JOURNAL OF FOREST SCIENCE, *63*, 2017 (6): 245–253

doi: 10.17221/130/2016-JFS

The influence of deforestation and anthropogenic activities on runoff generation

*Mohammad Reza KHALEGHI**

Department of Watershed Management Engineering, Torbat-e-Jam Branch, Islamic Azad University, Torbat-e-Jam, Iran

**Corresponding author: drmrkhaleghi@gmail.com*

Abstract

Khaleghi M.R. (2017): The influence of deforestation and anthropogenic activities on runoff generation. J. For. Sci., 63: 245–253.

In recent decades, due to rapid human population increases and in its results, destructive effects of anthropogenic activities on natural resources have become a great challenge. Land use and vegetation are important factors in soil erosion and runoff generation. This study was performed to assess the effects of different amounts of forest cover on the control of runoff and soil loss in the Talar basin, which is located in Mazandaran province, using a runoff-rainfall model, geographical information system (GIS) and remote sensing (RS) to determine the hydrologic effects of deforestation on the Talar watershed (north of Iran). A runoff-rainfall model has been presented using GIS (HEC-GeoHMS) and hydrologic model (HEC-HMS). Land use changes (deforestation) and anthropogenic activities (roads and impervious surfaces development) were evaluated using RS techniques and satellite images. We used the Soil Conservation Service and Curve Number methods for hydrograph simulation and runoff estimation, respectively. First, a model was performed and optimized. Afterward, the optimized model was evaluated by other six events of floods (model validation). According to the obtained results, the runoff generation potential has been increased in the Talar watershed due to deforestation during the last forty years. Land use changes cause an increase in runoff volume and flood peak discharge.

Keywords: rainfall-runoff model; forest; sediment; land use; Talar watershed; Iran

In recent decades, due to rapid human population increases, destruction of forest lands and improper cultivation practices (land use changes) have been seriously degrading native forest ecosystems and have caused undesirable effects in the watershed hydrologic conditions. Intensive cultivation and land use mismanagement are important factors in soil erosion and runoff generation (Bahrami et al. 2010; Gholzom, Gholami 2012). Human activities have always been accompanied by changes in land structure, destruction of natural resources and urban development (Amouei et al. 2012; Yousefi et al. 2013; Khaleghi et al. 2014). Cosmopolitan area developments on the surface of the watershed will include the increase of peak discharge and runoff volume of the watershed (Jain, Sinha 2003; Burns et al. 2005; Brilly et al. 2006; Pappas et al. 2008; Gholami et al. 2009, 2010; Seifan 2009). Iran is the second largest country in the Middle East and almost 87% of the country' territory is located in arid and semi-arid regions (Khaleghi et al. 2011). Deforestation in Iran has been more rapid in the past 50 years than at any time in Iran's history and hence as a result of deforestation and land use mismanagement, soil degradation is the most serious and main environmental problem (Dooge 1959; Dagnachew et al. 2003; Zheng et al. 2005; Bahrami et al. 2010). Deforestation, poor agricultural measurement practices and the use of marginal lands for cultivation purposes are notable examples of measures being implemented (UNEP 2000; Eswaran et al. 2001; Liu et al. 2002;

