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The influence of deforestation on runoff generation and soil erosion (Case study: Kasilian Watershed)

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ABSTRACT: Destroying of forest lands and landuse changes have caused undesirable effects in the watershed hydrologic conditions. Landuse and vegetation are important factors in soil erosion and runoff generation. This research has been done using a runoff-rainfall model, sediment-erosion model, Geographical Information System and remote sensing to determine the hydrologic effects of deforestation on Kasilian watershed (north of Iran). A runoff-rainfall model has been presented using GIS (HEC-GeoHMS extension) and hydrologic model (HEC-HMS). The SCS method has been used for presenting the hydrologic model. It is to note that the optimized model is evaluated by other six events of floods. Then, the optimized model has been validated. Erosion potential method model has been applied in GIS environment to simulate soil erosion and sediment rate. According to the obtained results, the runoff and sediment generation potential have been increased in the Kasilian watershed due to deforestation during the last forty years.

Keywords: forest; landuse; runoff-rainfall model; sediment; Iran

An increase in population, and consequently, an increase in the needs of human societies have caused the anomalous and incorrect use of natural resources in Iran. Destroying forest and rangelands and changing them into agricultural and residential lands have been very noticeable particularly in the northern part of Iran because of agricultural activities and development of human societies. The growth process of urban societies has been increased all over the world and it is predicated that it will have been increased up to 60% by the year 2030 (McGee 2001). Along with the destroying of forest and rangelands (Katz, Bradley 1999), the effects of the cosmopolitan area growth and population increase include as follows: groundwater discharge reduction, surface flow increase and annual runoff increase, peak discharge increase of the watershed, lag time reduction between beginning rainfall and runoff generation and hydrograph slope increase (Hirsch et al. 1999; Burnsa et al. 2005). Unfortunately, the population increase process, anomalous and incorrect use of natural resources in the northern part of Iran have been continued when they resulted in the occurrence of recent floods in the northern part of Iran. Therefore, it is necessary to prevent such deplorable events through managing the environment and natural resources. In the field of simulation of hydrologic behaviour of watersheds, Christopher et al. (2001) and Stone (2001) presented a runoff-rainfall model using GIS (Geographic Information System) and HEC-HMS software. Their results indicated the ability of the method in the simulation of flood hydrograph of a watershed. The present study was carried out to investigate the influence of deforestation on runoff generation and soil erosion in the Kasilian watershed.

MATERIAL AND METHODS

Located in the northern part of Iran, within the limits of eastern longitude 53°18' to 53°30' and northern latitude 35°58' to 36°07' in the north of Iran, Kasilian watershed has an area of about 68 km^2 (Fig.1). The climate of the zone is semi-humid and cold and its average annual precipitation is 791 mm and average temperature is 11°C. The minimum, average and maximum of the elevation in the watershed are 1,120, 1,672 and 3,349 m, respectively. The average slope of the watershed, the average slope of the main channel and the length of the main chan-

