani et al. 2013; Mohammady et al. 2014). Finally, the validity of the classification was tested by the Kappa statistic.

CLUE-s model

The CLUE model (Veldkamp and Fresco 1996; Verburg et al. 1999) was developed to simulate land use change using empirically quantified relationships between land use and its driving factors in combination with the dynamic modeling of the competition between land use types. Because of the differences in data representation and other features that are typical for regional applications, the CLUE model cannot be directly applied at the regional scale. Therefore, the modeling approach has been modified and is now called CLUE-s. CLUE-s is specifically developed for the spatially explicit simulation of land use change based on the empirical analysis of location suitability combined with the dynamic simulation of competition and interactions between the

Fig. 6 Land use map of year 2000

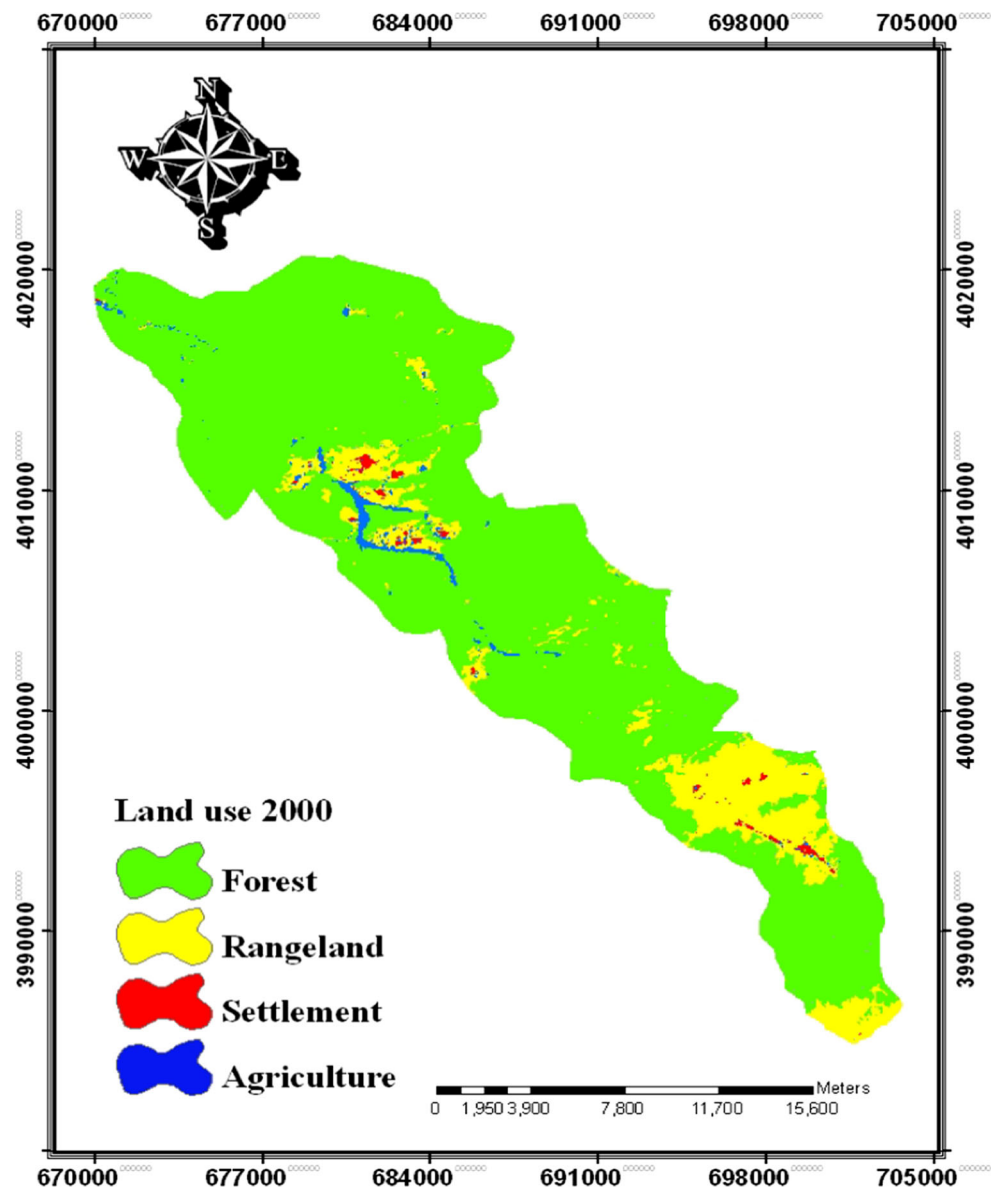
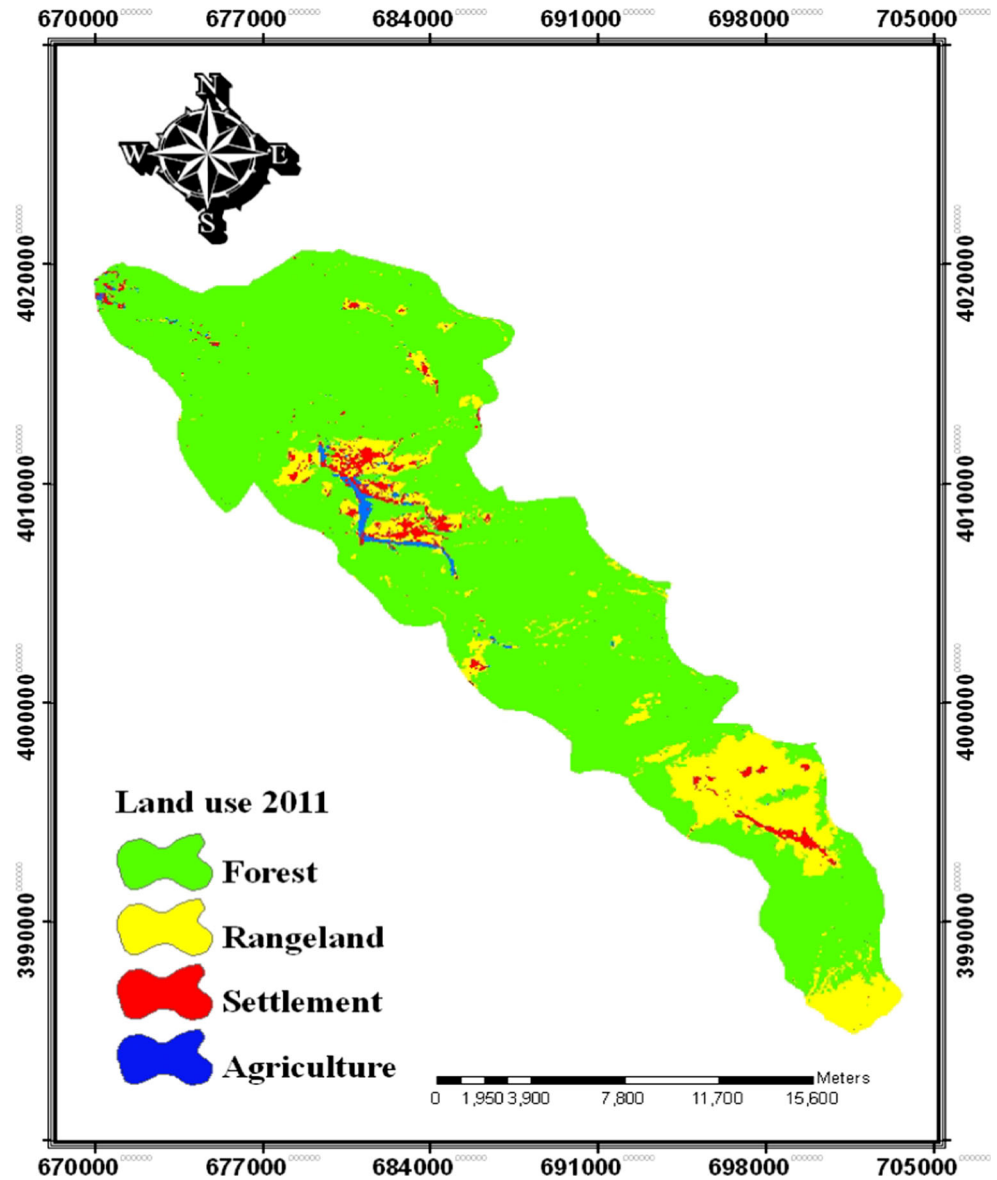


