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[Research]

Effects of impervious surfaces and urban development on runoff generation and flood hazard in the Hajighoshan watershed

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ABSTRACT
Urbanization is a pervasive global trend. The development of residential areas and road network in Hajighoshan watershed (northern Iran) has been observed in the recent several decades. The objective of this study is the quantitative investigation of the effects of impervious surfaces development and urban development on runoff generation and flood hazard. The study of urban area development was carried out using aerial photos, topographic maps and satellite images. Also a rainfall-runoff model was presented using GIS (HEC-GeoHMS extension) and HEC-HMS model. Then, the model was optimized with initial loss and SCS-Lag parameters. The optimized model was evaluated using the other 4 events of flood .In the next stage, the development of impervious surfaces was included in the validated hydrologic model and their effects on intensifying runoff generation and flood hazard was investigated quantitatively during the recent forty years. The results showed that the runoff generation potential has increased in Hajighoshan watershed because of urban development during forty years ago.

Keywords: *Urban, Road network, Runoff, HEC-HMS, Hajighoshan watershed.*

1. INTRODUCTION
The urban areas are complex systems, resulting from different land uses, development densities and proportions of the watershed land cover. Nearly, half of the world population resides in urban areas. Destruction of forests and range lands and changing them into residential lands has been noticeable particularly in the northern part of Iran because of the urban development of human societies. The growth process of urban societies all over the world has increased and it is predicted that it will be increased up to 60% in the year 2030 (Katz & Bradley 2001). The effects of suburban development has been characterized in several studies; increased flood frequencies in areas with impervious surfaces were reported in the late 1960s and early 1970s (Pappas et al. 2007; Seaburn 1969 and Anderson 1970). More recent studies have focused on the effects of engineered aspects of watersheds, (e.g. detention basins, riparian buffers and septic systems) on runoff volume and water quality (Booth et al. 2002; Chin & Gregory 2001; Griffin 1995 and Robertson et al.1991). Cosmopolitan area growth and population increase have been accompanied by the destruction of forests and range lands (Katz & Bradley 1999) whose undesired effects are 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 (Burns et al. 2005; Hirsch et al. 1990; McCuen 1998 and Ros & Peters 2001). Unfortunately, population increase process, anomalous and incorrect

use of natural resources in the northern part of Iran has continued and its consequence has been the occurrence of the recent floods in the northern part of Iran. Therefore, it is necessary to prevent such deplorable events by managing environment and natural resources. In the field of simulation of hydrologic behavior of watersheds, Christopher et al. (1998) and Stone (2001) presented a rainfall-runoff model by using GIS (Geographic Information System) and the HEC-HMS model. Their results proved the ability of this method in simulation of flood hydrograph of a watershed. The research has been carried out to investigate the influence of impervious surfaces development (urban development and road network) on intensifying runoff generation and flood hazard in the surface of Hajighoshan watershed (Golestan Province) during the recent forty years.

2. MATERIALS AND METHODS

Hajighoshan watershed has an area of about 2000 km^2 located in the northern part of Iran (Golestan Province) within the limits of eastern longitude 55˚ 20´ to 56˚ 05´ and northern latitude 37˚ 23´ to 37˚ 47´ (Fig1 and 2). The length of its main river is about 92 km. The maximum and minimum elevations are 80 and 2180 m respectively. Hajighoshan watershed contains poor range lands and dry farming terrains and a small part of the watershed is sparse forest. The climate of the zone is semi-humid and the total precipitation changes from 400 to 700 mm in the different places of the watershed. An extensive loss terrain in the watershed is observed.

