Research Journal of

# Environmental Sciences

ISSN 1819-3412

Academic
Journals Inc.

www.academicjournals.com

Research Journal of Environmental Sciences 3 (2): 193-201, 2009
ISSN 1819-3412


# Determination of Runoff Threshold Using Rainfall Simulator in the Southern Alborz Range Foothill-Iran

J. Vahabi and M. Ghafouri
Soil Conservation and Watershed Management Research Institute,
P.O. Box 13445-1136, Tehran, Iran

**Abstract:** In this research, the effects of slope, vegetal cover percentages, clay, sand, silt and moisture percentages on runoff generation threshold have been investigated using an outdoor rainfall simulator in an Iranian watershed. Two rainfall intensities of 24.5 and 32 mm $h^{-1}$ were tested over 145 experimental plots in Taleghan watershed and runoff thresholds were recorded. Visual interpretation of the scatter diagrams of both dependent and independent variables supported by the correlation matrix indicates the effective variables in runoff generation for 24.5 mm $h^{-1}$ as vegetal cover percentage, soil moisture, clay, sand, silt and slope, respectively. The orders of the effective variables for intensity of 32 mm $h^{-1}$ are vegetal cover, sand, soil moisture, silt, slope percentages and clay. Regression equations are developed and evaluated for runoff threshold prediction in different conditions of independent variables variations.

**Key words:** Rainfall intensity, runoff, runoff generation, slope, soil moisture, soil texture vegetation cover

## INTRODUCTION

Surface runoff is part of rainfall which after compensation of evaporation, abstraction, surface detention and infiltration flows over land and concentrates in stream network and finally discharges from the catchment through the main river. With the transformation of surface runoff to floods besides possible loss of life and damages to properties of industrial, urban and rural centers, some considerable fertile soils of catchments are eroded and environmental resources are lost. Consequently, production efficiency in agricultural and range lands is decreased due to wash off the fertile top soil horizon. Estimation of precise threshold of runoff not only leads to more accurate design flood but also it is important in optimum usage of precipitation in dry land farming land preparations. In this research runoff generation threshold is the time when initial infiltration is satisfied, excess rainfall fills up small and large depressions and water flows over land.

The threshold depends on some parameters including; soil infiltrability, rainfall intensity, slope, antecedent moisture conditions, land use, type and density of vegetal cover and soil texture. Having the runoff generation threshold over different soils and considering effective parameters enable users to plan for flood volume reduction, flood damage and erosion reduction. The accelerated erosion can be controlled and optimum usage of atmospheric precipitation would be possible in dry land farming and rangeland improvement.

The findings are in sharp contrast to other field and laboratory experiments carried out on small plots and involving slope lengths of less than 1 m, in which it was found that roughness substantially affects runoff (Cogo *et al*., 1983; Zobeck and Onstad, 1987; Renard *et al*., 1997). However, real catchments have slopes which are usually over 10 m in length and there is no information on the effect of micro-relief on plots of this size. Karnieli and Been-Asher (1993) using simulation of daily runoff,

**Corresponding Author:** Jalil Vahabi, Soil Conservation and Watershed Management Research Institute,
P.O. Box 13445-1136, Tehran, Iran
Tel: +98 21 44901415, 44901416 Fax: +98 21 44905709

