A Comparison between Natural Forests and Reforested Lands in Terms of Runoff Generation Potential and Hydrologic Response (Case Study: Kasilian Watershed)

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Abstract: Afforested lands are different from natural forests in terms of hydrologic conditions, runoff generation potential, and sediment generation rate. These differences emerge due to changes in soil structure and vegetation density, litter amount, trees heights, and so on. In this study, a comparison has been made between natural forests and afforested lands in Kasilian – a watershed located in Mazandaran province, Northern Iran. To achieve this purpose, harmonious units have been defined by overlay analysis of these layers in GIS environment: slope, aspect, Digital Elevation Model (DEM) and soil. Then, the location of couple plots was defined by field studies in the harmonious units. The plot locations were selected in a way that runoff generation was a function of tree species and tree conditions, assuming that rainfall intensity is equal in all areas. Initial loss and runoff volume were measured in even plots after rainfall. Then, the initial loss parameter in a rainfall-runoff model was applied to compare runoff volume and peak discharge in the afforested lands and natural forests. The rainfall-runoff model was presented using GIS and HEC-HMS model. The results showed that reforested lands have lower infiltration, lower initial loss, and higher runoff due to lower density, canopy, litter, and soil compaction. Furthermore, the runoff generation potential of reforested lands is several times higher than that of natural forests.

Keywords: couple plot; HEC-HMS; Kasilian watershed; natural forest; reforested lands; runoff

Human activities have always been accompanied by changes in land structure, destruction of natural resources, and urban developments. A high level of forest encroachment and illegal activities such as logging, overgrazing, and agricultural practices in forests in Northern Iran, have caused irreparable damage to these forests. Transformation of forests into farmlands, pastures, and roads in these areas resulted in an increase of runoff generation and flood. Cosmopolitan developments on the surface of the watershed result in an increase in peak discharge and runoff volume of the watershed (Burns *et al*. 2005; Brilly *et al*. 2006; Pappas *et. al*. 2008). With regard to the fact that forests play significant roles in natural ecosystems and provide human beings with foodstuffs, wood products, and paper products and prevent the erosion of soil and water loss, efforts to prevent damage to these resources are of great importance for preserving human lives. The flood is one of the natural phenomena whose devastating power has considerably increased due to human unbalanced interference in nature. This phenomenon is considered as one of the most complicated and devastating natural incidences that threatens human lives and properties more than any other natural disasters. Consequently, to prevent extensive flood damage, the causes of flooding should be studied and the solutions must be found to decrease the detrimental effects of flood waters. Today, reforestation is performed to grow trees on an area that was previously harvested. Controlling flood hazards requires the application of proper methods. Since hydrologic conditions in natural forests and afforested lands are different, it is required that these conditions be studied and thoroughly compared. The hydrological response of a river basin is based on the relationship between basin geomorphology (catchment area, shape of basin, topography, channel slope, stream density and channel storage) and its land use and hydrology (Loukas *et al*. 1996; Shamseldin & Nash 1998; Ajward & Muzik 2000; Hall *et al*. 2001; Jain & Sinha 2003; Nourani *et al*. 2009). With regard to hydrologic behaviour simulation in watersheds, Cristopher and Yung (2001) and Ston (2001) presented the rainfall-runoff model using GIS and HEC-HMS model. The results of their study proved HEC-HMS model ability to simulate a flood hydrograph of watershed. Iroume *et al*. (2005) investigated the effects of forests on the downstream runoff generation rate of watershed in Chile. Their study indicated that runoff rate is dependent on vegetation cover, road density, rainfall conditions and topography. They also claimed that forests play a role in decreasing downstream runoff. Other studies were also conducted showing that forests have a role in decreasing base flow and downstream peak discharge in the watershed (Harr 1976; Swanson & Hillman 1977; Keppeler 1986, 1988; Calder 1992; Jones & Swanson 2001; Gush *et al*. 2002). According to Phong *et al*. (2010), damaging the forests and decreasing the vegetation may lead to a significant increase of runoff and flood alternations in downstream lands because with increasing soil infiltration and water detention capacity in the watershed, the forests cause a significant decrease in runoff and flood hazard (Wahl *et al*. 2005). The present study has been carried out to study hydrology of natural forests and afforested lands, compare them in terms of runoff generation potential, and to decrease the flood hazards in the Kasilian watershed.