Fig. 7 Land use map of year 2011



spatial and temporal dynamics of land use system. The CLUE-s model has two parts: analysis of land use driving forces based on logistic method to calculate the relationship between the driving factors and each land use category, followed by the simulation of land use change by setting the rules of land transfer, policy and restrictions, demand and other parameters, using Dyna-CLUE software (Xu et al. 2013). The allocation procedure is summarized in Fig. 4.

Analysis of land use change drivers based on logistic methods

CLUE-s uses binary logistic regression between the present land use distribution and a selected panel of contributive variables defined a priori by the user. According to a

Table 1 Area of land use categories in different periods

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

prescribed change in the land use classes, CLUE-s distributes each land use across the landscape according to a statistical model built on the current situation and the distance to the initial distribution (Paroissein et al. 2015). The function that relates these probabilities to the biophysical and socioeconomic location characteristics is defined in a logit model as follows:

$$\text{Log}\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1X_1 + \beta_2X_2 + \dots + \beta_nX_n \quad (3)$$

where P_i is the probability of a grid cell for the occurrence of the considered land use type on location i and the X 's are the

driver factors. β coefficients are estimated through logistic regression using the actual land use pattern as the dependent variable (Verburg et al. 2002; Chen et al. 2009). The factors that drive land use change in the Kasilian watershed include

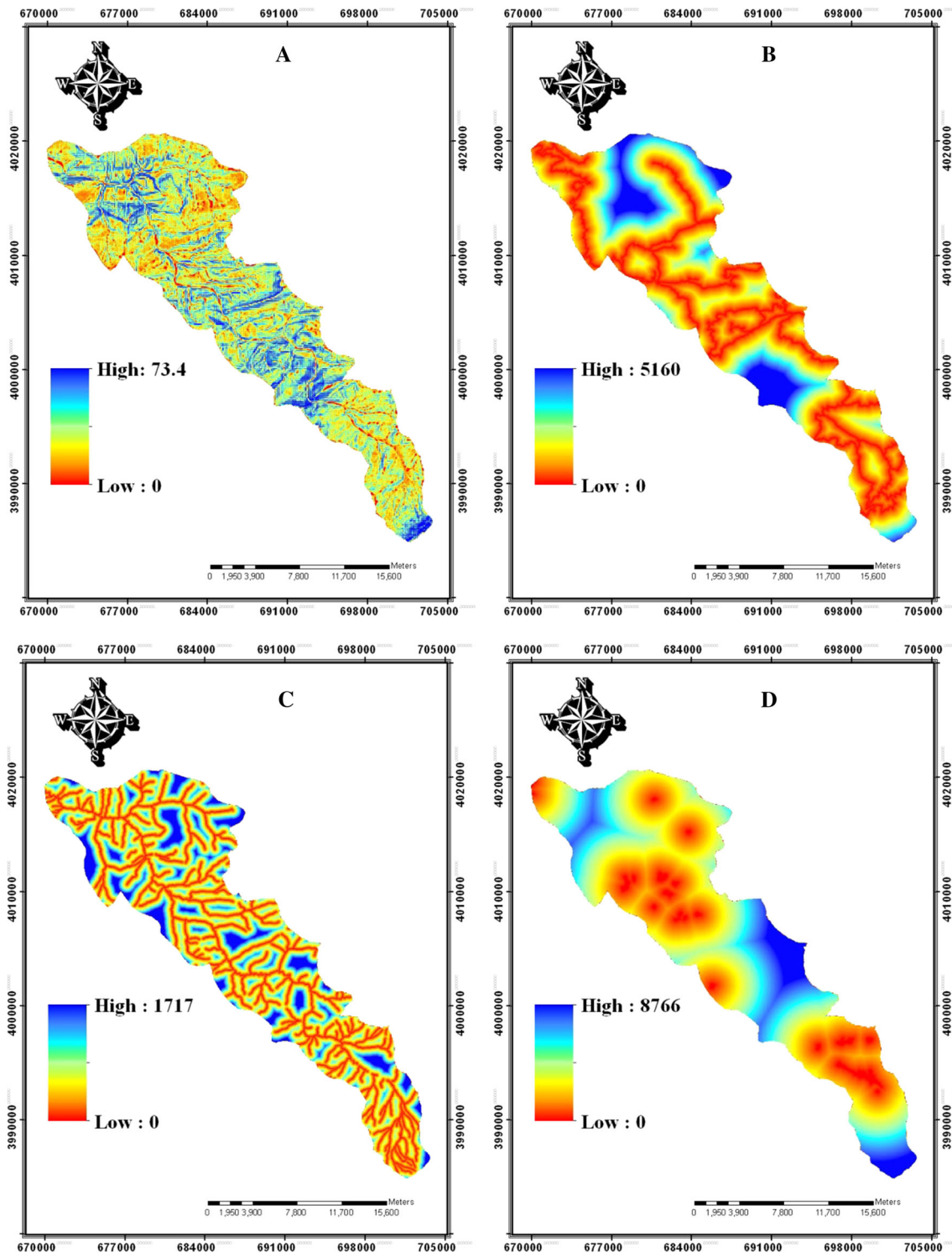


Fig. 8 Driving factor maps: slope (a), distance from road (b), distance from river (c), distance from settlement (d) in the study area. Lithology (e), elevation (f), slope aspect (g) and soil texture (h) in the study area