Solomon 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. Therefore, it is necessary to prevent such deplorable events through managing the environment and natural resources. Also, it is imperative to understand both direct and indirect influence and also relative importance of human activities on runoff generation and consequently accelerated soil erosion, which is critical to the management of regional water resources. However, quantitative analysis and evaluation of the anthropogenic effects of human activities on runoff in rivers are still limited. On the other hand, in watershed planning and flood management, estimation of the maximum flood discharge is necessary for predicting the watershed hydrological behaviour. Flood management in a basin would not be successful unless watershed hydrological behaviours are predicted (Parise 2003; Bhadra et al. 2008; Khaleghi et al. 2011). Runoff production and its behaviour are a function of different types of land use and land use changes. The hydrological response of a river basin is a function of the relationship between basin geomorphology (catchments area, shape of basin, topography, channel slope, stream density and channel storage) and its hydrology (Loukas et al. 1996; Shamseldin, Nash 1998; Ajward, Muzik 2000; Nourani et al. 2009). In the Mediterranean region, there is a great deal of evidence to show that unreasonable land use and soil cover accelerate water erosion processes and consequently land degradation (Nunes et al. 2011). Different studies have indicated the positive effect of vegetation cover in the regulation of hydrological processes and decrease of runoff and soil loss (Liu et al. 2002; Dunjó et al. 2004; Kirkby et al. 2005; Morgan 2005; Wei et al. 2007; Qadir et al. 2008; Salehi et al. 2008; Seeger, Ries 2008; Yimer et al. 2008; Huang et al. 2010; Gholami, Khaleghi 2013). In the field of simulation of the hydrological behaviour of watersheds, Christopher et al. (2001) and Stone (2001) presented a runoff-rainfall model using geographical information system (GIS) and the Hydrologic Engineering Centre's Hydrologic Modelling System (HEC-HMS) software (Version 2.0.3, 1999). Their results indicated the ability of the method in the simulation of flood hydrograph of a watershed. Simulation of a rainfall-runoff process for estimating the runoff volume and the peak discharge value of watershed has been investigated by different hydrologists. Knowing the peak discharge value and the runoff volume of a watershed has a crucial role in managing natural disasters and designing and constructing water structures. Therefore, different methods have been developed. Each of these methods has their own merits and demerits. Lack or low accuracy of rain data, high cost, lack of information in catchments and long waiting time in obtaining results are the major problems in hydrological prediction (Wang, Chen 1996; Maheepala et al. 2001; Vaes et al. 2001; Lopez et al. 2005; Vahabi, Ghafouri 2009). The Soil Conservation Service (SCS) curve number method, developed by the SCS of the United States Department of Agriculture (USDA) is widely used for predicting direct runoff volume for a given rainfall event and also for runoff simulations, and can be used for studying the effect of human activities on runoff (Soulis et al. 2009; Wang et al. 2009). The main reason for the selection of SCS method is that it accounts for many of the factors affecting runoff generation and hence describes the effects of land use/cover change on the hydrological process (Wang et al. 2009). Many studies have been carried out on the efficiency of SCS method as an artificial unit hydrograph (Gupta et al. 1980; Snyder et al. 2002; Jeng, Coon 2003; Geetha et al. 2008; Moretti, Montanari 2008; Singh et al. 2008; Tyagi et al. 2008; Soulis et al. 2009). Due to the widespread use and general acceptance of the Soil Conservation Service-Curve Number (SCS-CN) method, its applicability was investigated in various regions and for various land uses and climate conditions, while CN values were obtained experimentally from the Antecedent Moisture Conditions including rainfall and runoff measurements over a wide range of geographic, soil, and land management conditions (King, Balogh 2008; Soulis et al. 2009).

The main objective of this study is to investigate the fundamental mechanism for the generation of surface runoff, as well as to analyse the SCS-CN method applicability in the Talar watershed with regard to deforestation and subsequent intensive cultivation in different time spans in Mazandaran province, north of Iran. Therefore, the results enable a better understanding of different aspects of the human-induced soil degradation and the sustainable use of soil in the future.

MATERIAL AND METHODS

Study area. Talar watershed, the area of which is about 68 km^2, is located in the northern part of Iran, within the limits of eastern longitude 53°18' to

53°30' and northern latitude 35°58' to 35°07' in the eastern part of Mazandaran province (Fig. 1). The climate of the zone is semi-humid and cold and its average annual precipitation is 791 mm and the average temperature is 11°C. The average, maximum and minimum height of the watershed is 1,672, 3,349 and 1,120 m a.s.l., respectively. The average slope of the watershed, the average slope of the main channel and the length of the main channel are 15.8%, 13% and 16.5 km, respectively. There is a hydrometer station at the outlet of the watershed and a rainfall recorder station upstream of it.

Methodology. We used different satellite images for evaluating land use changes in the study area. Landsat Thematic Mapper and Enhanced Thematic Mapper Plus (ETM^+) images and remote sensing (RS) techniques were used to evaluate land use changes during about forty years (1967–2015). The land use maps of the watershed surface were applied using the curve number changes in Antecedent Moisture Conditions (AMC) II. In the next step, the influence of these changes on intensifying runoff generation on the surface of Talar watershed was studied quantitatively using a runoff-rainfall model. HEC-HMS was used for presenting the runoff-rainfall model. The physical model of the watershed was simulated using the Geospatial Hydrologic Modelling Extension (HEC-GeoHMS), extension in ArcGIS (Version 10.2, 2013) environment, and the digital elevation model when the surface of the watershed was divided into 32 small sub-basin areas. The implications of urbanization on runoff processes depend on the scale of the watershed area and magnitude of urban development. Small-sized river basins, which are densely urbanized, 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 secondary data of the rainfall of Sangdeh rain recorder station and the flood hydrograph of the Valicben hydrometric station and six rainfall events in 2004–2015 were applied for presenting the model (Table 1).

The method of hydrograph synthesis employed by the SCS of the USDA uses an average number of natural unit hydrographs for watersheds varying widely in size and geographical locations (Chow et al. 1988; Nourani et al. 2009). For the current