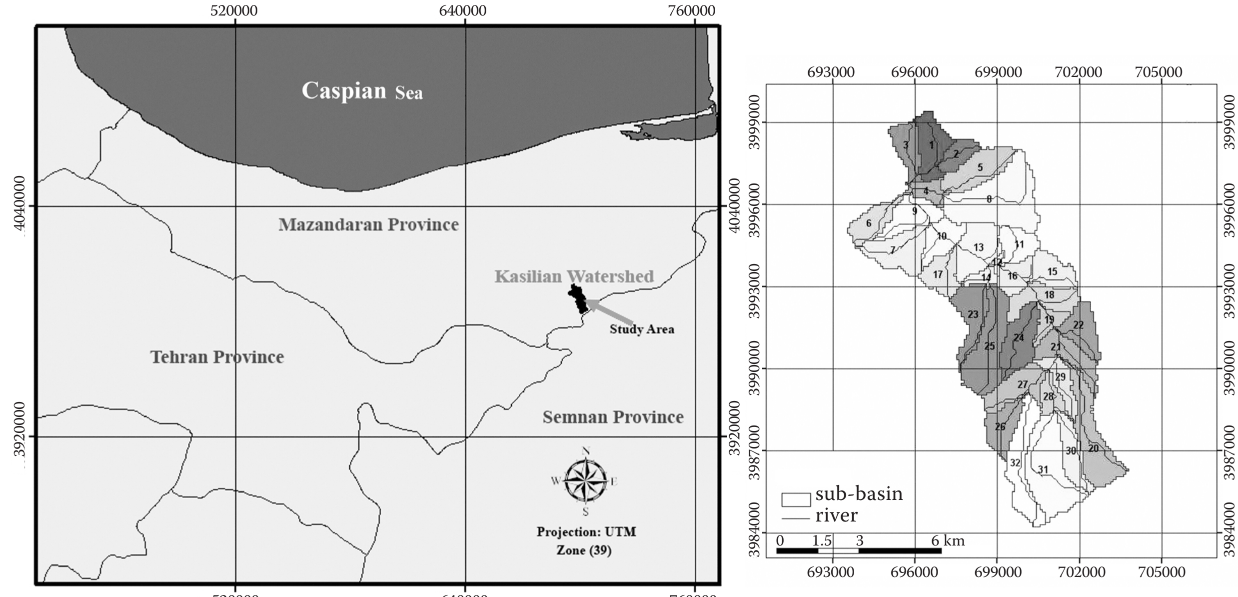

Fig. 1. The location of the study area (Kasilian watershed)

nel are 15.8%, 13% and 16.5 km, respectively. There is a hydrometric station in the outlet of the watershed and a rainfall recorder station in its upstream.

In the present study, the growth process of residential areas and road network in different time frames and also the destroying rate of forests and landuse changes have been studied using GIS and the data of remote sensing. The economy of the landuse maps of the year 1995, topographic maps 1:25 000 of the years 1995 and 2002 and ASTER satellite images of the year 2010 have been used for investigating the growth process of residential areas, road network and also landuse changes during the last forty years. The growth process of the residential areas, services installation equipment and asphalt road network have been investigated