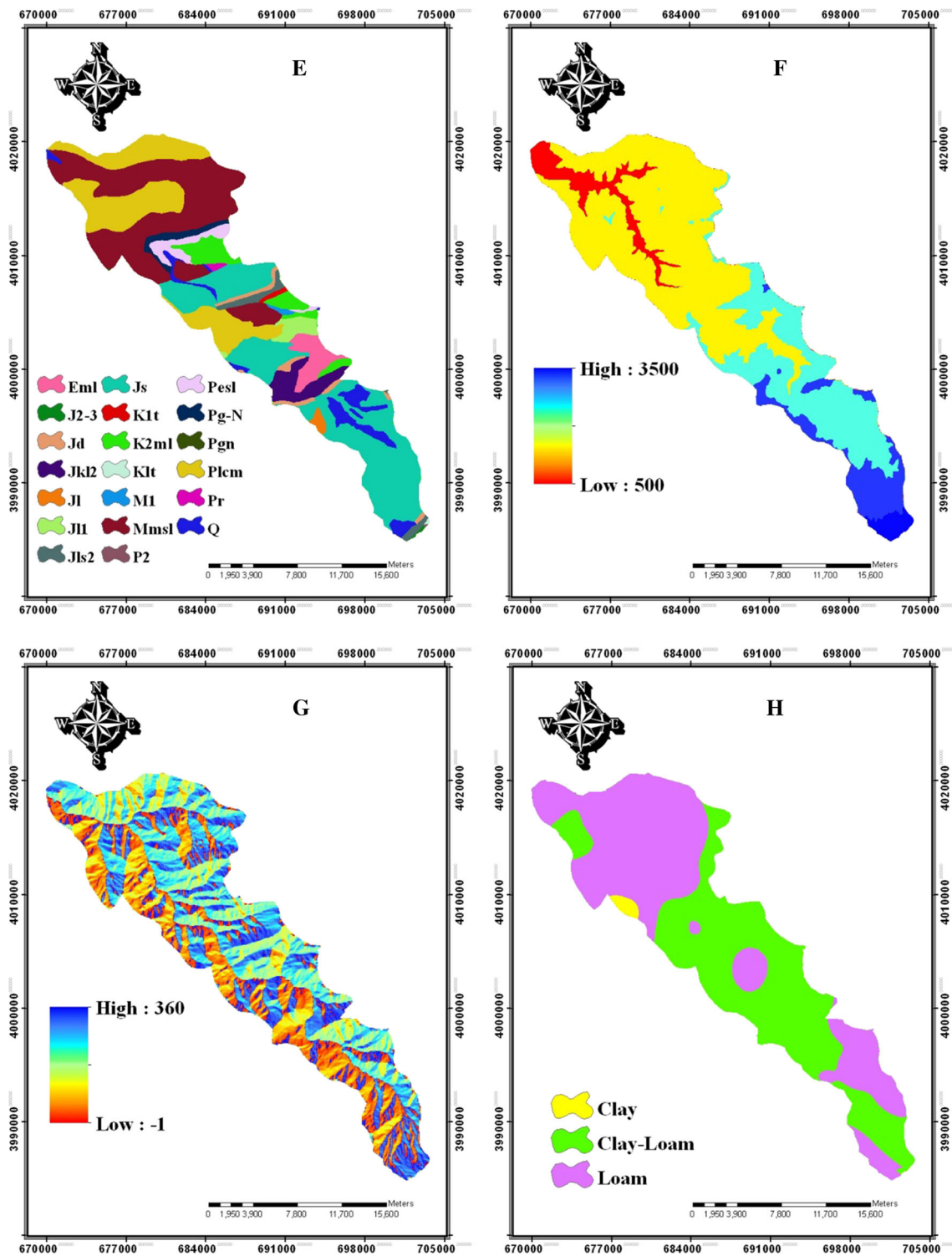


Fig. 8 continued

altitude (m), slope, distance from the river, soil, the erosion coefficient, soil texture, distance from major roads, distance from built-up area, lithology, slope aspect, and annual precipitation. In addition, we used relative operating

characteristic curve (ROC) to assess the goodness-of-fit of the model's logistic regressions. We performed forward stepwise logistic regression and ROC analysis using Statistical Package for Social Sciences (SPSS) for Windows.