MATERIAL AND METHODS

Kasilian watershed encompasses an area of about 68 km^2 and is located in Northern Iran within the limits of eastern longitude 53°18' to 53°30' and northern latitude 35°58' to 36°07' in the eastern part of the Mazandaran province (Figure 1). The climate of the area is semi-humid and cold with average annual precipitation of 791 mm and average temperature of 11°C. The average, maximum, and minimum heights of the watershed are 3349, 1120 and 1672 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. A hydrometric station is located at the outlet of the watershed (Valikben Station) and a rain recorder station (Sangdeh Station) is located upstream of the station. Natural forests of this watershed

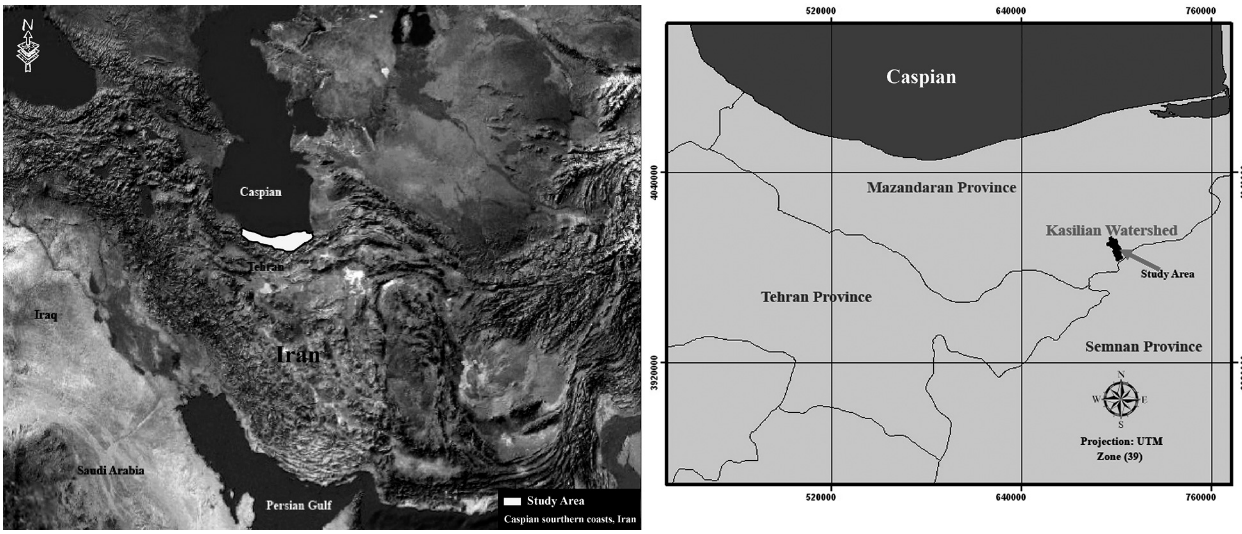

Figure 1. The location of the study area (Kasilian Watershed)