a number of researchers in four catchments in Arizona, in the USA, observed the threshold as a function of medium soil texture of each watershed where clayey and sandy soils had the shortest and the longest thresholds. It was concluded that in the south western catchments of the USA soil moisture magnitude has an important role in runoff generation. Some researchers in Mediterranean semi-arid regions of Spain studied the production process and influential factors on runoff in small scale basins. Two soil types with different hydrologic response were used in this research. The results of this study showed that fine texture soils with low permeability and few organic materials possess had higher runoff coefficient and lower runoff threshold in comparison with coarse texture soils with higher permeability and medium organic materials. On the other hand, the effect of rainfall characteristics on soil hydrologic reaction in different rainfall intensity was the main controlling factor of runoff in watersheds with fine soil with low permeability and sparse vegetation cover, while in coarse soils with high permeability and denser vegetation cover, total precipitation is related to runoff (Martínez-Mena *et al*., 1998). Armando *et al*. (2007) using a rainfall simulator in tropical mountain regions showed that, at the plot scale, more than 60% of the observed variance in runoff generation can be explained by a combination of land use class and surface vegetation cover. The vegetation cover has a direct physical impact on runoff generation, as plant and residue cover protect the soil from raindrop impact and splash, tend to slow down surface runoff and allow excess surface water to infiltrate. Katrien *et al*. (2006) showed that total vegetation cover is the most important plot variable explaining about 80% of the variation in runoff coefficients through an exponential decay function. Also the runoff generating rainfall threshold has a positive correlation with total vegetation cover. Runoff was found to be negligible when the vegetation cover exceeds 65%. Other important variables affecting runoff production in the study sites are soil organic matter, soil bulk density, litter cover and slope gradient. Poncea and Shetty (1995) made use of annual precipitation and a water balance model for simulating the changes in runoff and base flow within several watersheds in the USA, Africa, Canada and India. The results of these studies showed that runoff threshold depends on the climate and its rate in semi-arid areas is higher than semi-wet areas. The difference in runoff generation for two cases of wet and dry soil moisture is very high where in moist soil runoff starts after few initial minutes of rainfall. The magnitude of the threshold is related to the antecedent soil moisture condition as it is higher the infiltration rate is reduced and the threshold occurs quickly (Charkhabi and Eskandari, 2003). A group of researchers measured the threshold and amount of runoff by producing rainfall with different intensities on 20 small experimental plots (2×2 m) with various slope percentage, soil type and vegetal cover density using a portable rainfall simulator. The results obtained from this research show that the efficient variables on runoff threshold after rainfall intensity are respectively vegetation cover density, clay and slope percentages (Sharifi *et al*., 2004). In a filed study, using a portable rainfall simulator, the threshold of runoff of soils with agricultural application and rangeland for different moisture conditions and slopes were measured. It was concluded that in agricultural lands with the increase in slope the threshold uniformly decreases. On the contrary, in rangelands for two soil moisture conditions of wet and dry with the increase in slope from 25 to 35 the threshold has increased as well (Raeesiyan, 2005).

The objectives of this study are to find out the relations of slope, vegetation cover, soil moisture and texture with runoff generation threshold using a rainfall simulator and developing empirical relationships between the above variables in the southern Alborz Range foothill-Iran.

## MATERIALS AND METHODS

### General Characteristics of the Study Area

Simulated rainfall studies were conducted within the Talegan watershed located in Savojbolagh County, upstream of Sefidrood Dam, southern part of Alborz Mountains in the north-west and

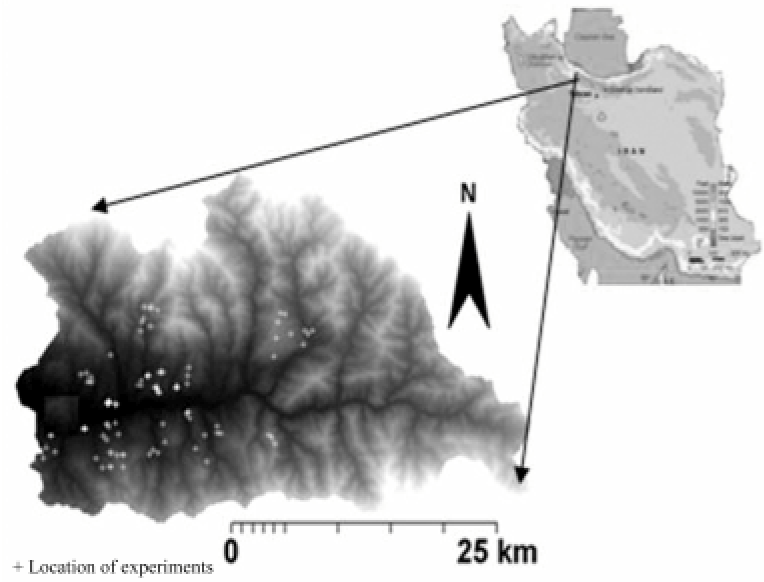


Fig. 1: Taleghan catchment and locations of test plots

100 km far from Tehran city, Iran, from June to September 2007. The catchment shares a boundary to the north with the Alamaoot watershed, to the south to Ziaran and Samgh Abad and to the east to part of Karaj watershed and to the west to the Shah Rood catchment. The catchment is located between 36°, 31', 5" and 36°, 23', 37" northern latitudes and 50°, 21' and 51°, 1', 16" eastern longitudes. It is a mountainous catchment with an area of approximately 1135 sq km and average annual rainfall of 591 mm of in both rain and snow forms.