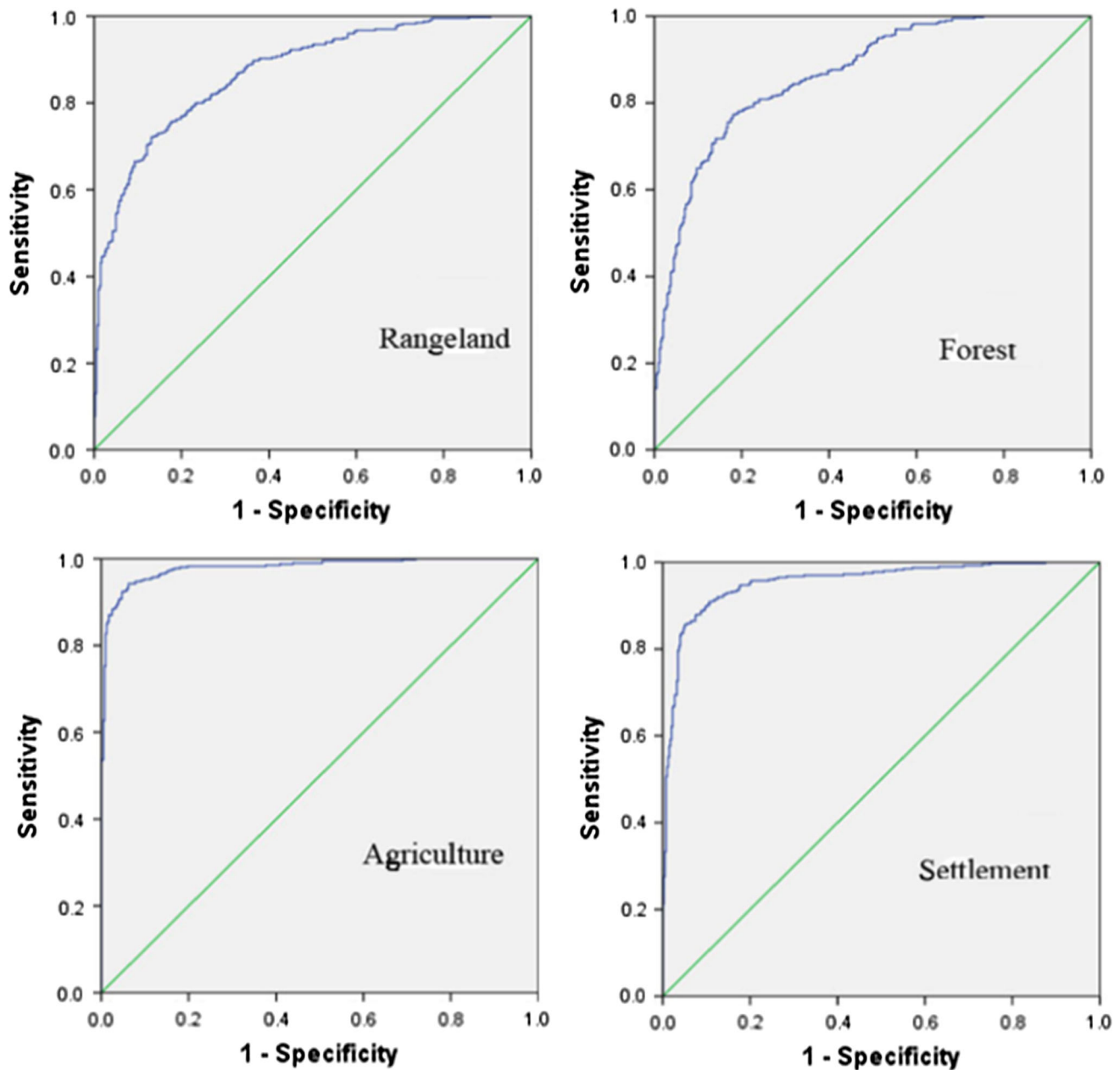


Fig. 9 ROC curve of land use types in the study area

Table 2 Area under receiver operator characteristic curve

Land use	Area	Std. error ^a	Asymptotic sig. ^b
Forest	0.865	0.011	0.000
Rangeland	0.873	0.012	0.000
Settlement	0.995	0.007	0.000
Agriculture	0.98	0.004	0.000

^a Under the nonparametric assumption

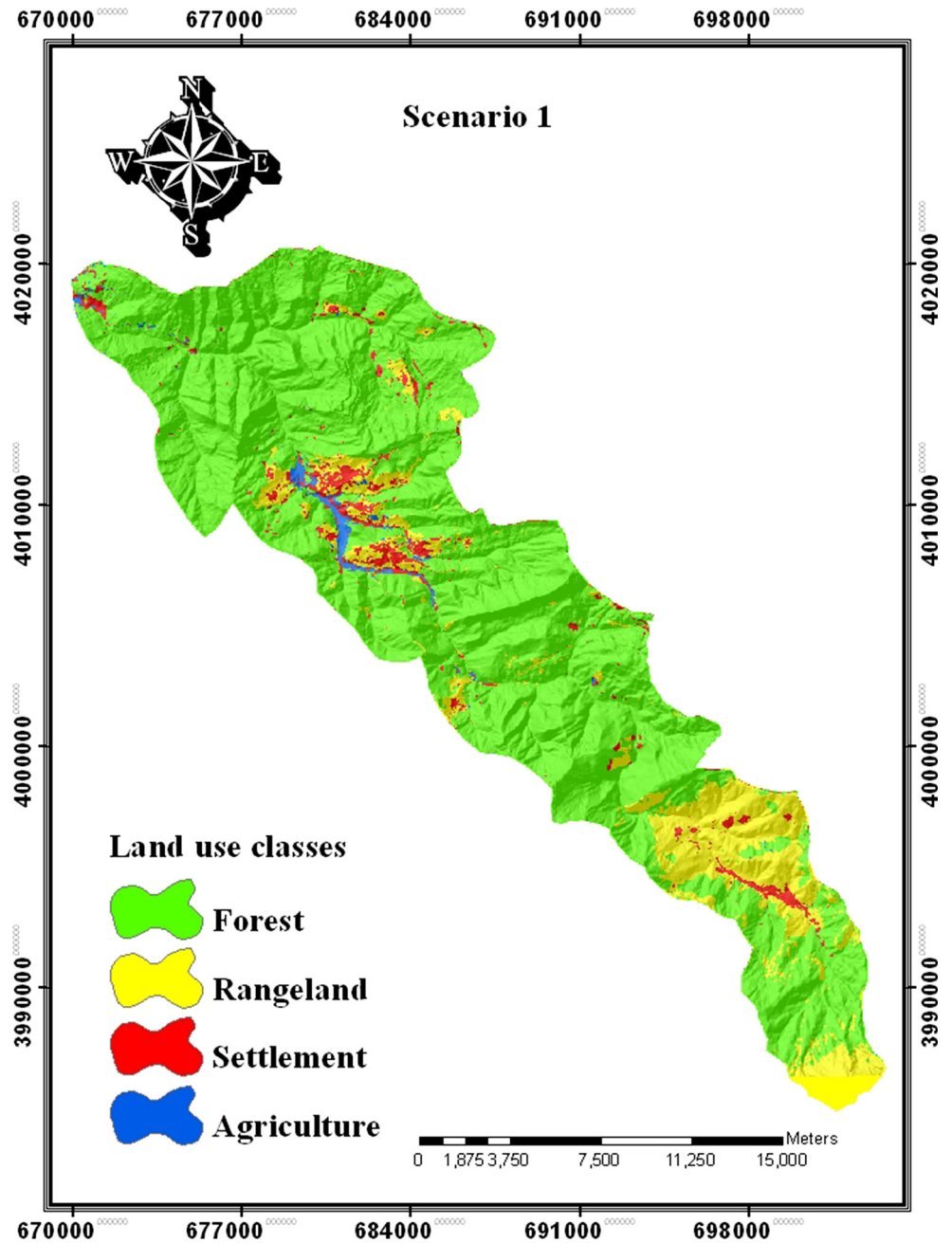
^b Null hypothesis: true area = 0.05

For all land uses, regression and correlation coefficients were calculated for each element in a text file called alloc1 stored and entered into the application CLUE-s.

Conversion matrix

This matrix is determined in the conversion of different land uses (Luo et al. 2010) and specifies to what other land use types the present land use type can be converted or not.