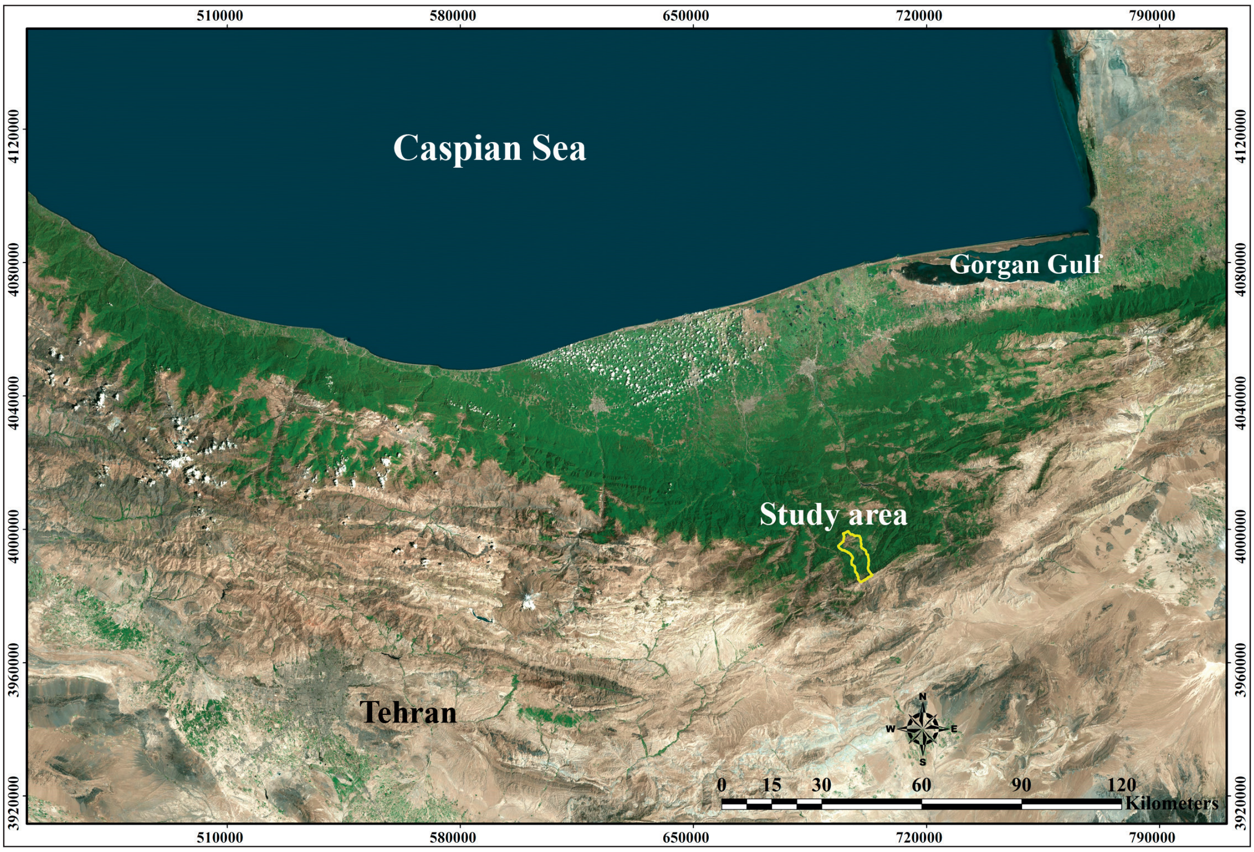

Fig. 1. The location of the study area (Talar catchment)

Table 1. Six rainfall events and the observed peak discharges have been used for modelling and optimizing the model

Event	Q_{max} ($m^3 \cdot s^{-1}$)	
	observed	simulated
August 11, 2004	10.30	10.28
May 8, 2007	9.36	9.20
September 15, 2011	11.70	11.50
May 26, 2013	7.80	7.70
October 5, 2014	12.20	11.90
September 17, 2015	1.56	1.52

Q_{max} – maximum flood discharge

analysis, all the storm events producing significant direct runoff that took place from August 2004 to September 2015 were used (6 events).

In the SCS model (flood hydrograph simulation), the lag time (flood routing method), t_l, shall be determined using watershed physical properties, such as area, main river length, average slope, CN, afterward the synthetic unit hydrograph can be computed. Curve number (runoff estimation method) is estimated with respect to land use and soil hydrological group maps in different AMC (dry, average and moist) and hydrological conditions. Initial losses (S, mm) including the whole interception, infiltration, transmission in the soil and surface are calculated as Eq. 1:

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

Runoff (Q, mm) calculation is given below as Eq. 2 taking values from 0, when $S => \infty$, to 100, when $S = 0$:

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

where:

P – maximum precipitation in 24 h (mm).

After calculating runoff due to a rain storm, the maximum flood discharge (Q_{max}, $m^3 \cdot s^{-1}$) was calculated (Eq. 3):

$$Q_{max} = \frac{2.083AQ}{t_p} \tag{3}$$

where:

A – basic area (km^2),

Q – runoff (mm),

t_p – time of flood crest which is evaluated by the time of concentration (t_c) in a minute.

Rainfall was simulated in 30 min increments on the watershed surface (based on the secondary data of rain gauge station). 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 Talar watershed, changes in land use (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 rainfall intensity on the whole watershed surface. At last, 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. Man's activities were evaluated based on the development of roads and impervious surface during the study period. We performed the modelling process using the secondary data of rainfall and flood hydrograph. Afterward, the model was optimized and validated. Finally, the validated model was used to evaluate the effects of land use changes on runoff generation (value and volume). The changes in CN and initial loss were used to evaluate the effects of land use change in the model. The percent of impervious areas was applied as criteria for man's activities in the model.