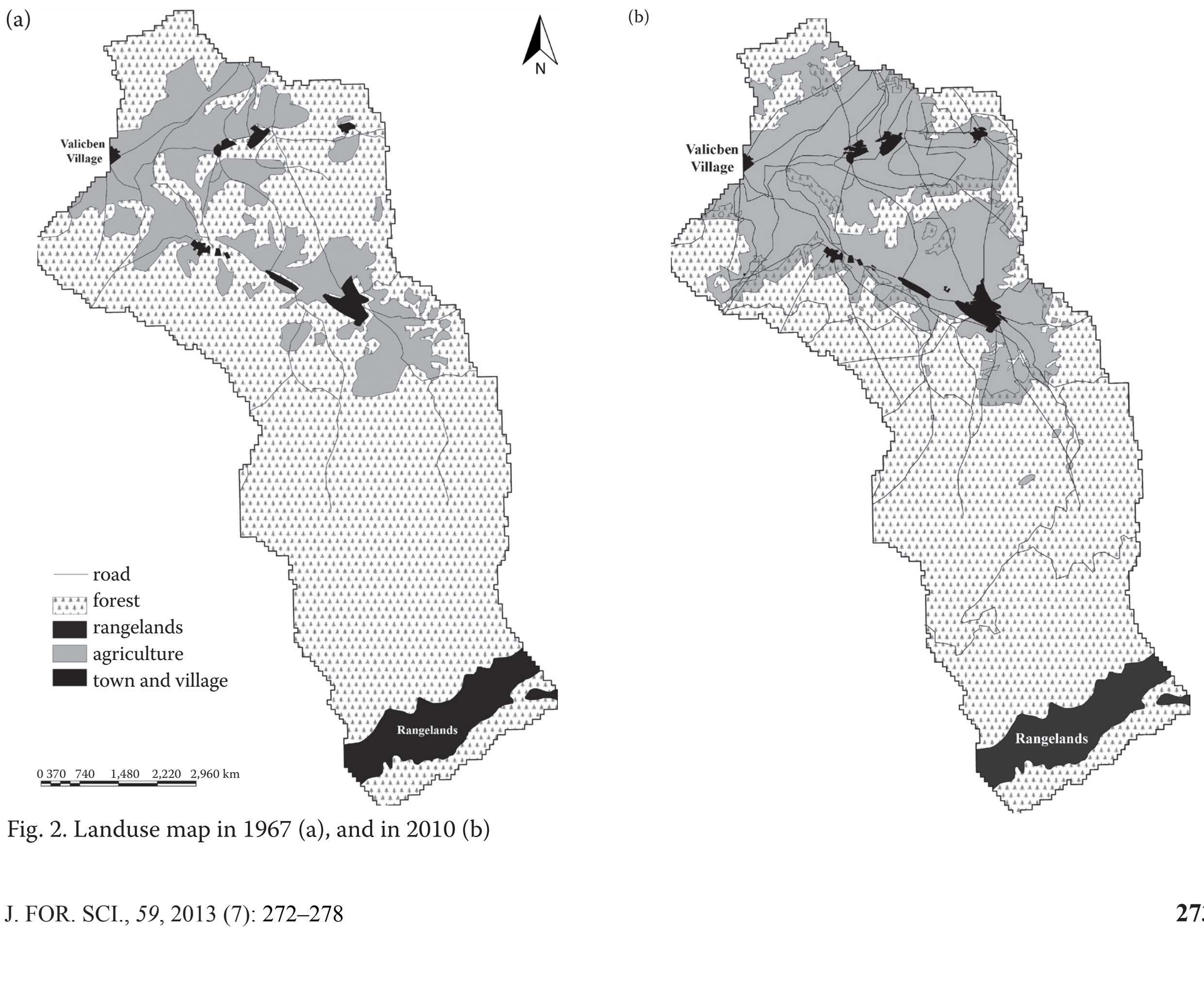

Fig. 2. Landuse map in 1967 (a), and in 2010 (b)

Table 1. Six rainfall events have been used for modelling and optimizing the model ($m^3 \cdot s^{-1}$)

Event	Observed Q_{max}	Simulated Q_{max}
24 May 1991	10.30	10.28
22 May 1991	9.36	9.20
22 Sep 1990	11.70	11.50
16 May 1992	7.80	7.70
22 Oct 1991	12.20	11.90
4 May 1993	1.56	1.52

using these data. The landuse map of the watershed surface can also be observed in two different time frames of 1967 and 2010 in Fig 2. and the curve number changes in the Antecedent Moisture Conditions (A.M.C) II. In the next step, the influence of these changes on intensifying runoff generation on the surface of Kasilian watershed has been studied quantitatively using a runoff-rainfall model. The hydrologic model (HEC-HMS) has been used for presenting the runoff-rainfall model. The physical model of the watershed has been simulated using the HEC-GeoHMS (extension in GIS environment) Arcview (ESRI, Redlands, USA) and the Digital Elevation Model (DEM) and the surface of the watershed was divided into 32 small sub-basin areas. The implications of urbanisation on runoff processes depend on the scale of the watershed area and magnitude of urban development. Small-sized river basins, which are densely urbanised, are more affected by the urban runoff flows than large-sized rivers flowing through large cities, where the local urban runoff peaks contribute towards a rather small proportion of the river flow (Maksimovic, Tucci 2001). Hence small urban rivers are more fitting for the study of these effects (Moldan, Cerny 1994; Foster et al. 1995). Then the physical model of the watershed was entered into the HEC-HMS software environment. The information on the rain intensity of Sangdeh rain recorder station and the flood hydrograph of Valicben hydrometric station and six rainfall events in 1990–1993 were applied for presenting the model (Table 1).

The SCS method, curve number method and lag method were used for presenting the runoff-rainfall model, for estimating the high runoff and for the flood routing in channels, respectively. Curve number determination was done with respect to landuse and soil hydrological groups maps in different antecedent moisture conditions (dry, average and moist) and hydrological conditions. Loss estimation, i.e. the total interception, infiltration, transmissivity in the soil and surface (mm), was performed. The runoff calculation is given below:

$$S = \frac{25{,}400}{CN} - 254 \tag{1}$$

where:
CN – runoff curve number,
S – losses (mm).

It is done using the following formula:

$$Q = \frac{(P - 0.25)^2}{P + 0.85} \tag{2}$$

where:
Q – runoff (mm),
P – maximum precipitation in 24 h (mm).