Fig. 10 First scenario of land use change by CLUE-s model



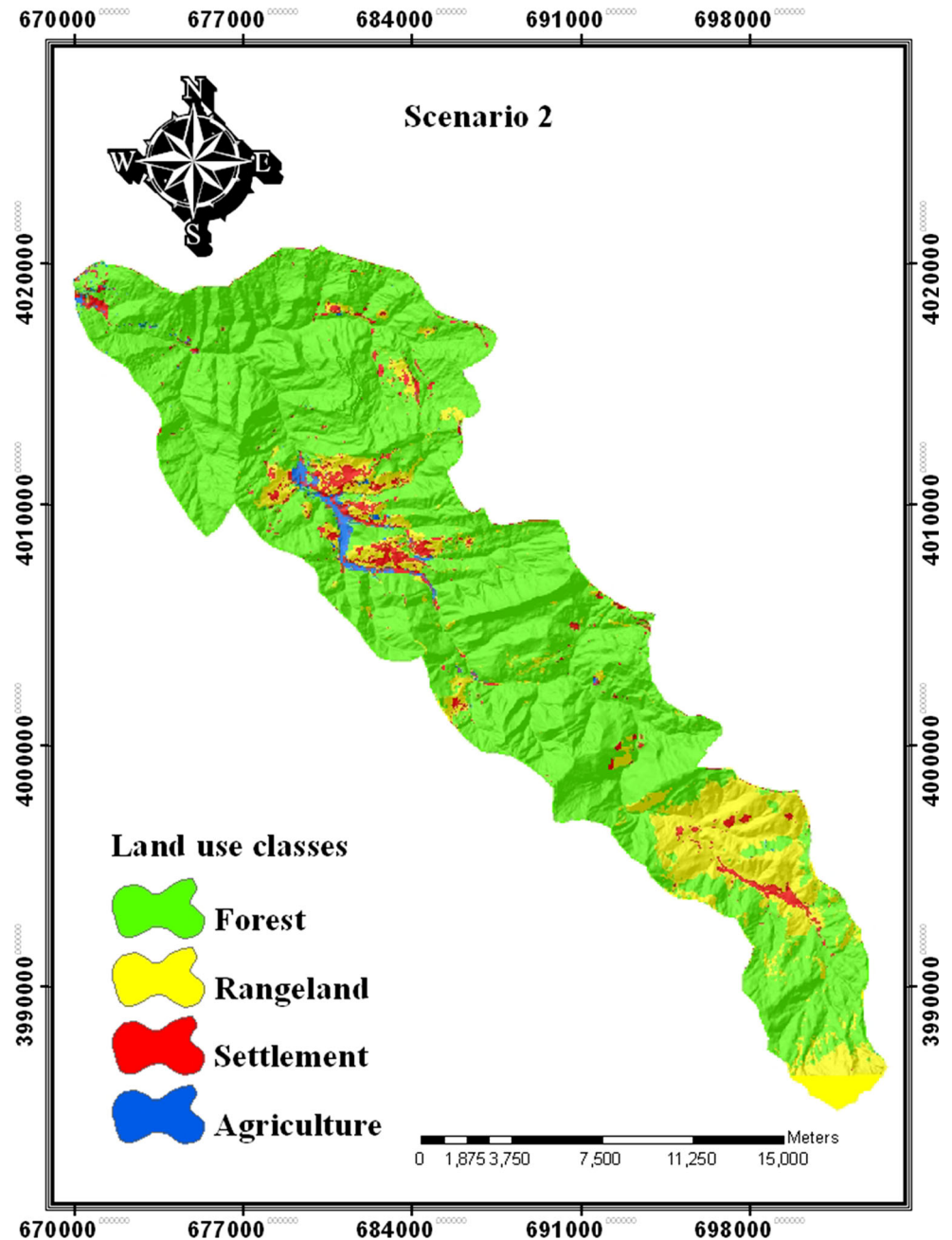
Therefore, the land use conversion matrix is stored with the name *allow.txt*.

Land use demand

For the land use demand module, different model specifications ranging from simple trend extrapolations to complex economic models are possible. The choice for a specific model greatly depends on the nature of the most important land use conversions taking place within the studied area and the scenarios that need to be considered.

The results from the demand module need to specify the area covered by different land use types on a yearly basis, which is a direct input for the allocation module. The land use requirements constrain the simulation by defining the total required change in land use. All changes in individual pixels should be added to these requirements. To use this factor, a file called *demand.in* was created for the CLUE-s model that has 4 columns and each column shows the specific land use (Forest, Rangeland, Settlement, and Agriculture). In this study, land use demand was calculated for 20 years (2011–2030).

Fig. 11 Second scenario of land use change by CLUE-s model



Land use change simulation by CLUE-s

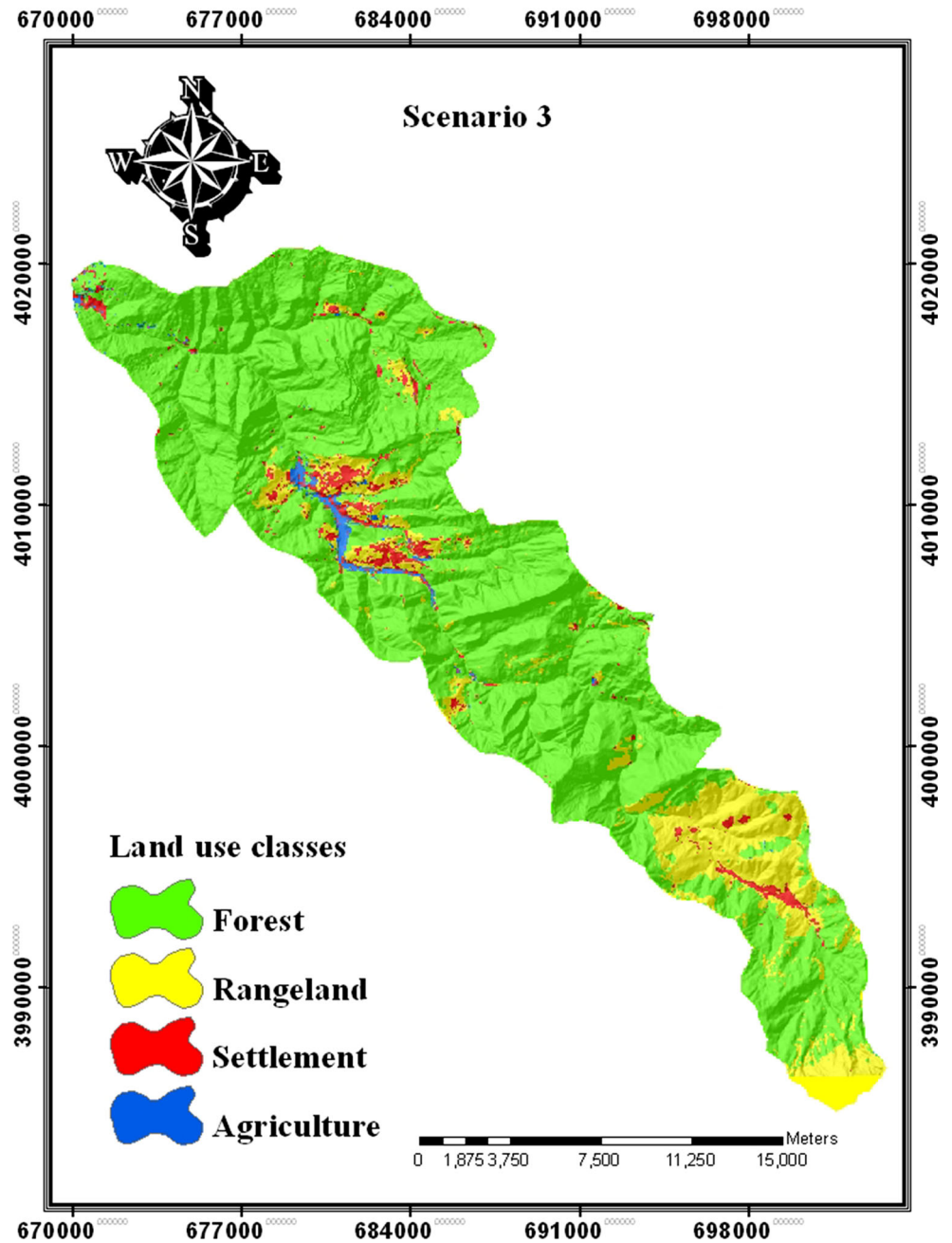
Data of logistic regression equations, conversion matrix, and land use demand factors were placed on the maps related to the application of CLUE-s, and simulation of land use was carried out on an annual basis.