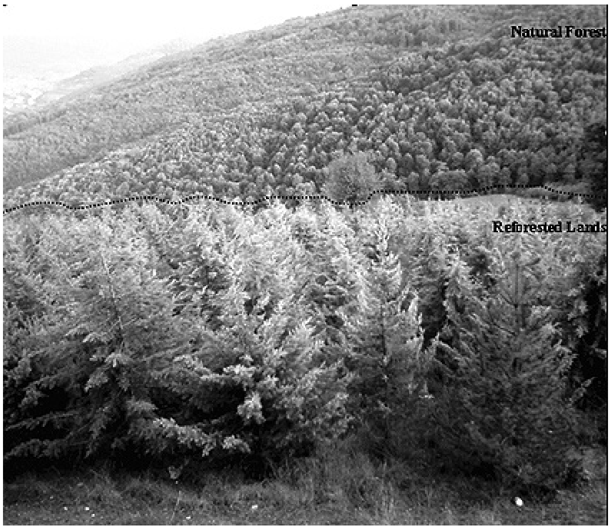

Figure 2. A picture of natural forests and afforested lands

consist of *Carpinus betulus*, *Buxus hyrcana*, *Fagus orientalis*, *Alnus subcordata.* Moreover, species of spruces, *Populus* and *Cupressus* trees can be seen in reforested lands (Figure 2). The different types of soil on the watershed surface contain immature Ranker, immature Rendzina, brown forest soil, brown forest soil with Alkali pH, argillic brown soil and yellow podzolic soil. The characteristics of each sub-basin have been investigated, including soil types and depth, soil texture, rooting, infiltration, active lime percentage, etc. Generally, the soil texture in forests of the watershed is loam-clay (Figure 3).This study compares natural forests and afforested lands in terms of runoff generation potential and its effects on decreasing the flood hazard in Kasilian watershed. At first, topographic maps, satellite images, and necessary data for the study were collected. The area of natural forests, afforested lands and impervious land percentage were estimated by means of field studies, existing satellite images and land use map. Besides, a soil hydrologic group map was provided by field studies. With regard to the limited surface of Kasilian watershed and the accessibility to one rain gauge recorder station named Sangedeh, the rainfall intensity was considered steady in the study and was simulated as incremental in a rainfall-runoff model (Figures 4–6).

Since our study was focused mainly on the comparison between natural forests and afforested lands in terms of runoff generation potential, the couple plots were established on these lands. First, harmonious units were defined on the watershed surface using overlay analysis maps in GIS environment: slope, aspect, elevation, geology, pedology and then the couple plot location in Kasilian watershed was selected: one in natural

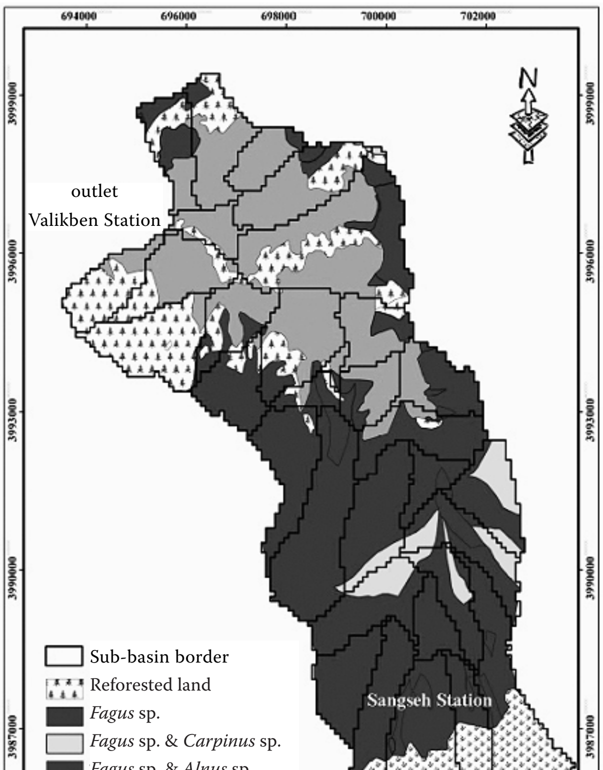

Figure 3. The land use map of Kasilian watershed

Figure 4. Established sample plot for estimating runoff during rainfall

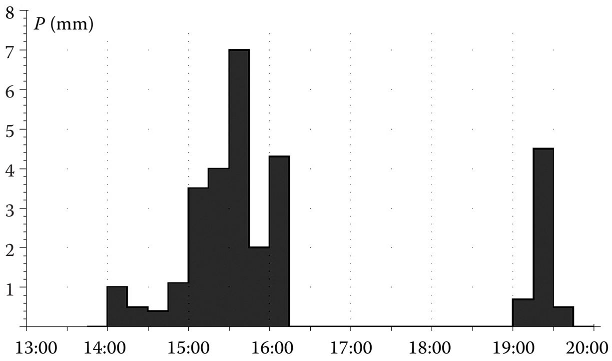

Figure 5. Rainfall hyetograph at the Sangedeh station (August 27, 2010)