RESULTS

Ten flood events were used for modelling the rainfall-runoff process. Six of them were used for modelling and the others for model validation. Two land use maps for the years 1967 and 2015 were provided. The land use maps show the changes in forest areas during the study period (Fig. 2). Table 1 presents the information on the rain intensity of Sangdeh rain recorder station and the flood hydrograph of the Valicben hydrometric station and six rainfall events in 2004–2015.

The efficiency of the model was evaluated and confirmed after optimizing the model using the optimized model for simulating the outlet hydrograph of Talar 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. 3. The simulated hydrographs of two events are shown in Fig. 4. Using the GIS abilities, the land use changes have been investigated during the last forty years and their results are shown in Table 2.

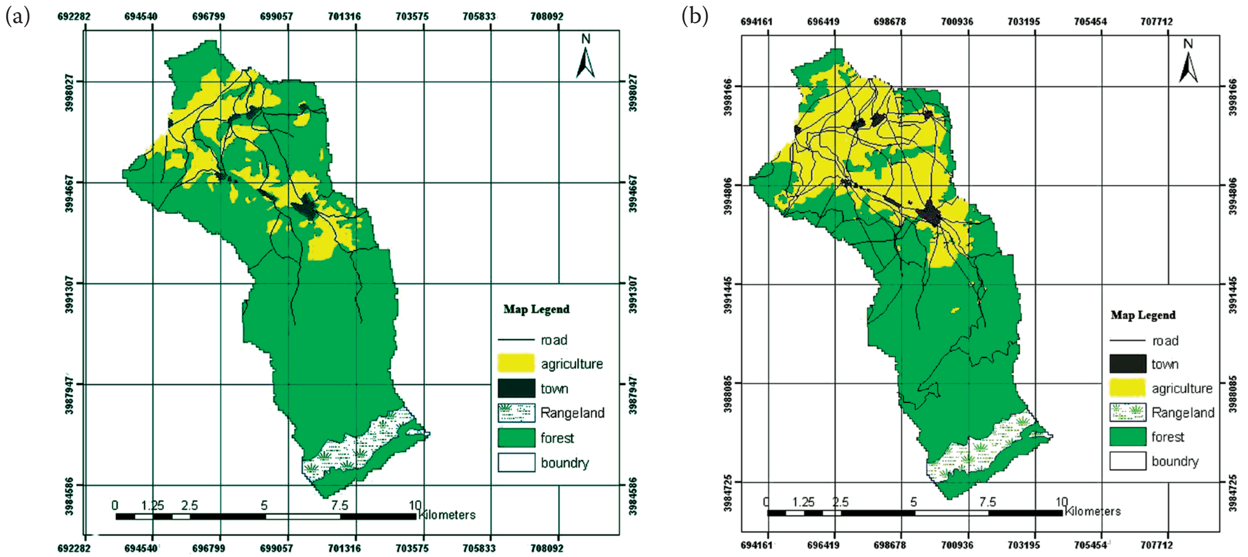

Fig. 2. Land use maps in 1967 (a), 2016 (b)

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 (land use and vegetation) and initial loss in different time frames and the influence of impervious land development, destruction 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 land use were applied in the model and their effects were investigated. The results from the influence of land use 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 a road network, urban development, destruction of forests and changing them into agricultural areas was investigated and the results are presented in Table 4.

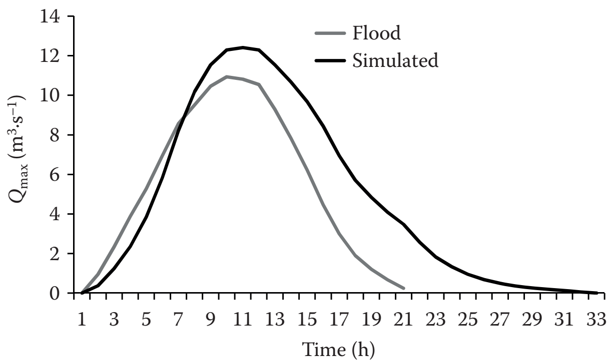

Fig. 3. Evaluating the hydrologic model of Talar watershed by a comparison of the simulated hydrograph by the model and the recorded hydrograph at a hydrometric station