To reach the objectives of the research, data and information were collected and studies and reports were investigated from different stakeholders' organizations. Using soil maps, vegetative cover maps and considering access roads, the locations of experiments were identified. The field tests for runoff measurement using a portable rainfall simulator was done on 145 plots in the catchment (Fig. 1).

**Rainfall Simulator Characteristics**

A non-pressure portable rainfall simulator made of Plexiglas with 120×89 cm dimensions and adjustable feet with minimum height of 1.5 m is used in the research. The simulator can be set up over different slopes. With a tank volume of 51.6 L the simulator is able to generate rainfall intensities of minimum 10 mm $h^{-1}$ to max of 80 mm $h^{-1}$ for different durations. To prevent concentration of drops on one point over the plots, a motor is installed on the apparatus framework to move the precipitation plane within the framework and provide a uniform distribution of droplets. Droplets with no initial velocity are released from the droppers and fall due to gravitational acceleration only. The precipitation plane consists of 216 droppers.

In the body of the apparatus a Plexiglas pipe is installed somehow that its inlet with a plastic cap is located at the upper tank and its other end at the bottom of the lower tank and plays the role of the starter and adjustment in the simulator very precisely.

After filling the upper tank and the lower via the inlet, the entrapped air in the apparatus to be vacuumed. Vacuum of the air and filling the tanks can be done simultaneously if the apparatus is leveled. The valves for air and water have to be closed quickly for a quick stoppage of the flow.

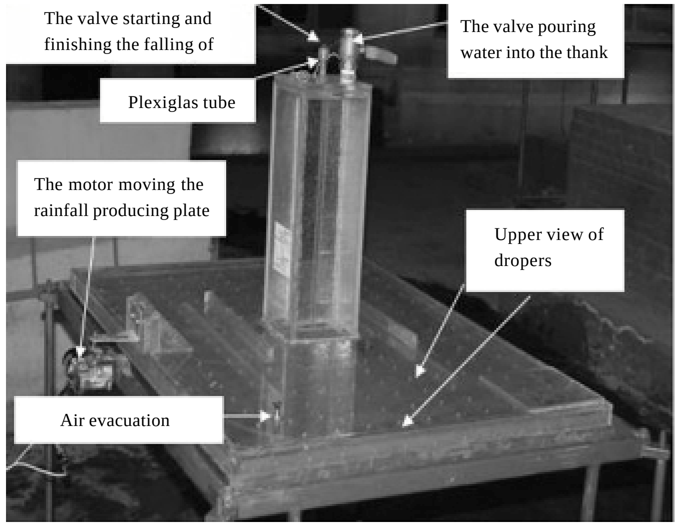


Fig. 2: The view of the upper part of the rainfall simulator

Locating the adjustment pipe at the desire height for the required intensity and removing the plastic cap causes rain to start. Figure 2 shows the view of the upper part of the rainfall simulator. In this research rainfall with intensities of 24.5 and 32 mm $h^{-1}$ in 30 min over plots of 125×95 cm on different slopes with different soil moisture at different parts of the Taleghan catchment were produced and the thresholds of runoff generation for 145 experiments were measured.