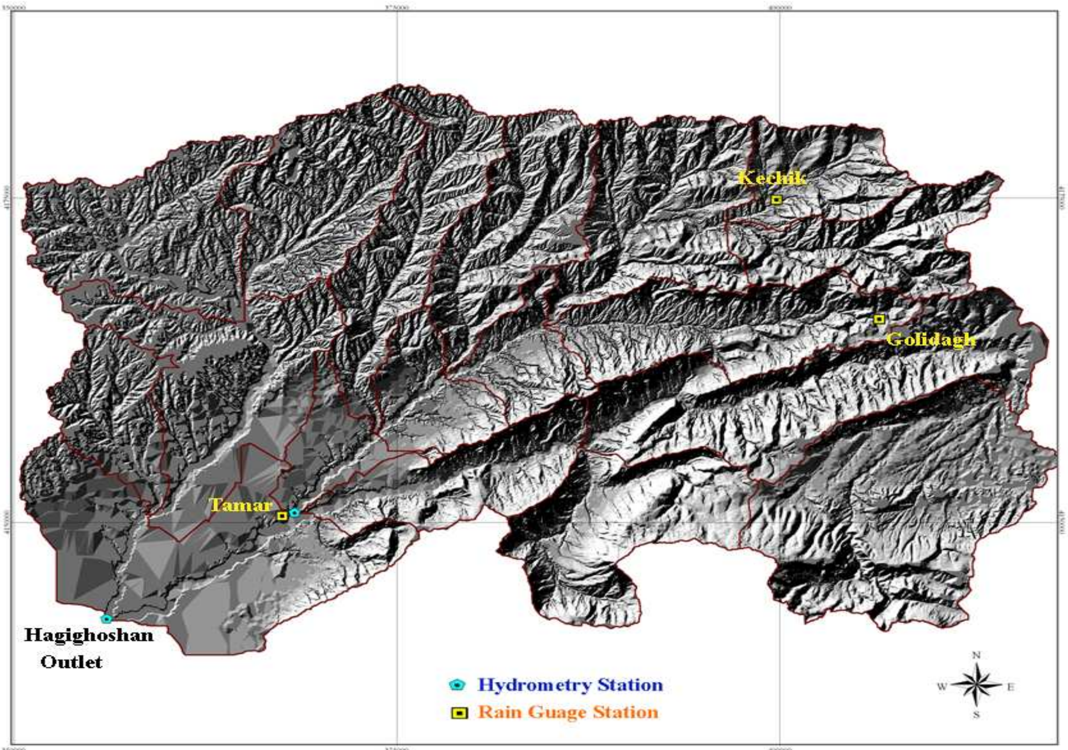

Fig. 1. Hajighoshan watershed, channels network and the study sub-basin areas.

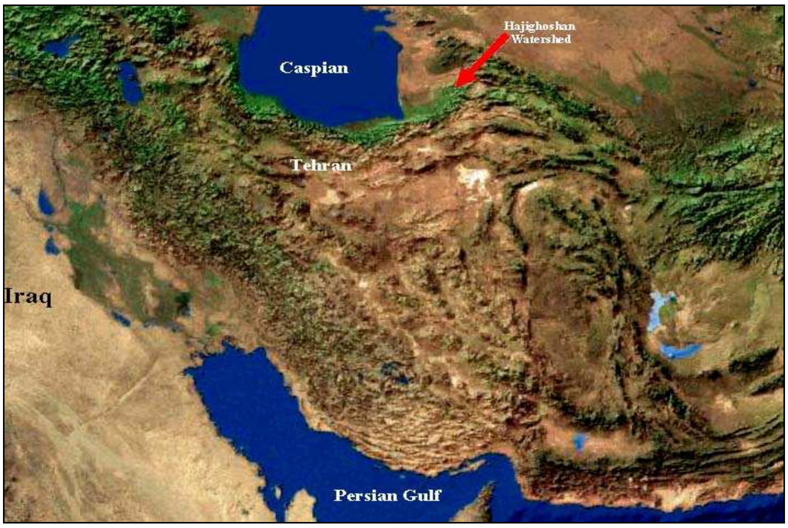

Fig. 2. The location of Hajighoshan watershed in Iran.

In this study, the growth process of residential areas and road network in different time frames has been studied using GIS and RS (Remote Sensing). The aerial photos of the year 1967, topographic maps 1:25000 of the year 2002 and IRS-PAN (2004) and Quickbird (2007) satellites images have been used for investigating the growth process of residential areas and road network during the recent forty years. The growth process of the residential areas, services of installation equipments and asphalt road network have been investigated by using these data. A sample of growth rate on the surface of Hajighoshan watershed (Tamar sub-basin) and the quantitative rate of these changes have been presented in Table 1, respectively. In the next step, the influence rate of these changes on intensifying runoff generation on the surface of Hajighoshan watershed has been studied quantitatively using a rainfall-runoff model. The hydrologic model (HEC-HMS) has been used for presenting the rainfall-runoff model. The physical model of the watershed has been simulated using the HEC-GeoHMS extension in GIS medium (Arcview) and the Digital Elevation Model (DEM 10m). For the surface of the watershed was divided into 23 small sub-basins. The simulated physical model of the watershed (using DEM and HEC-GeoHMS) entered into the HEC-HMS software medium. The information of three raingauge stations (Kechik, Golidagh and Tamar stations) and two hydrometric stations (Tamar, Hajighoshan) were gathered. Rainfall is simulated in the ways of incremental (15min) according to the affected area of three raingauge stations in the watershed surface (Fig.3). The affected surface of the three rain gauge stations was defined by Thiessen method. Sub-basins surface of the watershed were defined according to the affected surface of rain gauge stations. In fact, sub-basins separation has been done in a manner that their borders conform with the affected surface of the rain gauge stations. Five flood events in 2004-2007 were applied for presenting the model. The SCS method, curve number method and lag method have been used for simulating flood hydrograph, estimating the runoff high and the flood routing in channels, respectively. Curve number determination with respect to land use and soil hydrological groups maps in different antecedent moisture conditions (dry,average and moist)and hydrological conditions. Losses estimation, is the whole interception, infiltration, transmission in the soil and surface (in mm). Runoff calculation is given below:

$$S = \frac{25400}{CN} - 254 \qquad (1)$$

It is done through following formula (2):

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

Q = Runoff (mm)
S = Losses (mm)
P = Maximum precipitation in 24 h(mm).
Maximum flood discharge calculation:
after calculating runoff due to rain storm it was calculated by following formula(3):

$$Q_{max} = \frac{2.083AQ}{t_p} \qquad (3)$$

Q_{max}= maximum flood discharge (m^3/s)
A = Basic area (km^2)
Q = Runoff (mm)
tp = time of flood crest which is evaluated by time of concentration (tc) in minute.

The model was optimized by the initial loss and SCS-lag parameters of the sub-basins (The range of parameters changes was 20%). The efficiency of the optimized hydrologic model was confirmed by comparison the results through using the model for simulating the hydrograph of the other four flood events with the recorded flood hydrographs. In fact, model validation has been done in this stage of study. After evaluating the hydrologic model of Hajighoshan watershed, impervious surfaces growth was applied for two rainfalls (flood 2001 and 2004) events during recent forty years. It is noted that the model was implemented only by entering the changes of impervious surfaces. Finally, the influence of impervious area changes resulted from urban development on intensifying runoff generation and flood hazard have been investtigated quantitatively during the recent forty years.

3. RESULTS AND DISCUSSION

A rainfall- runoff model has been presented for simulating the hydrologic behavior in Hajighoshan watershed using the information of the five previous flood events (Fig.3). Model structure of Hajighoshan watershed is observed in fig.4. There were not any asphalt road in the region and the number and surface of residential areas were quite less than year 2007 in 40 years ago. Residential areas and road network map in 2007 is given in Figure 5. The development of residential areas and impervious surfaces is presented in Fig. 6-8. The results of comparison of simulated hydrograph with the observed hydrograph in hydrometric station (outlet of the watershed) from the five events after optimizing the model were shown in the Fig. 9-10. The efficiency of the model was evaluated and confirmed after optimizing the model using the optimized model for simulating the outlet hydrograph of Hajighoshan watershed for the five other flood events. The comparison of the simulated hydrograph with the observed hydrograph has been shown in Table 2 and Fig. 11-12. The rainfall of two past floods was considered for evaluating the influence of urban development on the potential of runoff generation and flood hazard. The model was implemented only by changing the impervious land percent, in two time frames(1967 and 2007) and the influence of impervious land development on runoff generation and the peak discharge increase and flood volume were investigated. In fact, a rainfall was considered for the model in two time frames and only the changes resulted from urban development were applied to the model and their effects were investigated. The results from impervious surfaces development in the rate of volume and peak discharge of flood in Hajighoshan watershed are shown in Table 3. The role of urban development in runoff generation and flood hazard intensify has been investigated in two time frames for a constant conditions from all the model parameters except impervious land percent of the sub-basin areas. The results have been indicated the influence of urban development on the volume and peak discharge of the sub-basin areas or in surface unit (Brown 1998 and Riley 1998). According to the results from research (Table 3), the runoff generation potential has increased approximately 8 % for the rainfall events in Hajighoshan watershed because of the urban development previous during previous forty years on the surface of the watershed.