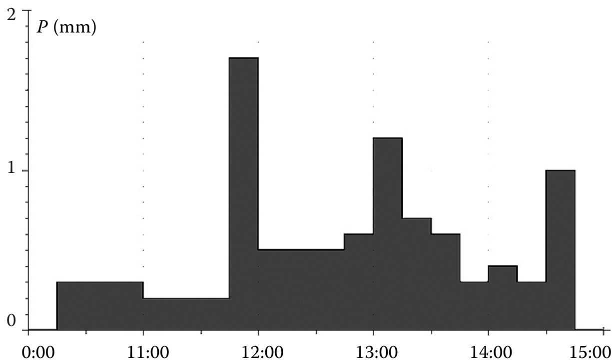

Figure 6. Rainfall hyetograph at the Sangedeh station (October 7, 2010)

forest and a similar plot in afforested land; in terms of soil texture, topography and equal rainfall intensity. The purpose was to find two places with similar conditions concerning height, type, density, canopy, litter, and soil humus (near locations), so that changes in runoff generation potential be the result of vegetation changes. After establishing plots in these locations, the runoff volume of plots, the runoff height and the initial loss rate in each plot were determined following a rainfall event. The initial loss parameter (infiltration, interception, depression storage) is one of the main unknown parameters in a rainfall-runoff model which are difficult to determine. It should be mentioned that the existing standards to determine this parameter are not appropriate in our country. By the way, the quality of land management and human interference in nature influence the parameter. When the initial loss parameter was determined on different slopes and in different AMC (antecedent moisture condition), the parameter was used in a rainfall-runoff model to compare the runoff generation potential of sub-basins in natural forests and afforested lands. The rainfall-runoff model was presented using GIS (HEC-GeoHMS) and hydrologic model HEC-HMS. The physical model of watershed was simulated in GIS using HEC-GeoHMS and Digital Elevation Model (DEM) 10 m. To define the boundary of sub-basins, the limits of natural forests and afforested lands were taken into consideration, so the watershed was divided into 32 small sub-basins. To present a hydrologic model, three methods were used: Soil Conservation Service (USA) method (SCS) for flood hydrograph simulation, Curve Number (CN) method was applied to estimate runoff height and Lag method was used for flood routing in channels. The model was presented by a number of occurrences containing rainfall statistics and last flood hydrograph, and was calibrated by parameters SCS-Lag and initial loss of sub-basins. Curve Number and initial loss were estimated by combining the land use map and soil hydrologic group map in GIS. At the next stage, the model was validated by some other flood occurrences. After validating the model and confirming its capability in simulating the hydrologic behaviour of Kasilian watershed, consequences of taking plots to estimate initial loss were performed and implemented in case-study sub-basins. In this

Table 1. The data on selected plots (1.85 m^2 each) for measuring runoff from rainfall

No.	X	Y	Forest	Vegetation	Vegetation canopy (%)	Slope (%)	Soil
1	695052	3994187	natural	low	10	0–10	loam-lay loam
2	695386	3993820	afforested	good	98	0–10	loam-clay loam
3	694506	3994902	natural	excellent	100	10–20	loam-clay
4	695139	3995113	afforested	low	10	10–20	loam-clay
5	695586	3994364	natural	excellent	100	20–30	loam-clay loam
6	696912	3994093	afforested	low	10	20–30	loam-clay loam

Table 2. Estimating the runoff of rainfall (August 27, 2010) in AMC I (rainfall value is 29.5 mm)

	Plot					
	1	2	3	4	5	6
Runoff volume (l)	2	16	4	8	0	12
Runoff height (mm)	1	8.64	2.16	4.32	0	6.48
Initial loss (mm)	28.5	20.86	27.34	25.18	29.5	23.02

study, comparison has been made in two ways: (A) supposing natural forests replaced by afforested lands that always cause ambiguity. In this case, plan successes and changes in soil structure are considered after implementing plans. (B) Physiographic parameters of sub-basins are estimated, using SPSS software through statistical analysis and cluster analyses of sub-basins which are similar in terms of physiographic conditions. On the whole, two sub-basins, one reforested and one forest land with similar soil and physiographic conditions and with different vegetation were compared by using the rainfall-runoff model and steady intensity of rainfall, in terms of hydrologic response and runoff generation potential (runoff volume and peak discharge).