Q_{max} – maximum flood discharge

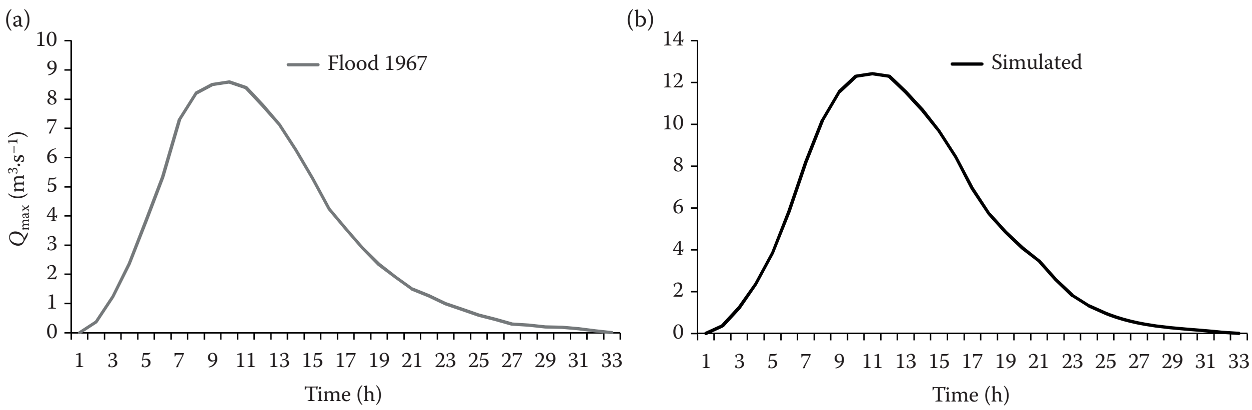

Fig. 4. The outlet hydrograph of Talar watershed with the rainfall May 24, 1991 in land use conditions and road network and residential areas in 1967 (a), 2016 (b), all of the model factors except land use and impervious land percent were considered constantly

Q_{max} – maximum flood discharge

Table 2. Land use changes on the surface of Talar watershed during the last 48 years

Year	Land use				
	farming (ha)	rangeland (ha)	forest (ha)	residential (ha)	road (km)
1967	1,235.0	346.8	5,396.1	74.99	50.2
2016	2,143.6	346.8	4,537.9	86.98	127.38

Comparing the simulated hydrograph by the model with the recorded hydrograph at Valicben hydrometric station for one or some of the events before and after optimizing the model is shown in Fig. 5.

DISCUSSION

The Talar watershed was selected for this study because as a forest area and also an area with low population density, it has been less exposed to destruction and land use changes in comparison with other places in Iran. But even in such watersheds, deforestation has been accompanied by land use changes, destruction of natural resources and urban development. Anthropogenic effects and man's activities, in the form of urban development and land use changes, have increased the hazard of flood events and watershed vulnerability to rainfalls and rain storms concerning runoff generation and peak discharge. Increasing runoff generation and peak discharge will be more drastic after heavier rainfalls (Camorani et al. 2005). In the case of outlet runoff values, not all tested methods possess high agreement with the observed hydrograph. Forests caused a reduction of runoff generation and flood hazard by increasing the permeability of the soil and water-holding capacity of the watershed

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

Year	Q_{max} ($m^3 \cdot s^{-1}$)	Runoff volume (m^3)	Runoff increase (%)
Due to land use changes			
1967	8.04	153.85	–
2010	11.11	197.19	28.1
Due to land use changes and impervious surface development			
1967	9.01	167.92	–
1995	9.57	178.43	6.25
2010	10.05	188.71	12.38

Q_{max} – maximum flood discharge

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

Year	Q_{max} ($m^3 \cdot s^{-1}$)	Runoff volume (m^3)	Runoff increase (%)
1967	7.67	147.77	–
2010	12.92	233.31	58.2

Q_{max} – maximum flood discharge

area (Wahl et al. 2005). But the 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). On the other hand, the influence of urban development has been much more remarkable on the surface of the sub-basin areas which have undergone considerable impervious surface development. Land use changes have occurred in the northern part of the watershed which regarding the local situation of these land use changes on the surface of the watershed, their influence on the peak discharge and the outlet runoff volume of the