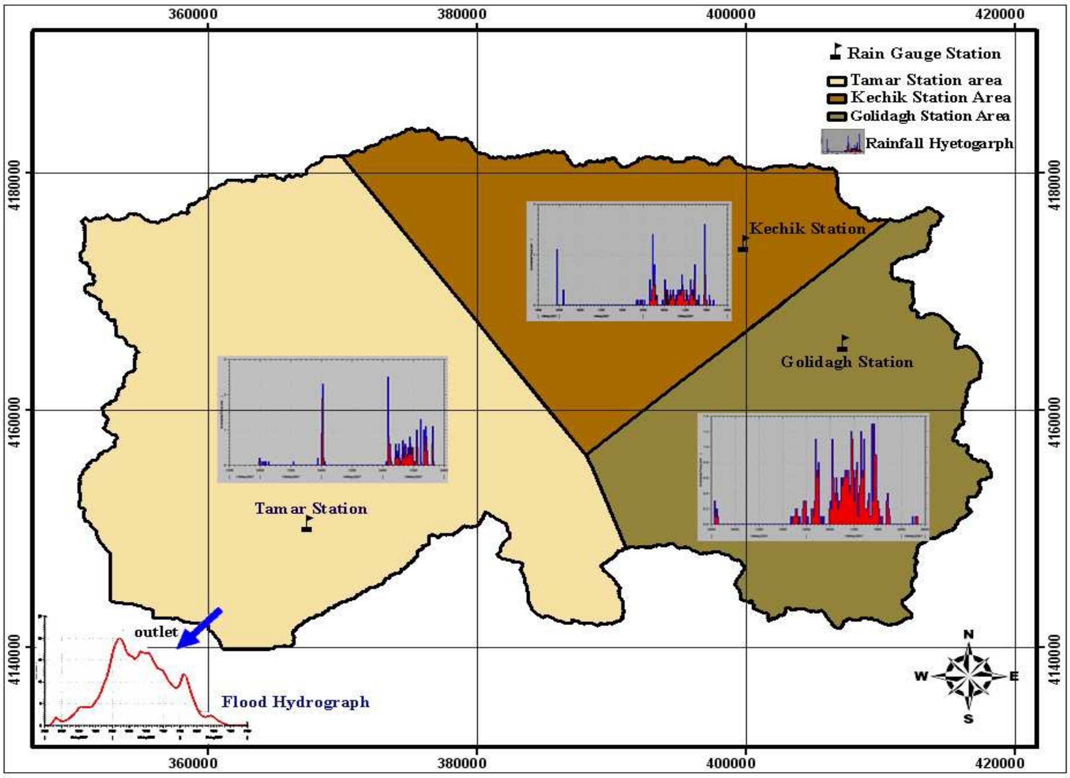

Fig. 3. The affected area of 3 raingauge stations (Thiessen method) in the watershed.