Maximum flood discharge calculation, after calculating the runoff due to a rain storm it was calculated by the following formula:

$$Q_{max} = \frac{2.083A \times Q}{tp} \tag{3}$$

where:
Q_{max} – maximum discharge ($m^3 \cdot s^{-1}$),
A – basic area (km^2),
Q – runoff (mm),
tp – time of the flood crest which is evaluated by the time of concentration (min).

Rainfall was simulated in the ways of incremental or even speed on the watershed surface. The model was optimized by the initial loss and lag time parameters of the sub-basin areas (SCS-Lag) and in the next step, the efficiency of the optimized hydrologic model was confirmed by comparing the results from using the model for simulating the hydrograph of the other six flood events with the recorded flood hydrographs. After evaluating the hydrologic model of Kasilian watershed, changes in landuse (with the curve number criterion) and impervious surface growth were applied for a rainfall event during the last forty years. It is to note that the model was implemented only by entering the changes and even speed rainfall on the whole watershed surface. And the influence of man's activities and environmental changes resulting from them in intensifying runoff generation and flood hazard have quantitatively been investigated during the last forty years. EPM (erosion potential method) model has been applied for erosion modelling in the Kasilian Watershed. So, practical models can be used to investigate the effect of landuse changes on soil erosion and sediment production (Tangestani 2006). There are four factors in EPM model. Landuse factor or *Xa* is one of the EPM model factors. In the model, if landuse is changed, consequently the landuse score or *Xa* will change. Two EPM models were provided

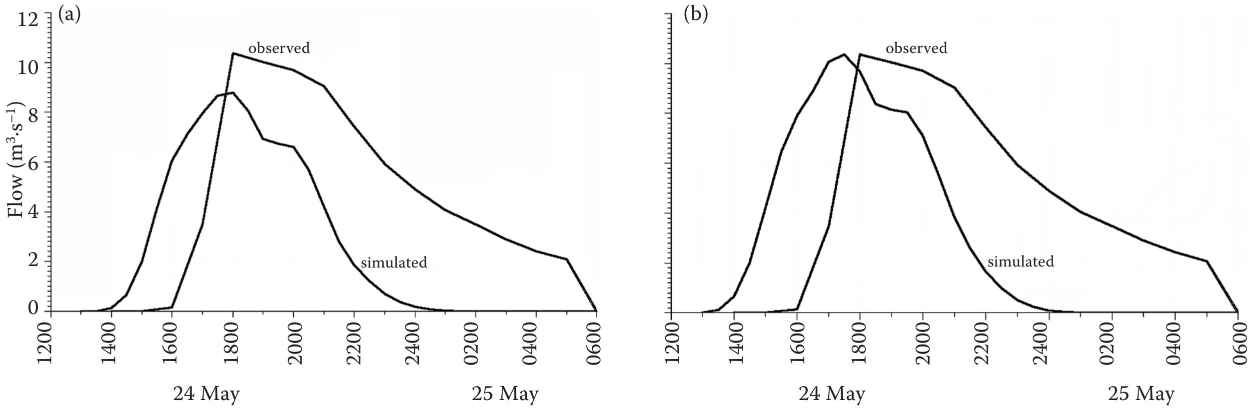

Fig. 3. Comparison of the simulated hydrograph by the model with the observed hydrographs, flood event: 24 May 1991 (a), and after optimizing the model (b)

in GIS environment for Kasilian watershed that were different in landuse score or *Xa* (forest converted to gardens and farms) and erosion was quantitatively and qualitatively investigated by these models. The results showed that landuse changes increased erosion intensity and erosion rate notably. The coefficient of erosion intensity (*Z*) is calculated by the following equation in this model:

$$Z = Y \times Xa\ (\Psi + I^{0.5}) \quad (4)$$

where:
Y – the susceptibility of rock and soil to erosion,
Xa – landuse coefficient,
Ψ – existence erosion coefficient,
I – mean sub-basin slope or study unit.