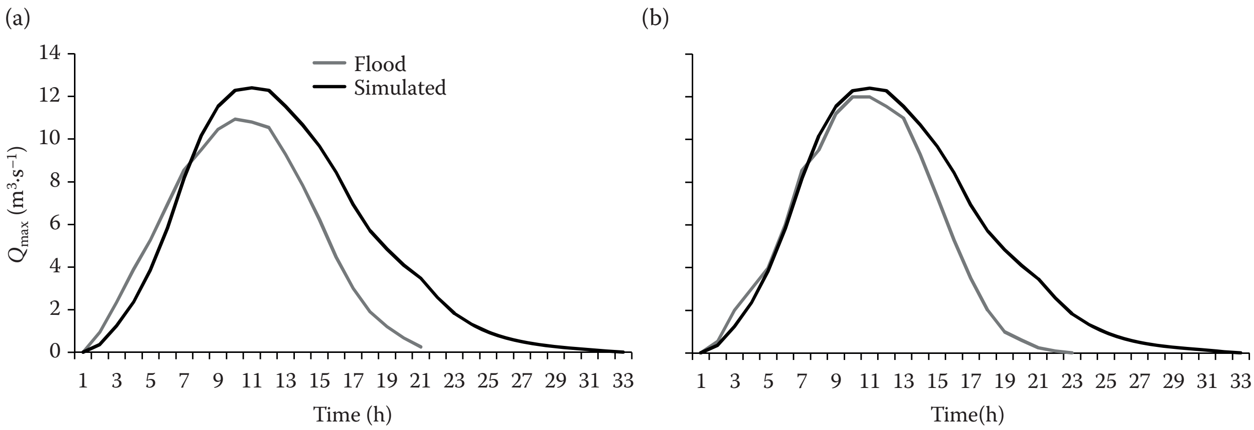

Fig. 5. Comparison of the simulated hydrograph by the model with the observed hydrographs for a flood event on May 24, 1991 (a), and after optimizing the model (b)

Q_{max} – maximum flood discharge

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 the surface unit (Brown 1988; Riley 1998). According to the results obtained from the research, the runoff generation potential has been increased by approximately 60% for a rainfall event in Talar watershed due to deforestation on the surface of the watershed during forty years. Also, the runoff and sediment generation potential has been increased in Talar watershed due to deforestation during the last forty years. Unfortunately, the process of land use change and forest destruction is to be continued in northern Iran. Moreover, climate changes will affect the forest growth in the study area (Gholami et al. 2017). Therefore, we will observe undesired conditions of the forest areas in northern Iran due to an increase in runoff generation and flood hazard.

The purpose of this study was to evaluate the effects of human activities on runoff generation and flood hazard. This goal has been achieved by the use of GIS, RS and HEC-HMS model. It is to note that the study area is a forest area with the 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 by heavier rainfalls and this process of the urban development and destruction of forest lands is being continued. The runoff generation potential increases throughout soil compaction and land use changes. Moreover, runoff increases during the stronger rainfall. Hence, land use management and forest conservation practices should be considered for the study area. Therefore, afforestation projects are suggested to control the flood hazard and to decrease the runoff generation potential.

Acknowledgement

The authors would like to thank the Mazandaran Regional Water Company and TAMAB (Researches Organization of Water Resources) for providing the data on rainfall, flood hydrograph and for helping us with data preprocessing.

References

Ajward M.H., Muzik I. (2000): A spatially varied unit hydrograph model. Journal of Environmental Hydrology, 8: 1–8.

Amouei A.I., Yousefi Z., Mahvi A.H., Naddafi K., Tahmasbizadeh M. (2012): Heavy metal concentrations in industrial, agricultural, and highway soils in northern Iran. Environmental Justice, 5: 153–157.

Bahrami A., Emadodin I., Ranjbar Atashi M., Rudolf Bork H. (2010): Land-use change and soil degradation: A case study, North of Iran. Agriculture and Biology Journal of North America, 1: 600–605.

Bhadra A., Panigrahy N., Singh R., Raghuwanshi N.S., Mal B.C., Tripathi M.P. (2008): Development of a geomorphological instantaneous unit hydrograph model for scantily gauged watersheds. Environmental Modelling & Software, 23: 1013–1025.

Brilly M., Rusjan S., Vidmar A. (2006): Monitoring the impact of urbanization on the Glinscica stream. Physics and Chemistry of the Earth, 31: 1089–1096.

Brown R.G. (1988): Effects of precipitation and land use on storm runoff. Water Resources Bulletin, 24: 421–425.

Burns D., Vitvar T., McDonnell J., Hassett J., Duncan J., Kendall C. (2005): Effects of suburban development on runoff generation in the Croton River basin, New York, USA. Journal of Hydrology, 311: 266–281.

Camorani G., Castellarin A., Brath A. (2005): Effects of land-use changes on the hydrologic response of reclamation systems. Physics and Chemistry of the Earth, 3: 561–574.

Chow V.T., Maidment D.R., Mays L.W. (1988): Applied Hydrology. NewYork, McGraw-Hill: 572.

Christopher A., Johnson A., Yung A.C. (2001): The Use of HEC-GeoHMS and HEC-HMS to Perform Grid-based Hydrologic Analysis of a Watershed. Houston, Dodson & Associates, Inc.: 4.

Dagnachew L., Vallet C., Gasse F. (2003): Hydrological response of a catchment to climate and land use changes in Tropical Africa: Case study South Central Ethiopia. Journal of Hydrology, 275: 67–85.

Dooge J.C.I. (1959): A general theory of the unit hydrograph theory. Journal of Geophysical Research, 64: 241–256.

Dunjó G., Pardini G., Gispert M. (2004): The role of land use-land cover on runoff generation and sediment yield at a micro plot scale, in a small Mediterranean catchment. Journal of Arid Environments, 57: 239–256.

Eswaran H., Lal R., Reich P.F. (2001): Land degradation: An overview. In: Bridges E.M., Hannam I.D., Oldeman L.R., Pening de Vries F.W.T., Scherr S.J., Sompatpanit S. (eds): Responses to Land Degradation. Proceeding of the 2nd International Conference on Land Degradation and Desertification, Khon Kaen, Jan 25–29, 1999: 20–35.