**Characteristics of the Experiment Plots**

With respect to the determined specifications for the site of field experiments in the research method, the initial map of proper regions was prepared. Regarding mentioned specifications in range lands of the watershed by means of digital soil, slope and vegetation cover maps of watershed. The locations of the experiment plots in rangelands of the watershed was determined using the initial map, in a way that while originating the necessary conditions for implementing the experiments as many times as predicted, also the changes in given specifications would be accomplished based on the research method. The experiment plots had the following conditions to investigate independent variables:

- Experiment plots, from the slope point of view: were located on the hillsides with the slope between 12-20 and 20-30%
- Experiment plots from the vegetation cover density point of view: were selected in the rangelands with poor and medium vegetation cover density with 9-24 and 24-49% cover, respectively
- The locations of the experiment plots in the research basin were determined in a way that while consider above mentioned specifications (sections 1 and 2), also they have in a well balanced distribution in soils with light, medium and heavy texture
- The amounts of soil moisture were measured using a TDR device before starting each experiment as an independent variable

Rainfall simulator has been settled in the plots with above mentioned specifications. The given independent variables and the amount of runoff caused by the simulated rainfall intensity were recorded in the prepared forms in the each experiment. Finally the recorded data were analyzed.

**Data Analysis**

Degree and type of relations of each variable of slope, vegetal cover, sand, clay, silt and soil moisture with the threshold of runoff generation were determined. The relations of the dependant variables with the threshold magnitude were found using SPSS software through correlation matrix and multiple regressions with stepwise and backward methods for two rainfall intensities of 24.5 and 32 mm $h^{-1}$. Both ANOVA and regression coefficients of dependant and independent variables were used to choose a suitable model from some derived models.

## RESULTS AND DISCUSSION

**Effective Variables**

The scatter diagram of the independent variables and magnitude of thresholds was prepared in order to investigate the degree and type of their linkage for two rainfall intensities of 24.5 and 32 mm $h^{-1}$. Visual interpretation resulting from different experiments indicates the highest correlation between both clay and soil moisture with the thresholds of runoff generation for both selected rainfall intensities. Correlation matrix is built for variables to find out the degree and type of relations of slope, vegetal cover, sand, clay, silt and soil moisture percentages with the threshold (Table 1).

Table 1 supports visual interpretation of the scatter diagrams for dependent and independent variables in the study. The effective variables on threshold of runoff generation for 24.5 mm $h^{-1}$ rainfall are vegetal density, soil moisture, clay, sand, silt and slope, respectively while for 32 mm $h^{-1}$ rainfall they are found as vegetal cover, sand, soil moisture, silt, slope and clay in order of importance.

According to these results, correlation coefficient of all variables except sand and vegetal cover percentage are negative which shows the decrease in the threshold with the increase in these variables. In other words with the increase in soil moisture, silt, clay and slope, the threshold of runoff generation increases. On the other hand with the increase in sand and vegetal cover percentages, the threshold will increase which is quite reasonable.

The degree of correlation of variables with the threshold is studied through correlation coefficient interpretation. The coefficients for slope with the threshold for 24.5 mm $h^{-1}$ rainfall is -0.170, respectively while these coefficients for 32 mm $h^{-1}$, are -0.038 and -0.044 for clay and slope percentage. Although they are statistically significant correlation coefficients but they are very low. This result corresponds to the obtained result by Sharifi *et al*. (2004). The results presented from the correlation matrix for 24.5 mm $h^{-1}$ indicate the correlation coefficient of -0.443, -0.538 and -0.564 for silt, sand and clay percentages. The coefficients for silt, soil moisture, sand and vegetal cover percentage, with the threshold for 32 mm $h^{-1}$ rainfall are -0.475, -0.496, 0.546 and 0.606, which are significant at 0.01 levels. Variables with correlation coefficients within the range of 0.35 to 0.65 can be used in combination with other variables for individual or group prediction in multiple regressions with a reasonable error. For 24.5 mm $h^{-1}$, vegetal cover and soil moisture have -0.693 and -0.894 correlation coefficients which are significant at 0.01 levels.