RESULTS

After rainfalls, the runoff obtained from couple plots was taken. Then, the runoff height, volume, and initial loss rate in each couple plot were estimated. In Tables 1 and 2, the results of measuring 3 couple plots (number 1 to 6) for 2 rainfall events are shown. According to the results, the generated runoff rate of afforested lands is higher than that of natural forests (Table 3). The runoff height is the quotient of runoff volume to plot surface. The initial loss for rainfall is the runoff height of each plot minus total rainfall rate. After presenting the rainfall runoff model and improving the model by SCS-Lag and initial loss parameters, the model calibration was done. Totally the model with the last five rainfall events was presented and calibrated and then it was validated by other four events. In the next procedure, the average amounts of initial loss which was estimated by the results of couple plots in the model entered the sub-basins with natural forests and afforested lands, and the rainfall-runoff model was used to analyse and compare sub-basin hydrologic conditions. Similar sub-basins were recognized in terms of soil and physiographic parameters using cluster analyses in SPSS software (Table 4) and then the peak discharge and runoff volume (hydrologic) of

Table 3. Estimating the runoff of rainfall (October 7, 2010) in AMC II (rainfall value is 10.8 mm)

	Plot					
	1	2	3	4	5	6
Runoff volume (l)	3	18	7	14	3	16
Runoff height (mm)	1.62	9.78	3.78	7.56	1.62	8.64
Initial loss (mm)	9.88	1.08	7.02	3.24	9.18	2.16

Table 4. Physiographic parameters of harmonious sub-basins in the Kasilian watershed

Circular coefficient	Shape coefficient	Main channel slope (degree)	Main channel lengh(m)	Average height (m)	Average slope of watershed	Perimeter (km)	Surface (km^2)	Sub-basin
1.7	4.8	13.5	3013	1525	17.2	7780	1.62	6
1.59	2.6	11.5	3219	1455	14.5	9260	2.65	7
1.61	1.97	11.1	1978	1405	15.1	7420	1.66	17
2.22	7.0	7.8	3700	2171	25.5	15020	3.6	20

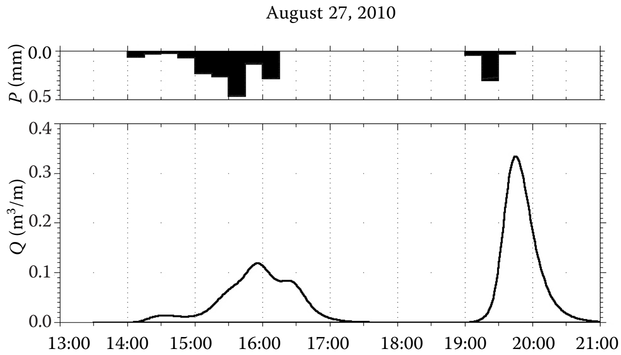

Figure 7. Hydrograph of sub-basin6 in the Kasilian watershed with afforested land (similar sub-basin17)

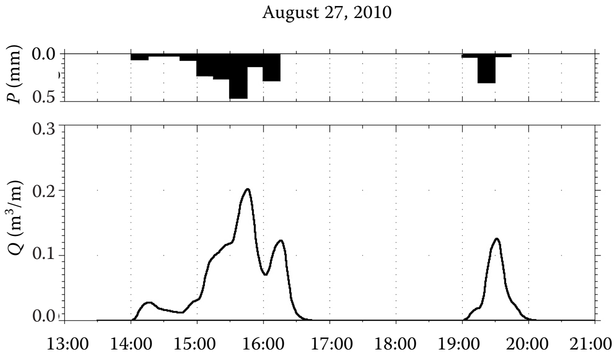

Figure 8. Hydrograph of sub-basin17 in the Kasilian watershed with natural forest (similar sub-basin 6)