Foster I., Gurnell A., Webb B. (1995): Sediment and Water Quality in River Catchments. Chichester, John Wiley & Sons: 473.

Geetha K., Mishra S.K., Eldho T.I., Rastogi A.K., Pandey R.P. (2008): SCS-CN-based continuous simulation model for hydrologic forecasting. Water Resources Management, 22: 165–190.

Gholami V., Khaleghi M.R. (2013): The impact of vegetation on the bank erosion (case study: The Haraz River). Soil and Water Research, 8: 158–164.

Gholami V., Ahmadi Jolandan M., Torkaman J. (2017): Evaluation of climate change in northern Iran during the last four centuries by using dendroclimatology. Natural Hazards, 85: 1835–1850.

Gholami V., Mohseni Saravi M., Ahmadi H. (2010): Effects of impervious surfaces and urban development on runoff generation and flood hazard in the Hajighoshan watershed. Caspian Journal of Environmental Sciences (CJES), 8: 1–12.

Gholami V., Jokar E., Azodi M., Zabardast Rostami H., Bashirgonbad M. (2009): The influence of anthropogenic activities on intensifying runoff generation and flood hazard in Kasilian watershed. Journal of Applied Sciences, 9: 3723–3730.

Gholzom E.H., Gholami V. (2012): A comparison between natural forests and reforested lands in terms of runoff generation potential and hydrologic response (case study: Kasilian watershed). Soil and Water Research, 7: 166–173.

Gupta V.K., Waymire E., Wang C.T. (1980): A representation of an instantaneous unit hydrograph from geomorphology. Water Resources Management, 16: 855–862.

Huang Z., Ouyang Z., Li F., Zheng H., Wang X. (2010): Response of runoff and soil loss to reforestation and rainfall type in red soil region of southern China. Journal of Environmental Sciences, 22: 1765–1773.

Jain V., Sinha R. (2003): Derivation of unit hydrograph from GIUH analysis for a Himalayan river. Water Resources Management, 17: 355–376.

Jeng R.I., Coon C.G. (2003): True form instantaneous unit hydrograph of linear reservoirs. Journal of Irrigation and Drainage Engineering, 129: 11–17.

Khaleghi M.R., Ghodusi J., Ahmadi H. (2014): Regional analysis using the Geomorphologic Instantaneous Unit Hydrograph (GIUH) method. Soil and Water Research, 9: 25–30.

Khaleghi M.R., Gholami V., Ghodusi J., Hosseini H. (2011): Efficiency of the geomorphologic instantaneous unit hydrograph methods in flood hydrograph simulation. Catena, 87: 163–171.

King K.W., Balogh J.C. (2008): Curve numbers for golf course watersheds. Transactions of the ASAE, 51: 987–996.

Kirkby M.J., Bracken L.J., Shannon J. (2005): The influence of rainfall distribution and morphological factors on runoff delivery from dry land catchments in SE Spain. Catena, 62: 136–156.

Liu S.L., Fu B.J., Lü Y.H., Chen L.D. (2002): Effects of reforestation and deforestation on soil properties in humid mountainous areas: A case study in Wolong Nature Reserve, Sichuan province, China. Soil Use and Management, 18: 376–380.

Lopez V., Napolitano F., Russo F. (2005): Calibration of a rainfall-runoff model using radar and rain gauge data. Advances in Geosciences, 2: 41–46.

Loukas A., Quick M.C., Russell S.O. (1996): A physically based stochastic-deterministic procedure for the estimation of flood frequency. Water Resources Management, 10: 415–437.

Maheepala U.K., Takyi A.K., Perera B.J.C. (2001): Hydrological data monitoring for urban storm water drainage systems. Journal of Hydrology, 245: 32–47.

Maksimovic C., Tucci C.E.M. (2001): Urban Drainage in Specific Climates: Urban Drainage in Humid Tropics. Paris, UNESCO: 227.

Moldan B., Cerny J. (1994): Biochemistry of Small Catchments – a Tool for Environmental Research. Chichester, John Wiley & Sons: 419.

Moretti G., Montanari A. (2008): Inferring the flood frequency distribution for an ungauged basin using a spatially distributed rainfall-runoff model. Hydrology and Earth System Sciences, 12: 1141–1152.

Morgan R.P.C. (2005): Soil Erosion and Conservation. 3rd Ed. Oxford, Wiley-Blackwell: 316.

Nourani V., Singh V.P., Delafrouz H. (2009): Three geomorphological rainfall-runoff models based on the linear reservoir concept. Catena, 76: 206–214.

Nunes A.N., de Almeida A.C., Coelho C.O.A. (2011): Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. Applied Geography, 31: 687–699.

Pappas E.A., Smith D.R., Huang C., Shuster W.C., Bonta J.V. (2008): Impervious surface impacts to runoff and sediment discharge under laboratory rainfall simulation. Catena, 72: 146–152.