In this research the vegetal cover is the most dominant factor determining runoff threshold and conforms with the obtained results by Karnieli and Been-Asher (1993), Martínez-Mena *et al*. (1998), Sharifi *et al*. (2004), Katrien *et al*. (2006) and Armando *et al*. (2007). On the other hand, on the result

Table 1: Correlation matrix between runoff threshold and independent variables

| Rainfall intensity | Parameter | Area slope (%) | Vegetation cover density (%) | Initial moisture (%) | Clay (%) | Silt (%) | Sand (%) |
|---|---|---|---|---|---|---|---|
| 24.5 mm $h^{-1}$ | Pearson correlation | -0.170 | 0.894** | -0.693** | -0.564** | -0.433** | 0.538** |
| | Sig. (2-tailed) | 0.541 | 0.089 | 0.015 | 0.000 | 0.000 | 0.000 |
| 32 mm $h^{-1}$ | Pearson correlation | -0.044 | 0.606** | -0.496** | -0.038 | -0.475** | 0.546** |
| | Sig. (2-tailed) | 0.713 | 0.000 | 0.000 | 0.749 | 0.000 | 0.000 |

** Correlation is significant at the 0.01 level (2-tailed test) of this research initial soil moisture is the other most efficient factor determining runoff threshold that conforms with obtained results by Karnieli and Been Asher (1993), Poncea and Shetty (1995), Charkhabi and Eskandari (2003) and Raeesiyan (2005). Although land slope is an important factor affecting runoff threshold, the results of this research showed that slope changes have only a slight effect on the runoff threshold. This slight effect of land slope could be related to the short lengths of slopes (1.2 m) when working with small plots.

**Correlation of Variables with the Threshold**

Of the important objectives of statistical analysis is finding equation among two or more variables to be used for dependent variable magnitude prediction for different conditions of the independent variables e.g., soils. The calculation of the threshold for two rainfall intensities of 24.5 and 32 mm $h^{-1}$ was carried out in 73 and 72 experimental plots, respectively.

**Rainfall Intensity of 24.5 mm $h^{-1}$**

Stepwise and backward methods have presented six models between independent variables and the threshold. Descriptive statistics and F-value and the related significance level in the existing ANOVA table were used for two methods. The first model was derived from backward method with Fisher test significant level of less than 0.01 which is 99% significant and with $R^2$ of 0.993. The $R^2$ shows 99.3% of the variations of the observed dependant variable is explained by the equation which consists of 5 independent variables. Also the correlation coefficient of 0.996 with a good prediction capability was selected as a suitable model for threshold magnitude for 24.5 mm $h^{-1}$ in different conditions. Interpretive statistics and correlation coefficient of the selected model are given in Table 2 and 3.

To evaluate the regression relations between the function variable and the observed variables, a linear equation was developed. The correlation coefficients between the threshold and other variables such as slope, vegetal cover, soil moisture, clay, silt and sand are presented in Table 4. The linear Eq. 1 between the threshold and observed variables is derived as follows:

$$Y = 0.065X_1 + 0.161X_2 - 0.119X_3 - 0.021X_4 + 0.033X_5 + 2.69 \quad (1)$$

Where:

| | |
|---|---|
| Y = The threshold magnitude | $X_3$ = Soil moisture |
| $X_1$ = Slope | $X_4$ = Silt |
| $X_2$ = The vegetal cover | $X_5$ = Sand |

Table 2: Descriptive statistics of the selected model

| | | | | Change statistics | | | | |
|---|---|---|---|---|---|---|---|---|
| R | $R^2$ | Adjusted $R^2$ | SEE | $R^2$ change | F change | $df_1$ | $df_2$ | Sig. F change |
| 0.996 | 0.993 | 0.992 | 0.37069 | 0.993 | 1828.021 | 5 | 67 | 0.000 |

Predictors: (Constant), sand (%), Area slope (%), Initial moisture (%), Vegetation cover density (%), Silt (%)

Table 3: Correlation coefficients of runoff threshold magnitudes with independent variables

| | Unstandardized coefficients | | Standardized Coefficients | | |
|---|---|---|---|---|---|
| Parameter | B | SE | Beta | t-value | Sig. |
| Constant | 2.690 | 0.579 | | 4.645 | 0.000 |
| Area slope (%) | 0.065 | 0.011 | 0.066 | 5.925 | 0.000 |
| Vegetation cover (%) | 0.161 | 0.003 | 0.673 | 49.316 | 0.000 |
| Initial moisture (%) | -0.119 | 0.004 | -0.361 | -29.351 | 0.000 |
| Silt (%) | -0.021 | 0.011 | -0.062 | -1.938 | 0.057 |
| Sand (%) | 0.033 | 0.006 | 0.190 | 5.843 | 0.000 |