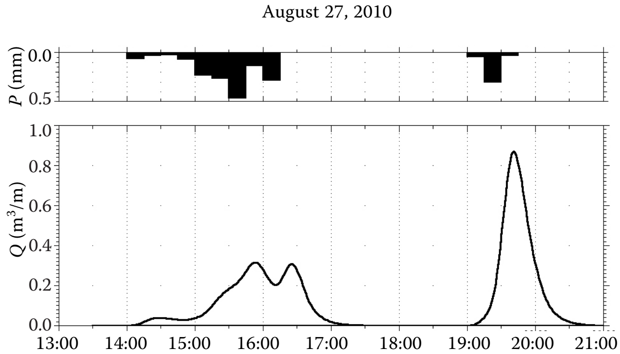

Figure 9. Hydrograph of sub-basin 7 in the Kasilian watershed with afforested land (similar sub-basin 20)

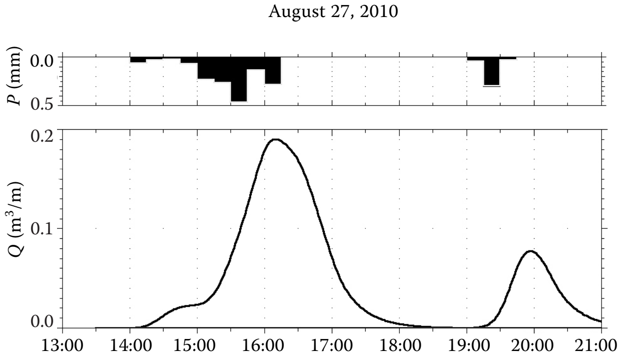

Figure 10. Hydrograph of sub-basin 20 in the Kasilian watershed with natural forest (similar sub-basin7)

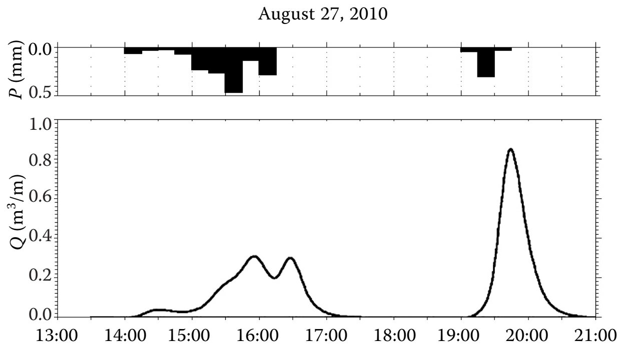

Figure 11. Hydrograph of sub-basin 7 in the Kasilian watershed with afforested land

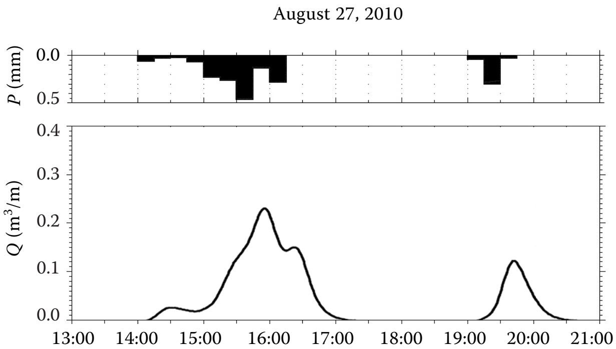

Figure 12. Hydrograph of sub-basin 7 in the Kasilian watershed with the assumption of substituting natural forests with afforested lands