Also, the rate of soil erosion is calculated by the following equation in this model.

$$W_{SP} = T \times H \times \pi \times Z^{1.5} \quad (5)$$

where:
W_{SP} – the rate of soil erosion ($m^3 \cdot km^2 \cdot yr^{-1}$),
T – coefficient of temperature,
H – the mean annual precipitation (mm),
π – 3.14,
Z – erosion intensity.

The coefficient of temperature is calculated by the equation below:

$$T = (t/10 + 0.\ 1)^{0.5} \quad (6)$$

where:
t – the mean annual temperature.

The sediment production rate in the EPM model is calculated based on the ratio of eroded materials in each study unit of the stream to the total erosion in the watershed area (the equation below):

$$Ru = 4\ (P \times D)^{\frac{0.5}{L + 10}} \quad (7)$$

where:
Ru – coefficient of sedimentation,
P – the circumference of the watershed,
D – height difference in the watershed area (km),
L – watershed length (km).

After the calculation of *Ru* value, the special sediment rate is estimated by these equations:

$$G_{SP} = W_{SP} \times Ru \quad (8)$$

$$G_S = G_{SP} \times A \quad (9)$$

where:
G_{SP} – special sediment rate,
W_{SP} – the volume of special erosion,
Ru – coefficient of sedimentation,
G_S – total sediment rate ($m^3 \cdot yr^{-1}$),
A – total watershed area (km^2).

RESULTS

Comparing the simulated hydrograph by the model with the recorded hydrograph at Valicben hydrometric station for one or some of the events

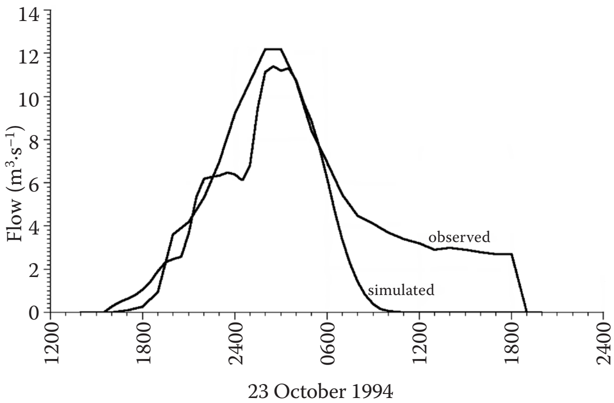

Fig. 4. Evaluating the hydrologic model of Kasilian watershed with comparison of the simulated hydrograph by the model and the recorded hydrograph at a hydrometric station.

Table 2. Landuse changes on the surface of Kasilian watershed during the last forty years

Year	Farming	Range-land	Forest	Residen-tial	Road (km)
	(ha)				
1967	1235.0	346.8	5396.1	74.99	50.2
2010	2143.6	346.8	4537.9	86.98	127.38

are shown in Fig. 5. Using the GIS abilities, the landuse changes have been investigated during the last forty years and their results are shown in Table 2. The rainfall of one of the previous events was considered for evaluating the influence of deforestation on the potential of runoff generation and flood hazard. The model was implemented only by changing the impervious land percent, the curve number changes (landuse and vegetation) and initial loss in different time frames and the influence of impervious land development, destroying of forests and changing them into agricultural lands on runoff generation and the peak discharge increase and flood volume were investigated. In fact, a rainfall was considered for the model in different time frames and only the changes resulting from landuse were applied in the model and their effects were investigated. The results from the influence of landuse changes on runoff generation, peak discharge and flood volume are presented in Table 3. Finally, the influence of the set of activities such as making