Dependent Variable: observed Runoff threshold (minute)

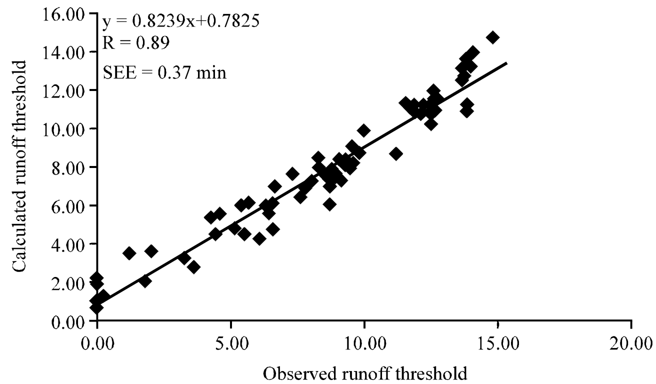


Fig. 3: The relation between actual and calculated runoff threshold

Considering the resulting values from Eq. 1 and using the observed data for the threshold, the diagram for the computed and the observed shown in Fig. 3 where the correlation coefficient has been calculated as 0.89 indicating fair simulation of the threshold.

**Rainfall Intensity of 32 mm h$^{-1}$**

Similar to the 24.5 mm h$^{-1}$ rainfall intensity, the backward model was selected with a 0.805 coefficient of determination with the same level of significance (Table 4, 5). The linear Eq. 2 was derived for the higher intensity as well.

$$Y = -0.026X_1 - 0.085X_2 + 0.009X_3 + 0.159X_4 + 0.133X_5 + 0.155X_6 - 8.598 \quad (2)$$

Where:

| | | |
|---|---|---|
| Y = The threshold magnitude | $X_3$ = Soil moisture | $X_6$ = Sand |
| $X_1$ = Slope | $X_4$ = Clay | |
| $X_2$ = The vegetal cover | $X_5$ = Silt | |

Figure 4 shows the observed thresholds and the computed ones from Eq. 2 with a regression coefficient of 0.87 showing a good accuracy of prediction.

Table 4: Descriptive statistics of the selected model

| | | | | Change statistics | | | | |
|---|---|---|---|---|---|---|---|---|
| R | $R^2$ | Adjusted $R^2$ | SEE | $R^2$ change | F change | $df_1$ | $df_2$ | Sig. F change |
| 0.897 | 0.805 | 0.787 | 0.843491 | 0.805 | 44.599 | 6 | 65 | 0.000 |

Predictors: (Constant), Sand (%), Area Slope(%), Initial Moisture(%),Vegetation Cover (%), Silt (%)
Dependent Variable: Observed runoff threshold (minute)

Table 5: Correlation coefficients of runoff threshold magnitudes with independent variables

| | Unstandardized coefficients | | Standardized coefficients | | |
|---|---|---|---|---|---|
| Parameter | B | SE | Beta | t-value | Sig. |
| Constant | -8.598 | 8.5980 | | 0.999 | 0.322 |
| Area Slope (%) | -0.026 | 0.0220 | -0.068 | -1.236 | 0.221 |
| Vegetation cover (%) | -0.085 | 0.0090 | -1.095 | -9.604 | 0.000 |
| Initial moisture (%) | 0.009 | 0.0080 | -0.072 | -1.094 | 0.278 |
| Clay (%) | 0.159 | 0.0860 | 0.738 | 1.841 | 0.070 |
| Silt (%) | 0.133 | 0.0850 | 1.313 | 1.559 | 0.124 |
| Sand (%) | 0.155 | 0.0888 | 1.298 | 1.764 | 0.082 |

Dependent variable: observed runoff threshold (minute)