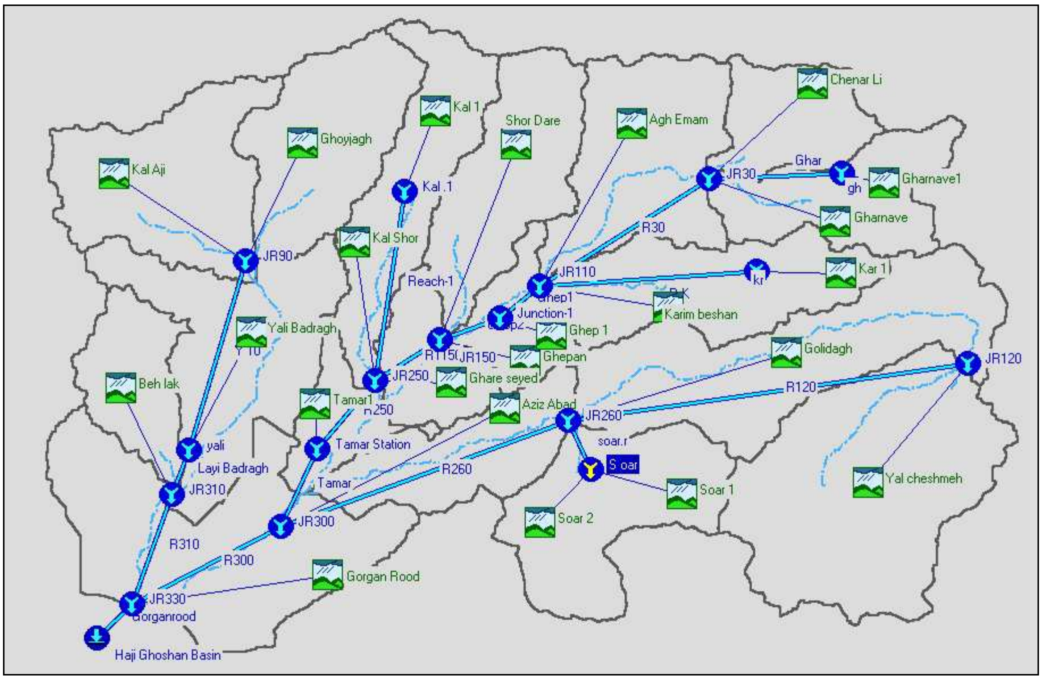

Fig. 4. The HEC-HMS model structure of Hajighoshan watershed.

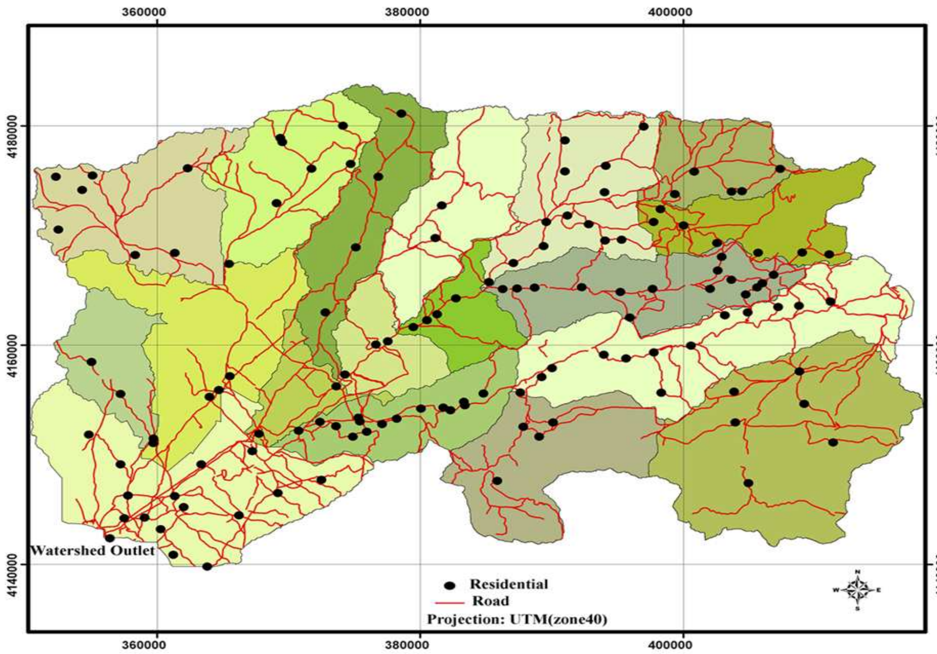

Fig. 5. Residential areas and road network in the Hajighoshan watershed (2007, based on satellite images and 25000 maps).

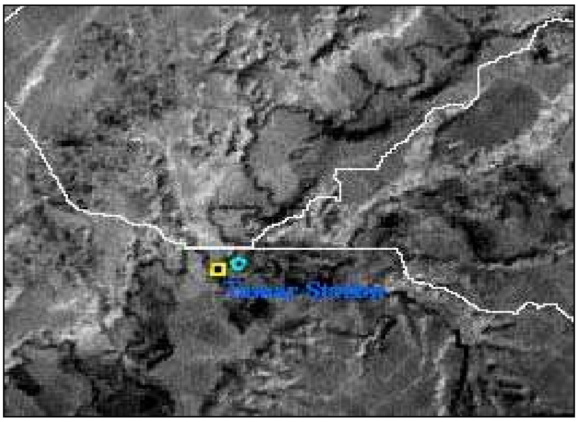

Fig. 6. The year 1967, Tamar Sub-basin (reference: aerial photo, scale: 20000).

Fig. 7. The year 2004, Tamar Sub-basin (reference: IRS-PAN Image- 6m).

Fig. 8. The year 2007, Tamar Sub-basin (reference: Quick bird Image, 1m)

Figures 6, 7 and 8 show the development of residential areas and impervious surfaces in Hajighoshan watershed during the recent forty years.