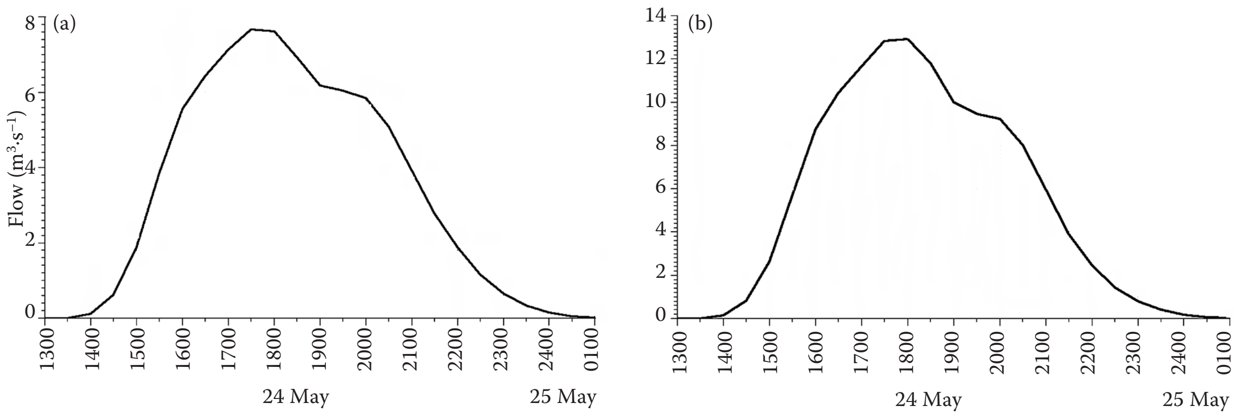

Fig. 5. The outlet hydrograph of Kasilian watershed with the rainfall 24 May 1991 in landuse conditions and road network and residential areas in 1967 (a), and (b) in 2010 (all of the model factors except landuse and impervious land percent were considered constantly)

before and after optimizing the model is shown in Fig. 3. The efficiency of the model was evaluated and confirmed after optimizing the model using the optimized model for simulating the outlet hydrograph of Kasilian watershed for six flood events. The comparison of the simulated hydrograph with the observed hydrograph of one of the events used for evaluating the model is shown in Fig. 4. The simulated hydrographs of two events

Table 3. Changes in peak discharge and runoff volume (rainfall 24 May 1994)

Year	Q_{max} ($m^3 \cdot s^{-1}$)	Runoff volume (m^3)	Runoff increasing (%)
Due to landuse changes			
1967	8.04	153,850	–
2010	11.11	197,190	28.1
Due to landuse changes and impervious surface development			
1967	9.01	167,920	–
1995	9.57	178,430	6.25
2010	10.05	188,710	12.38

Table 4. Changes in peak discharge and runoff volume in Kasilian watershed because of landuse changes and impervious surface development (rainfall 24 May 1994)

Year	Peak discharge ($m^3 \cdot s^{-1}$)	Runoff volume (m^3)	Runoff increase (%)
1967	7.67	147,440	–
2010	12.92	233,310	58.2

a road network, urban development, destroying of forests and changing them into agricultural areas were investigated and the results are presented in Table 4. The EPM model of Kasilian watershed has been provided twice (1960 and 2010 decades). The changes in erosion intensity and erosion rate on the surface of the study watershed are presented in Fig. 6

Table 5. Changes in sediment generation in Kasilian watershed during 40 years (in $t \cdot ha^{-1}$)

Erosion	1967	2001	2010
Model estimated	2.78	3.24	4.2
Observed at hydrometric station	2.85	3.16	4.4