similar forest sub-basins with different vegetation type were compared. Statistical analysis by a cluster method showed that afforested sub-basin 7 is similar to natural forest sub-basin 6 and 20. The comparison between hydrograph natural forest and afforested sub-basins is shown in Figures 7 to 10. One comparison methods, substitution assumption in the model was evaluated. Comparing the effect of natural forest vegetation and afforested one was done with the assumption of substituting the vegetation type and the results are shown in Figures 11 and 12. Sub-basin 17 with natural forest vegetation contained the area nearly equal to sub-basin 6 with afforested one. Other physiographic parameters are nearly identical. Similar soil hydrologic group and rainfall intensity in the entire watershed were performed in a steady model. Sub-basin 20 with natural forest vegetation contains an area twice larger than sub-basin 6 with afforested vegetation or even more, but its runoff rate for one rainfall event is lower.

CONCLUSION

The results of the present study revealed that in the case of incremental and steady rainfall in Kasilian watershed, the runoff changes in sub-basins with nearly similar physiographic conditions are dependent on the type of vegetation. Hydrographic comparison of the mentioned sub-basins shows that reforested lands contain more runoff and higher peak discharge than natural forests. It is interesting to note that sub-basin 20 with natural forest vegetation contains less runoff and lower peak discharge than a similar sub-basin with reforested land vegetation despite having a larger area. Runoff height is the quotient of runoff volume to plot surface. The difference between total rainfall rate and runoff height defines the initial loss rate that is the sum of infiltration, interception and depression storage. The results showed that because of the appropriate soil structure and much litter in some natural forests, the initial loss rate is high and consequently runoff height is low and sometimes even zero. The estimated initial loss domain in AMC I and II is different, but on the whole it is between 20 and 25 mm for afforested lands and between 27 and 30 mm or even more (because the runoff volume is zero and the rainfalls in this study are less than 30 mm) for natural forests. It is important to mention that the initial loss rate for the same plots in slighter rainfall is different in diverse AMC, between 1 and 3 mm for reforested lands, and between 7 and 9 mm for natural forests. Previous studies (Gholami *et al.* 2009) showed that based on existing practical relations, the first estimated amounts of initial loss are different from the real amounts, so it is important to determine the real amount of the parameter in rainfall-runoff models. In forests, runoff rate is dependent on vegetation cover, road density, rainfall conditions, and topography (Iroume *et al.* 2005; Pappas *et al.* 2007). Since the Kasilian watershed is a forest watershed in the central Alborz Mountains, which were not influenced by land use changes (Gholami *et al.* 2010), the number of roads and habitats (impervious lands) in harmonious sub-basins is nearly identical. In afforested lands, maximum runoff generation can be observed in heavy-textured soil and on the slope of 0–10 degrees. Then, slopes of 10–20 and 20–30 degrees exist, respectively. It is obvious that the slope decreases infiltration and increases runoff, but in these couple plots runoff is dependent on soil conditions, tree canopy percentage, density and height, especially on the existing litter in the plots. In the above-mentioned plots, diverse results regarding reforestation plans have been achieved. We observed kinds of trees with different height, density, and canopy. Populus and cupressus trees and white poplar have density and canopy dissimilar to natural forests. Furthermore, their litter does not cover the ground surface just like broadleaf trees. We should point out that reforesting age rather than natural forests cannot be compared and this point is not considered directly in this study. Concerning natural forests, minimum runoff can be observed in forests covered with maximum vegetation density, canopy as well as much litter but in slopes of 20–30°. Maximum runoff rate in existing plots was seen in a field full of *Alnus* and *Fagus* with the slope of 0–10 degrees. This is due to heavy-textured soil and less litter density. The results showed that dispersal is less in natural forests due to the broadleaf litter which absorbs some runoff and prevents runoff movement. Consequently, they are considered to be one of the important factors in generating and runoff flow. Additionally, appropriate soil structure, more humus, and vegetation canopy decrease the runoff generation potential as well as flood hazard in natural forests.

Acknowledgements. The authors would like to thank the Mazandaran Regional Water Company and Mr. A. Khodabakhshi for providing rainfall data, flood hydrographs and for aiding in the pre-processing of data.

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Received for publication May 6, 2012
Accepted after corrections June 21, 2012

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