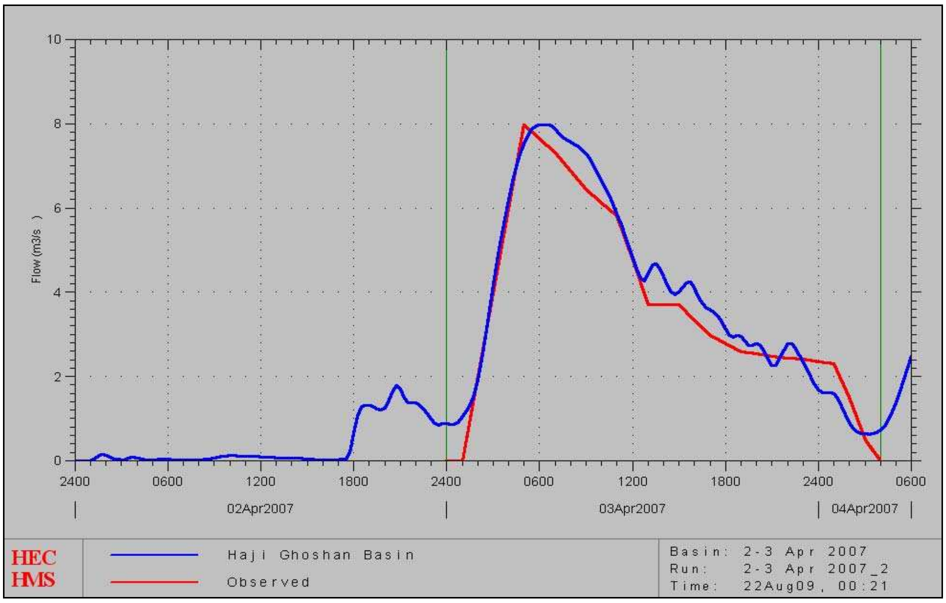

Fig. 9. Comparison between the optimized hydrograph by the model and the observed hydrograph. Model optimization by using initial loss and SCS-Lag parameters (3 Apr 2007).

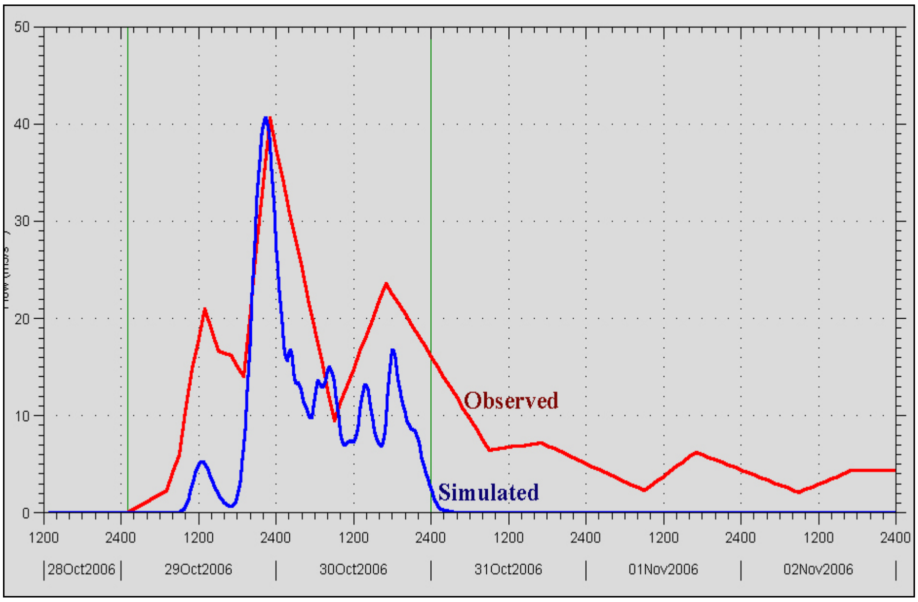

Fig. 10. Comparison between the optimized hydrograph by the model and the observed hydrograph. Model optimization by using initial loss and SCS-Lag parameters, flood event (28 Oct 2006).