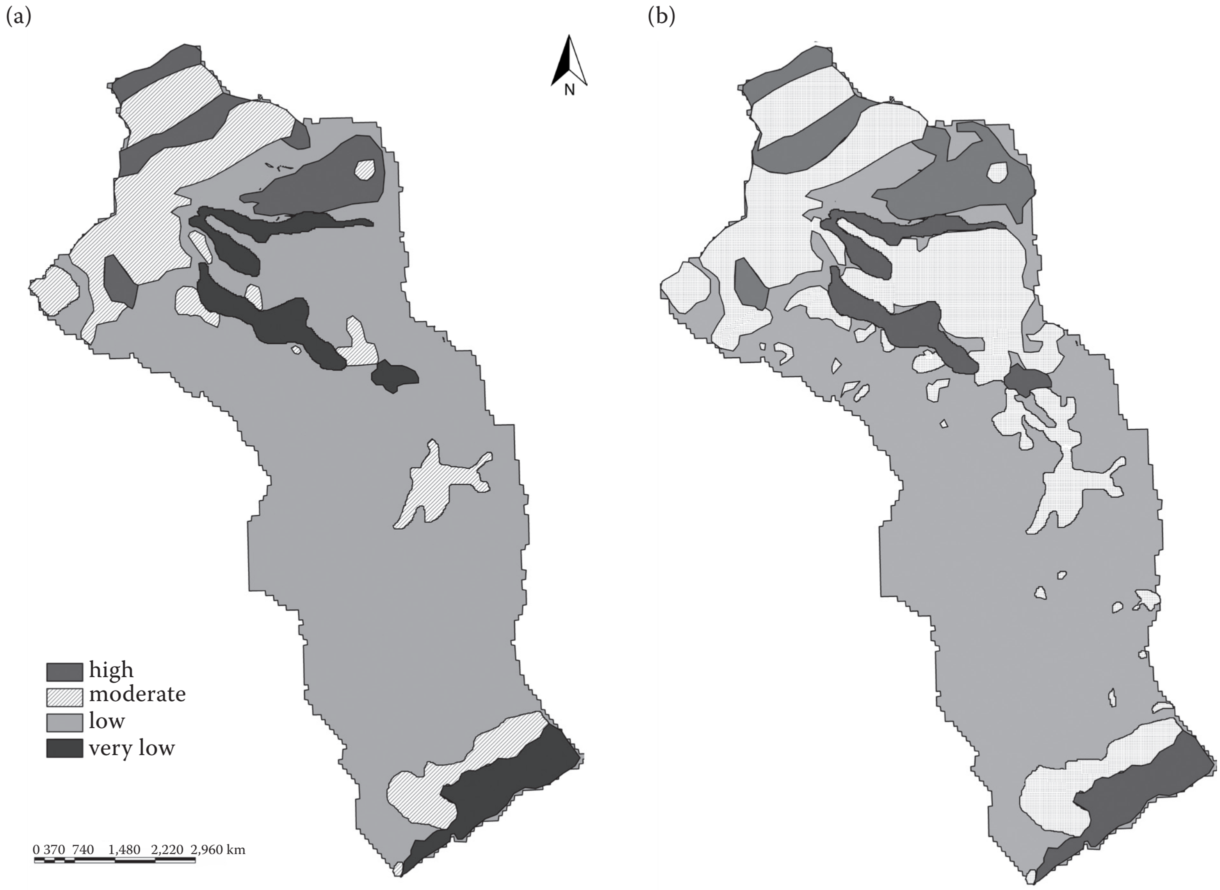

Fig. 6. The erosion intensity map of Kasilian watershed in 1967 conditions (a), and in 2010 conditions (b)

and in Table 5. The results revealed that the rate of generated sediment has increased twice in the Kasilian watershed within 40 years.

CONCLUSIONS

Deforestation has been accompanied by landuse changes, destroying of natural resources and urban development. Impervious area development on the surface of the watershed will include the increase in peak discharge and runoff volume of the watershed (Brilly et al. 2006; Pappas et al. 2008). Forests caused a reduction of runoff generation and flood hazard by increasing the permeability of soil and water-holding capacity of the watershed area (Wahl et al. 2005). Deforestation in the form of urban development and landuse changes caused to increase the hazard of flood events and watershed vulnerability to rainfalls and rain storms in terms of runoff generation and peak discharge when the increase in runoff generation and peak discharge is higher for heavier rainfalls (Camorani et al. 2005). Landuse changes have occurred in the northern part of the watershed which regarding the local situation of these landuse changes on the surface of the watershed, their influence on the peak discharge and the outlet runoff volume of the watershed has been greater than the influence of the impervious surface development. The research results have indicated a higher influence of urban development on the volume and peak discharge of the sub-basin areas or in surface unit (Brown 1988; Riley 1998). According to the results obtained from the research, the runoff generation potential has been increased approximately 60% for a rainfall event in Kasilian watershed due to deforestation on the surface of the watershed during forty years. Also, the runoff and sediment generation potential have been increased in Kasilian watershed due to deforestation during the last forty years. Field studies and modelling results showed that the rate of erosion and erosion intensity were increased in Kasilian watershed during 40 years. It is to note that the study area is a forest area with low population density which in comparison with other areas has been exposed to deforestation to a lesser extent and where the rate of runoff volume and peak discharge and finally intensifying flood hazard will be increased for heavier rainfalls and this process of the urban development and destroying of forest lands are being continued.

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