Land use change scenarios

Land use changes in the Kasilian watershed are expected to follow the trends of the land use demand and indicate

the runoff volume in each of the specifications, as stated above. Four scenarios were considered, the first three of which were based on assuming that the current rate of degradation of natural forest areas will decline due to more stringent regulatory controls in this area in the future. Therefore, the demand for change was calculated with 10, 20, and 30 % decrease. Also, due to the weakness of the regulatory agencies, land use demand will have to increase. Then, considering the new request, a 10 % increase in demand for these scenarios will be simulated.

Fig. 12 Third scenario of land use change by CLUE-s model



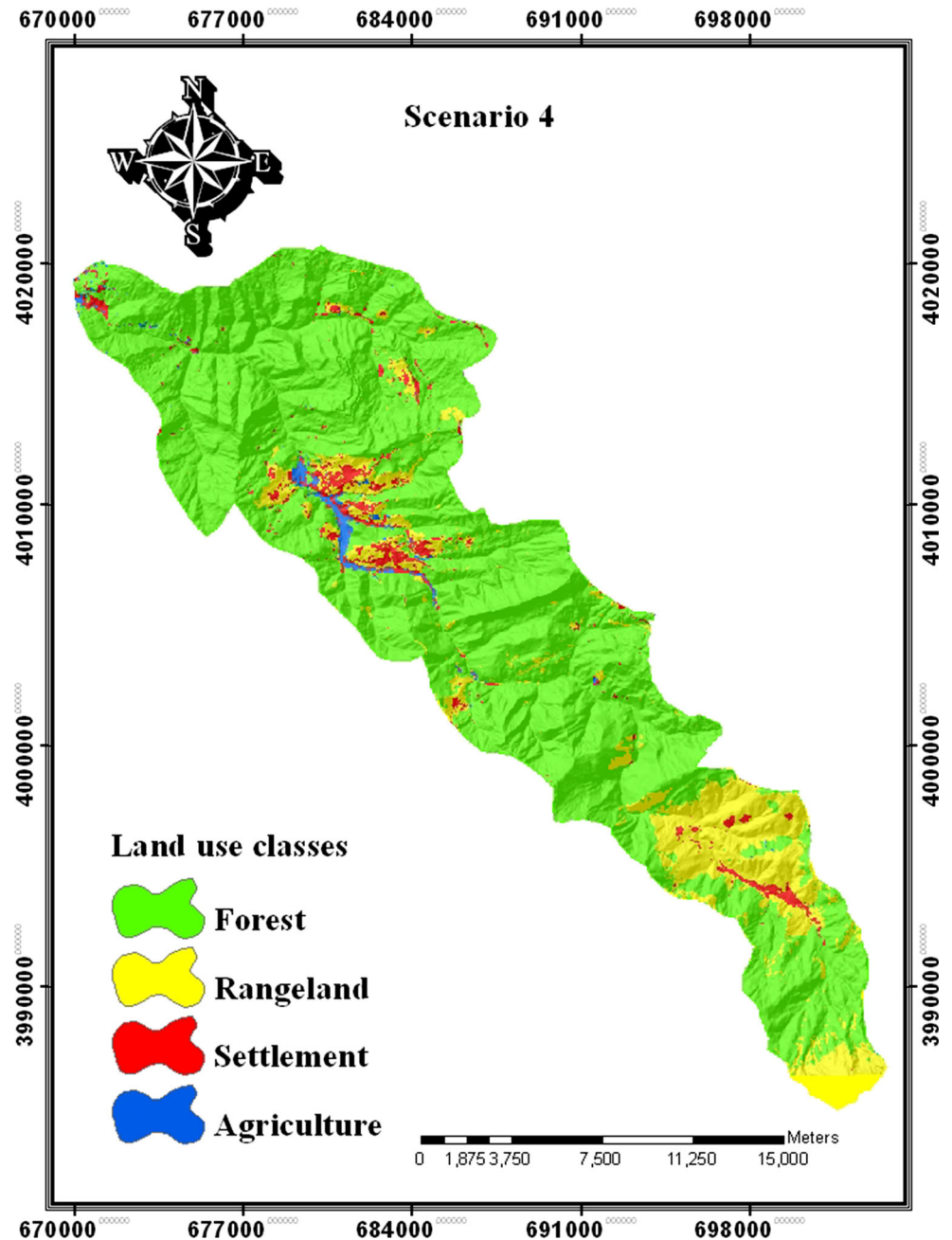
Results

Land use changes and simulation

Using the maximum likelihood method, the land use map of the study area in 1986, 2000, and 2011 was obtained. These maps include land use categories for forest, rangeland, residential, and agricultural areas (Figs. 5, 6, 7). The area of each land use type in different years and the change procedure over 25 years are shown in Table 1, which indicates that forest is the largest land use in the area. The results of land use changes showed an overall decrease in

the forest land use category. The area of the watershed under forest has decreased by about 2014 hectares over a 25-year period, and the highest decrease has occurred from 1986 to 2000. The results also showed that the rangelands category has increased by 1850 hectares over 25 years. However, this increase had the greatest change from 1986 to 2000 and no significant change has been made from 2000 until 2011 in the amount of rangelands in the area. Consequently, there was only a slight increase in construction activity in the area from 1986 to 2000, but the trend has greatly increased from 2000 to 2011. The majority of the Kasilian watershed was covered by the