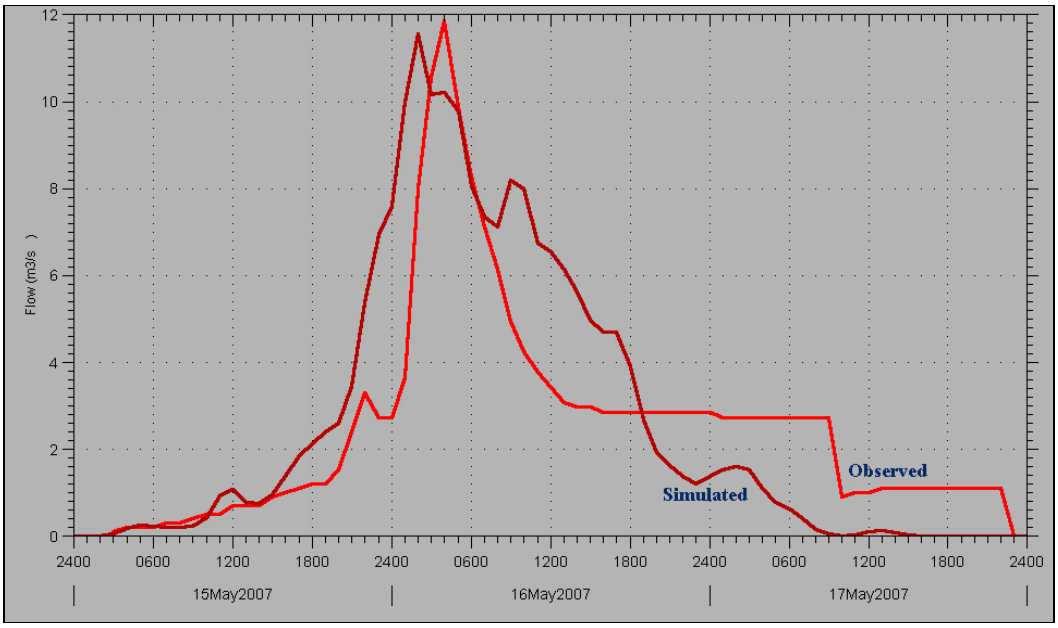

Fig. 11. Comparison between the simulated hydrograph and the observed hydrograph (Tamar Station-model Validation).

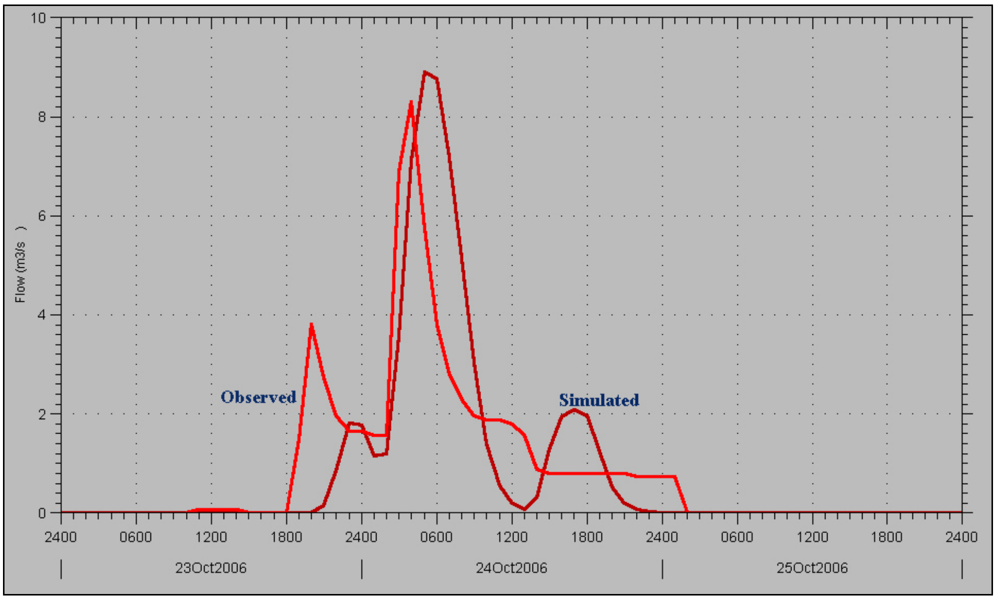

Fig. 12. Comparison between the simulated hydrograph and the observed hydrograph (model Validation).

Table 1. Curve Number (CN), initial loss (IL), SCS-Lag and Impervious land percent (٪) changes in the sub-basin areas of Hajighoshan watershed during the recent forty years.