Parise M. (2003): Flood history in the karst environment of Castellana-Grotte (Apulia, southern Italy). Natural Hazards and Earth System Sciences, 3: 593–604.

Qadir M., Qureshi A.S., Cheraghi S.A.M. (2008): Extent and characterization of salt-affected soils in Iran and strategies for their amelioration and management. Land Degradation & Development, 19: 214–227.

Riley A.L. (1998): Restoring Streams in Cities: A Guide for Planners, Policymakers and Citizens. Washington, D.C., Island Press: 445.

Rodríguez-Iturbe I., Valdes J. (1979): The geomorphologic structure of hydrologic response. Water Resources Research, 15: 1409–1420.

Rodríguez-Iturbe I., Sanabira M.G., Caamaño G. (1982): On the climatic dependence of the IUH: A rainfall-runoff analysis of the Nash model and the geomorphoclimatic theory. Water Resources Research, 18: 887–903.

Salehi A., Wilhelmsson E., Söderberg U. (2008): Land cover changes in a forested watershed, southern Zagros, Iran. Land Degradation & Development, 19: 542–553.

Seeger M., Ries J.B. (2008): Soil degradation and soil surface process intensities on abandoned fields in Mediterranean mountain environments. Land Degradation & Development, 19: 488–501.

Seifan M. (2009): Long-term effects of anthropogenic activities on semi-arid sand dunes. Journal of Arid Environments, 73: 332–337.

Shamseldin A.Y., Nash J.E. (1998): The geomorphological unit hydrograph – a critical review. Hydrology and Earth System Sciences, 2: 1–8.

Singh P.K., Bhunya P.K., Mishra S.K., Chaube U.C. (2008): A sediment graph model based on SCS-CN method. Journal of Hydrology, 349: 244–255.

Snyder N.P., Whipple K.X., Tucker G.E., Merritts D.J. (2002): Interactions between onshore bedrock-channel incision and near-shore wave base erosion forced by ecstasy and tectonics. Basin Resources, 14: 105–127.

Solomon H. (2005): GIS-based Surface Runoff Modeling and Analysis of Contributing Factors: A Case Study of Nam Chun Watershed, Thailand. Enschede, International Institute for Geo-information Science and Earth Observation (ITC): 110.

Soulis K.X., Valiantzas J.D., Dercas N., Londra P.A. (2009): Investigation of the direct runoff generation mechanism for the analysis of the SCS-CN method applicability to a partial area experimental watershed. Hydrology and Earth System Sciences, 13: 605–615.

Stone B.S. (2001): Geospatial database and preliminary flood hydrology model for the Lower Colorado Basin. [MSc Thesis.] Austin, University of Texas at Austin: 173.

Tyagi J.V., Mishra S.K., Singh R., Singh V.P. (2008): SCS-CN based time-distributed sediment yield model. Journal of Hydrology, 352: 388–403.

UNEP (2000): Global Environment Outlook. Paris, United Nations Environment Programme: 12.

Vaes G., Willems P., Berlamont J. (2001): Rainfall input requirements for hydrological calculations. Urban Water Journal, 3: 107–112.

Vahabi J., Ghafouri M. (2009): Determination of runoff threshold using rainfall simulator in the Southern Alborz Range Foothill – Iran. Research Journal of Environmental Sciences, 3: 193–201.

Wahl N.A., Wöllecke B., Bens O., Hüttl R.F. (2005): Can forest transformation help reducing floods in forested watersheds? Certain aspects of soil hydraulics and organic matter properties. Physics and Chemistry of Earth, 30: 611–621.

Wang G.T., Chen S. (1996): A linear spatially distributed model for a surface rainfall-runoff system. Journal of Hydrology, 185: 183–198.

Wang G., Xia J., Chen J. (2009): Quantification of effects of climate variations and human activities on runoff by a monthly water balance model: A case study of the Chaobai River basin in northern China. Water Resources Research, 45: 1–12.

Wei W., Chen L.D., Fu B.J. (2007): The effect of land uses and rainfall regimes on runoff and soil erosion in the semi-arid loess hilly area, China. Journal of Hydrology, 335: 247–258.

Yimer F., Messing I., Ledin S., Abdelkadir A. (2008): Effects of different land-use types on infiltration capacity in a catchment in the highlands of Ethiopia. Soil Use and Management, 24: 344–349.

Yousefi Z., Amouei A.I., Tahmasbizadeh M. (2013): Effect of chemical additives on availability of heavy metals (Pb, Cd and Zn) of soil. Asian Journal of Chemistry, 25: 6496–6498.

Zheng F., He X., Gao X., Zhang C., Tang K. (2005): Effects of erosion patterns on nutrient loss following deforestation on the Loess Plateau of China. Agriculture Ecosystems and Environment, 108: 85–97.

Received for publication November 25, 2016
Accepted after corrections April 10, 2017
Published online May 24, 2017