Fig. 13 Fourth scenario of land use change by CLUE-s model



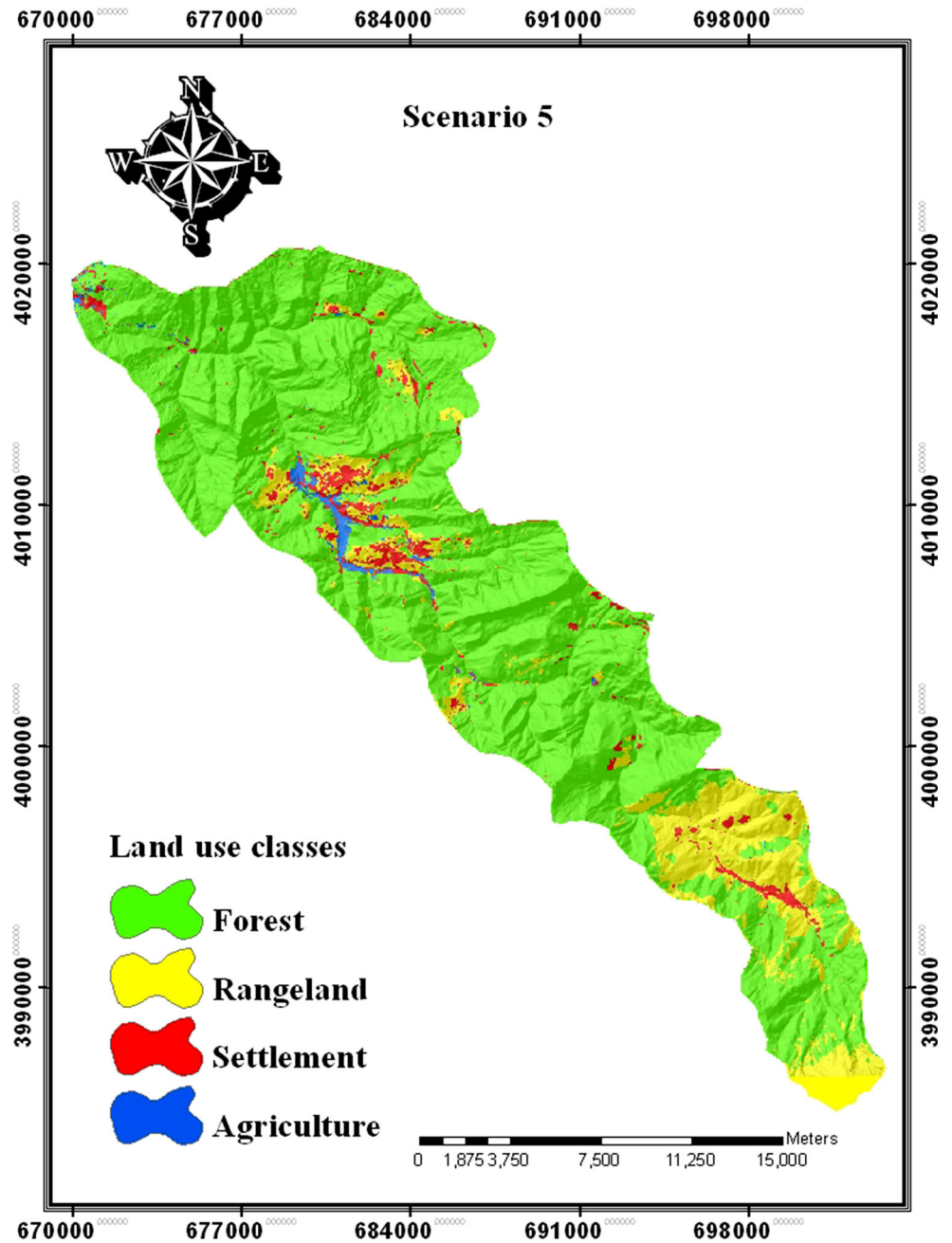
forest vegetation, with rangeland holding the second place. In addition, due to specific topographic condition and slope of the region which are unsuitable for agricultural purposes, this land use had minimum contribution in the region. In order to prioritize the factors affecting land use changes, logistic regression was used (Fig. 8).

ROC curves were used for accuracy assessment of regression model. ROC curves and area under curve (AUC) show for forest, rangeland, residential, and agriculture in Fig. 9 and Table 2. The results showed AUC was higher than 0.8 for total land use types. The asymptotic

significance was less than 0.05, which means the assessment of the driving factors of land use was accurate.

By entering the required text files and maps, a land use map for the year 2030 was simulated using the CLUE-s model and, considering the restrictions and changing demand, land use scenarios were designed. Scenarios investigated in the model included 5 scenarios of changes in land use demand based on past trends (the first scenario), changes in land use demand with 10, 20, and 30 % reduction in degradation (the second, third, and fourth scenario), and changes in land use demand with 10 %

Fig. 14 Fifth scenario of land use change by CLUE-s model

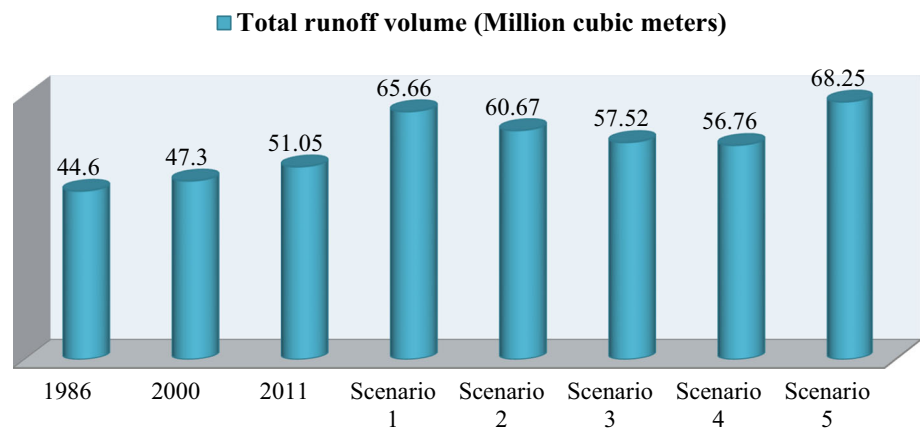


increase in degradation (the fifth scenario) (Figs. 10, 11, 12, 13, 14).

Runoff calculation

As mentioned above, L-THIA model was used to calculate runoff. Each land use map was entered to L-THIA model, and runoff was calculated. The aim of this research was investigating the impacts of land use on runoff generation, so climate condition and rainfall were considered constant. In fact, the other factors of model were considered constant

in the total period of research so runoff change is related to land use changes. Figure 15 and Tables 3 and 4 show runoff generation for total land use maps. The results of modeling have indicated that the greatest height and volume of runoff in the base period took place in 2011 (143.2 mm and 128.88 m³/cell, respectively) and the amount of runoff increased from the start of the base period to the end, so that it is increased by 9 % over a 25-year period. The results of land use changes simulation using CLUE-s model and its effect on runoff for 2030 showed that the height and volume of runoff is increased in all

Fig. 15 Total runoff volume in all the periods**Table 3** Runoff generation for basis and simulation period

Periods	Runoff depth (mm)	Runoff volume (m ³ /cell)
Basis period		
1986	132.55	119.295
2000	135.07	121.563
2011	143.2	128.88
Simulation period		
Scenario 1	160.23	144.207
Scenario 2	157.76	141.984
Scenario 3	155.92	140.328
Scenario 4	152.24	137.016
Scenario 5	165.31	148.779

scenarios of CLUE-s model compared to the base period, so that the 30 % decreased scenario of land use demand has the lowest runoff and the 10 % increased scenario of demand allocated the highest amount of runoff among other scenarios. In fact, the results have shown that the amount of runoff is totally affected by the amount of land use change demand, so that the amount of runoff reduces with the decrease in demand and the other way around. The change of total runoff volume was 44.6–68.25 million m³ in both periods (Fig. 15) so that the least and most of runoff were related to 1986 and 2030 (scenario 5), respectively. Furthermore, the mean of total runoff volume was 47.65 and 61.77 million m³ in base and future periods, respectively. The runoff height and volume mean is 136.94 mm and 123.24 m³/cell, respectively, while runoff height and volume mean for future period and under different scenarios is increased 21.35 mm and 19.22 m³/cell compared to base period (Table 3). Whoever, the amount of height and volume runoff will change depending on land use change (Table 4) so that in between all land uses and different periods in the region, forest areas have the least height and volume runoff (126.43 mm and 113.79 m³/cell)

in 1986. In contrast, settlement area has the most height and volume runoff (312.36 mm and 281.22 m³/cell) in 2030 and scenario 5.