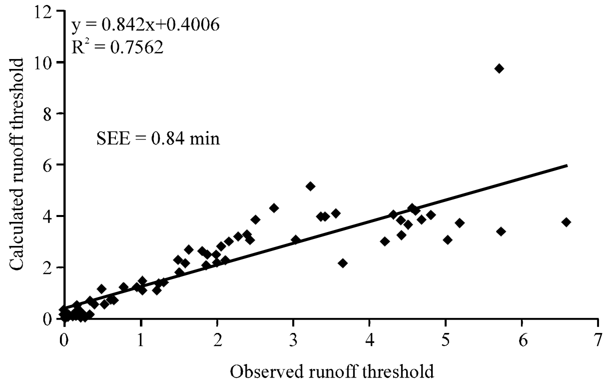


Fig. 4: The relation between actual and calculated runoff threshold

## CONCLUSIONS

The reviews of the results in this study and their comparison with those of the other research indicate a general compatibility between them. In the literature, the vegetal cover is highlighted as one important factor affecting runoff and also reducing the threshold in wet condition compared with the dry condition. Slope has been mentioned as another effective parameter. In this research both vegetal cover density and soil moisture were identified as the most effective parameters. Contradicting to the other results for both rainfall intensities tested, slope has indicated very low correlation with the threshold.

Considering time limitation of the current research tests were carried out for both 24.5 and 32 mm $h^{-1}$ only. The intensities tested in this research were found to be most frequent with return periods of 5 and 25 years. These experiments have to be carried out for a variety of rainfall intensities to extrapolate the results to other regions.

## ACKNOWLEDGMENTS

Honorable authorities of Soil Conservation and Watershed Management Research Institute (SCWMRI) are highly appreciated for supplying necessary materials and instruments for this research and especially the researcher's sincere thanks goes to the head and all staffs of the technical sector of SCWMRI who offered their valuable help in all phases of manufacturing and calibrating of the rainfall simulator and conducting related field experiments.

## REFERENCES

Armando, M., G. Gerard, V. Veerle, P. Jean, Z. Edwin and C. Felipe, 2007. Runoff generation in a degraded Andean ecosystem: Interaction of vegetation cover and land use. CATENA, 71: 357-370.

Charkhabi, M. and Z. Eskandari, 2003. Effect of soil moisture and time on runoff and sediment generation. Proceeding of 8th Soil Science Congress of Iran, 30 August-September 2, Rasht, Iran, pp: 899-901.

Cogo, N.P., W.C. Moldenhauer and G.R. Foster, 1983. Effect of crop residue, tillage-induced roughness and runoff velocity on size distribution of eroded soil aggregates. Soil Sci. Soc. Am. J., 47: 1005-1008.

Karnieli, A. and J. Been-Asher, 1993. A daily runoff simulation in semi-arid watersheds based on deficit calculations. J. Hydrol., 149: 9-25.

Katrien, D., N. Jan, P. Jean, R. Dirk, H. Mitiku, M. Bart and D. Seppe, 2006. Runoff on slopes with restoring vegetation: A case study from the Tigray highlands, Ethiopia. J. Hydrol., 331: 219-241.

Martínez-Mena, M., J. Albaladejo and V.M. Castillo, 1998. Factors influencing surface runoff generation in a Mediterranean semi-arid environment: Chicamo watershed, SE Spain. Hydrol. Procisses J., 12: 741-754.

Poncea, V.M. and A.V. Shetty, 1995. A conceptual model of catchment water balance: 2. Application to runoff and base flow modeling. J. Hydrol., 173: 41-50.

Raeesiyan, R., 2005. Investigation of slope, soil moisture conditions and land use in runoff generation time. Proceeding of 3rd Erosion and Sediment National Conference, August 27-30, Tehran, Iran, pp: 305-309.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool and D.C. Yoder, 1997. Predicting soil erosion by water: A guide to conservation planning with the revised soil loss equation (RUSLE). US Department A Agricultural Handbook (AH) 703. http://www.ott.wrcc.osmre.gov/library/hbmanual/rusle703.htm.

Sharifi, F., S. Safarpour, S.A. Ayoubzadeh and J. Vakilpour, 2004. An investigation of factors affecting runoff generation in arid and semi-arid area using simulation and rainfall runoff data. Iranian J. Natural Res., 57: 33-45.

Zobeck, T.M. and C.A. Onstad, 1987. Tillage and rainfall effects on random roughness-a review. Soil Tillage Res., 9: 1-20.