Sub-basin	$\bar{CN}$ (I)	Optimized IL (mm)	Optimized SCS-Lag (min)	1967 (٪)	2007 (٪)
Kal Aji	73.02	18.7	157	0.32	1.58
Ghoy Jagh	69.28	21.5	112	0.21	1.55
Yali Badragh	73.11	18.68	170	0.1	0.33
Behlak	75.8	18.37	133	0.1	0.24
Kal shor(1)	72.26	19.5	78	0.6	1.39
Kalshor(2)	74.74	17.16	103	0.4	1.44
Shordare	69.39	21	132	0.25	1.43
Aghemam	72.88	18.1	109	1.1	6
Chenarli	76.99	18.44	97	0.2	0.6
Gharnave(1)	64.02	24.6	36	0.42	1.47
Gharnave(2)	73.26	17.3	49	0.8	2.13
Karim beshan(1)	78.98	16.03	54	0.9	2.11
Karim beshan(2)	74	17.8	69	0.55	1.56
Golidagh	67.31	24.67	190	0.34	1.62
Yalcheshme	66.95	25.07	102	0.15	0.61
Soar(1)	64.63	26.55	47	0.12	0.49
Soar(2)	66.55	25.5	55	0.09	0.74
Aziz abad	73.06	18.7	170	0.5	2.75
Gorganrood	68.33	23.5	76	0.61	2.63
Ghepan (1)	76.78	17.15	36	0.4	1.49
Ghepan (2)	75.24	16.2	33	1.2	7.79
Gharesyed	75.24	16.7	52	0.3	1.34
Tamar	76.53	20.7	112	0.33	1.71

Impervious land percent changes in the sub-basin areas were estimated based on the length and width of roads and the surface of residential areas in 1967 and 2007.

Table 2. The rainfall-runoff model validation based on the past flood events, Hajghoshan Staion (Qp is peak discharge and V_F is flood or runoff volume).

Date	Observed Qp	Simulated Qp	Observed V_F	Simulated V_F (1000m^3)
20 Sep 2004	519	511	2150	2249
9 Nov 2006	32	30	2066	2240
24 Oct 2004	8.4	8.9	421	394
28 Mar 2007	9	10	805	847

Table 3. The changes of peak discharge and runoff volume because of the development of impervious surfaces and residential areas in two time frames for a constant conditions from all the model parameters except impervious land percent of the sub-basin areas (Flood 2001 and 2004) .

Year	Q p (m3/s) flood 2001	VF (m^3) Flood 2001	Q p(m3/s) Flood 2004	VF(m^3) Flood 2004
1967	1392	91476000	475	2073000
2007	1517	94567000	510	2249000

4. Conclusion

Cosmopolitan area development in the surface of the watershed will include the increase of peak discharge and runoff volume in the watershed (Brilly et al. 2006 and Pappas et al. 2007). Now, runoff generation potential in the surface of the Hajighoshan watershed has been increased by destroying forests and range lands. Human's activities in the form of urban development and land use changes have led to increase of flood hazard and watershed sensitivity against rainfalls and rain storms in respect to in runoff generation and peak discharge in which the increase of runoff generation and increase of peak discharge will be more for heavier rainfalls (Camorani et al. 2005). As agricultural watersheds are urbanized, the resultant increase in impervious rooftops and transportation surfaces becomes a major controlling factor of the new urban watershed hydrology. In particular, the addition of impervious cover increases the overall hydrologic efficiency of a catchment. When rainfall falls on rooftops and pavements, it quickly runsoft, instead of infiltrating into the soil as it would generally do in a natural or farmed landscape. This shift in the landscape setting typically leads to increasing runoff volume and peak flow rates (Moscrip & Montgomery 1997) subsequent increasing magnitude, frequency of local flooding and soil erosion (Doyle et al. 2000), contaminant transport (Schueler 1995), and decrease in time of concentration. (Nelson & Booth (2002) found a nearly 50% increase in sediment yield after urban development, mainly due to altered watershed hydrology. The economic and environmental impacts of the resulting damage to property and ecosystems are significant (Booth & Jackson 1997; Novotny et al. 2001). Urban development and increasing impervious surfaces have remarkably affected the potential runoff generation and flood hazard (pick discharge and volume runoff) in the Hajighoshan watershed. But the influence of urban development has been much more remarkable in the surface of the sub-basin areas which have had considerable impervious surface development. Also, according to the results, flood runoff is more affected by urban development. 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 for the study of these effects small urban rivers are more fitting (Foster et al. 1995; Moldan & Cerny 1994). It is noted that the study area is an area with low population density. The rate of runoff volume and peak discharge and intensifying flood hazard will be increased for heavier rainfalls and this process of the urban development and destruction of forest lands is not going to stop. So, it is necessary to manage landuse in the Hajighoshan watershed.

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