Discussion

Land use changes

In this study, the land use change procedure was evaluated over a 25-year period from 1986 to 2011 using TM sensor images and the maximum likelihood method. A ROC curve was used in order to evaluate the accuracy of obtained land use maps, and the results showed that the prepared land uses had a high accuracy. As said before the results of land use changes showed an overall decrease in the forest land use category. Due to the lack of attention by regulatory agencies in these areas over the mentioned years, the early inhabitants began the indiscriminate cutting of trees, which increased levels of rangelands for the livestock. Subsequently, these areas were used for residential construction. The result of this trend was the increased level of rangelands and construction over this period. With an increase in regulatory control and the enforcement of legal standards, this trend has declined greatly. Similar trends have been reported in Greece by Pérez-Vega et al. (2012) who indicated that there had been a 35 % decrease in forest area over an eight-year period and that area of residential areas increased by 290 % over the same period. Similarly, Shan et al. (2012) reported a 50 % decrease in agricultural land use and a 220 % increase in residential land use from 1972 to 2000 in an area in Taiwan.

Results of similar studies show that conversion of natural forest to residential areas is a global concern and many countries have this problem. These have been only limited agricultural development in the Kasilian watershed due to the steepness of the topography. Consequently, there was a reduction in agricultural land use from 1986 to 2000, but

Table 4 Runoff generation for basis and simulation period in land use type

Periods	Land use	Runoff depth (mm)	Runoff volume (m ³ /cell)
Basis period			
1986	Forest	126.43	113.79
	Rangeland	161.16	145.04
	Settlement	399.5	359.55
	Agriculture	304.3	273.87
2000	Forest	128.77	115.89
	Rangeland	175.55	158.00
	Settlement	406.24	365.62
	Agriculture	388.88	349.99
2011	Forest	133.6	120.24
	Rangeland	177.8	160.02
	Settlement	550.07	495.06
	Agriculture	311.9	280.71
Simulation period (2030)			
Scenario 1	Forest	147.3	132.57
	Rangeland	221.7	199.53
	Settlement	769.3	692.37
	Agriculture	309.6	278.64
Scenario 2	Forest	145.78	131.20
	Rangeland	201.33	181.20
	Settlement	698.2	628.38
	Agriculture	307.18	276.46
Scenario 3	Forest	143.21	128.89
	Rangeland	198.12	178.31
	Settlement	689.32	620.39
	Agriculture	298.45	268.61
Scenario 4	Forest	142.83	128.55
	Rangeland	195.65	176.09
	Settlement	671.14	604.03
	Agriculture	295.77	266.19
Scenario 5	Forest	150.07	135.06
	Rangeland	229.5	206.55
	Settlement	809.47	728.52
	Agriculture	312.36	281.12

has been increasing from 2000 to 2011 and almost returned to the area covered in 1986. In fact, the human driving forces in the study area could be considered as the most important factor in land use change. Economic problems, the non-affordability of agricultural activities (the increased agriculture costs and the problems of selling products) along with the increased price of land due to tourism has caused the progressive transformation of forests and rangelands to residential lands. Some constraints were considered to design the scenarios through demand in the development of land uses. According to the maps of 2030, if the current trends continue, there would be a noticeable decline of forest areas in 2030 and an increase in

rangelands. Residential areas also would have a faster growth compared to the other land uses, especially in the vicinity of rangelands.

Effect of land use change on runoff

In this study, the effect of land use changes on runoff in the base period (1986, 2000, and 2011) and the simulated period (2011–2030) has been evaluated separately under 5 land use change scenarios. The results indicated that the greatest runoff in the base period took place in 2011. According to land use conditions in the study area, the results showed that the smallest area of forest occurred in

2011 and the largest areas of rangeland and the greatest increase in residential areas occurred in the same period. The L-THIA model was also applied to each of 4 land uses of forest, rangeland, residential, and agricultural areas in order to evaluate the amount of runoff they each produced. The modeling results indicated that forested areas had the lowest runoff for all simulated time periods. The forests with more canopy cover, more extensive rooting system, and humus layers cause increase in the infiltration and interception and as a result reduce the runoff (Fullen 1998; Neary et al. 2009). The high evaporation and transpiration of forests due to the more leaf coverage and also deep roots and facilitation of penetration and flow of water in the soil lower layers are the causes of decrease in runoff (Hundechea and Bardossy 2004). Ott and Uhlenbrook (2004), Lyon et al. (2010) and Van der velde et al. (2013) also emphasized the role of forest destruction in the increase in runoff. The results also have shown that residential land use has created the highest runoff among all the land uses due to the large proportion of paved and other impermeable surfaces in urban areas. Previous research also has shown increase in runoff caused by impermeable areas. For example, Engle et al. (2003) reported that an increase in impermeable areas due to the land use change has resulted in 80 % increase in the runoff volume. In the same way, Tang et al. (2005), Perry and Nawaz (2008) also emphasized the effect of the increased runoff volume due to the land use changes and the increased impermeable areas. The results showed that the height and volume of runoff is increased in all scenarios of CLUE-s model compared to the base period. In fact, the results have shown that the amount of runoff is totally affected by the amount of land use change demand. The modeling has indicated that if the current trend of land use changes continues without constraints until 2030, the amount of runoff will increase by 12 % compared with 2011 and only with minimal constraints on forest clearing; it can be expected that the runoff volume decreased by 2.22 million m³/yr. The type of land use change in different scenarios and its effect on runoff results have indicated that residential areas have the highest change among other land uses. Liu et al. (2004) emphasized the role of residential areas compared to forests. Their findings showed that the increased residential areas scenario and deforestation scenario, respectively, increased the runoff by 36.6 and 12 % and the afforestation scenario decreased the runoff by 7.8 %. A comparison of the runoff total volume produced in the base and simulated periods showed that 10 % increased scenario of demand in 2030 created the highest runoff volume 68.25 million m³, whereas the lowest runoff volume is related to 1986 with 44.6 million m³. The modeling has indicated that in a 44-year period (1986–2030), in the case the demand is not changed, the total volume of runoff will increase by 54 %

and the increase seems to be mostly related to the land use changes. In fact, the other factors of model were considered constant in the total period of research so runoff change is related to land use changes. It should be noted that results of L-THIA do not predict the events in any specific year, but also create a general perspective of long-term hydrologic effects resulted from the different land use scenarios (Pandey et al. 2000). The results show that L-THIA model has appropriate capability in explanation of the effect of land use changes in the amount of runoff height and volume, according to different scenarios.

Conclusions

Modeling undertaken in this study has indicated that the clearing of forests and the conversion of agricultural land to residential areas play an important role in producing runoff in the north of Iran. A comparison of the runoff produced in the base and simulated periods has indicated that in all the simulated land use scenarios, the amount of runoff in 2030 will be higher than the base period and these changes are closely related to the demand of each land use. The modeling has indicated that increases in runoff in 2030 could be minimized if strict regulatory controls are imposed on forest clearing. Modeling of this type is an important tool for ensuring that planning of land use change is made on the basis of the best available scientific information to reduce potential hydrologic impacts associated with land clearing and the paving of urban areas.

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