

# Rainfall simulation for the study of the effects of efficient factors on run-off rate

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Depending upon the watershed characteristics and weather conditions, a substantial part of the precipitation may be changed into run-off. Knowledge about the discharge and volume of the run-off generated by rainfall, especially in ungauged catchments, plays an important role in water resources management planning. In the absence of sufficient data recorded from the real rainfall events, use of rainfall simulators in the field and laboratory may be recommended to simulate run-off in different conditions of soil, vegetation cover, slope and rainfall. In this study, a rainfall simulator (a portable non-pressurized type) was used to examine the effects of slope steepness, vegetation cover, clay, sand, silt and antecedent soil moisture content on run-off amount. Two sets of simulated rainfall events with 24.5 and 32 mm/h intensity were applied on 145 experimental plots with dimensions 1.2 m × 0.89 m in Taleghan watershed, Iran, and the relevant run-off amounts were measured in each experimental plot. Based on the results obtained from the correlation matrix, the most influential factors on run-off were vegetation cover, antecedent soil moisture content, clay, sand, silt and slope, for rainfall intensity of 24.5 mm/h. While for the rainfall intensity of 32 mm/h, vegetation cover, sand, antecedent soil moisture content, silt, clay and slope were the most influential factors. Two regression equations were also developed for predicting surface run-off with different field and rainfall conditions.

**Keywords:** Antecedent soil moisture content, rainfall simulator, run-off rate, slope and vegetation cover.

SURFACE run-off is a part of the precipitation which flows over land after experiencing surface evaporation, storage and infiltration into the ground and finally runs out of the basin through the main rivers. Accumulation of rainwater and its conversion into floods, decreases the production efficiency in agricultural and pasture lands after every rainfall event due to washing and transporting away a considerable amount of fertile surface soil, which causes loss of valuable biological resources in addition to imposing heavy casualty and financial damage to industrial, urban and rural areas. Estimation of run-off rate with high accuracy not only leads to a realistic prediction of the de-

sign floods and decrease but also helps to optimize the cost of construction of projects.

Run-off yield depends on various factors such as soil permeability, precipitation intensity, slope steepness, antecedent soil moisture content, land use/type, and density of vegetation cover and soil texture. Considering the above-mentioned efficient factors, it is possible to decrease floodwater volume and the resultant damages, and control the accelerating soil erosion and optimal use of precipitation.

According to Warrington *et al.*<sup>1</sup>, an increase in the slope in unstable soil slightly decreased the run-off rate. As one of the reasons for the impermeability of unstable soil in semi-arid areas is the formation of a surface sealing during rainfall, an increase in the slope leads to erosion and removal of such a sealing and consequently results in an increase in permeability rate and decrease in run-off.

Eatemadi<sup>2</sup> examined the effect of various factors on the value of run-off coefficient in Darjazin basin, Semnan, Iran, and obtained the following results: (i) the value of the run-off coefficient changes with a change in each of the influential factors; (ii) with increase in the rainfall intensity, run-off coefficient shows an increasing trend; (iii) the run-off coefficient shows a descending trend with increase in air temperature; (iv) with increase in the value of the antecedent soil moisture, the run-off coefficient shows an increasing trend, and (v) with increase in the amount of evaporation and transpiration, the run-off coefficient decreases.

Giorddanengo<sup>3</sup> examined the effect of vegetation cover with three values of 0, 30 and 60% on run-off production. The results of this study showed that in the first year, the decrease in vegetation cover affected the run-off yield significantly, and the starting time of run-off was found to depend on the total live plant area and topography.

Lasanta *et al.*<sup>4</sup> calculated the sediment yield in fallow land as 40 g/m<sup>2</sup> and the sediment concentration as 12 g/l in a study to estimate the run-off and sediment yield using a rainfall simulator in a semi-arid region. Based on the results obtained, they recommended the use of the rainfall simulator.

In a study in Spain, the amount of run-off and sediment in over-grazed terraces was calculated using a rainfall simulator to examine the effect of livestock grazing on the amount of run-off and sediment. The results of these experiments showed that the velocity and intensity of the

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hydrologic response and erosion increased due to overgrazing of plots<sup>5</sup>.

Barthes and Roose<sup>6</sup> used a rainfall simulator to study the relationships between run-off and erosion in small plots of 1 m × 1 m. After reviewing the results of the experiments, they concluded that these were almost similar to the results obtained from field studies. In this study, the run-off depth and the amount of soil erosion with a 30 min rainfall data did not show any significant relation with organic carbon. But when the rainfall continued, the run-off rate and sediment concentration showed significant correlation with organic carbon. The difference between run-off yield in the two antecedent moisture conditions (dry and wet) was high and the run-off rate reached its peak during simulated rainfall in wet soil, a short while after the commencement of rainfall.

The objective of this study was to determine the effect of slope steepness, vegetation cover, clay, sand, silt and antecedent soil moisture content on the run-off discharge using a rainfall simulator in the Taleghan basin, as a representative mountainous terrain in Iran.

## Materials and methods

### *General characteristics of the study area*

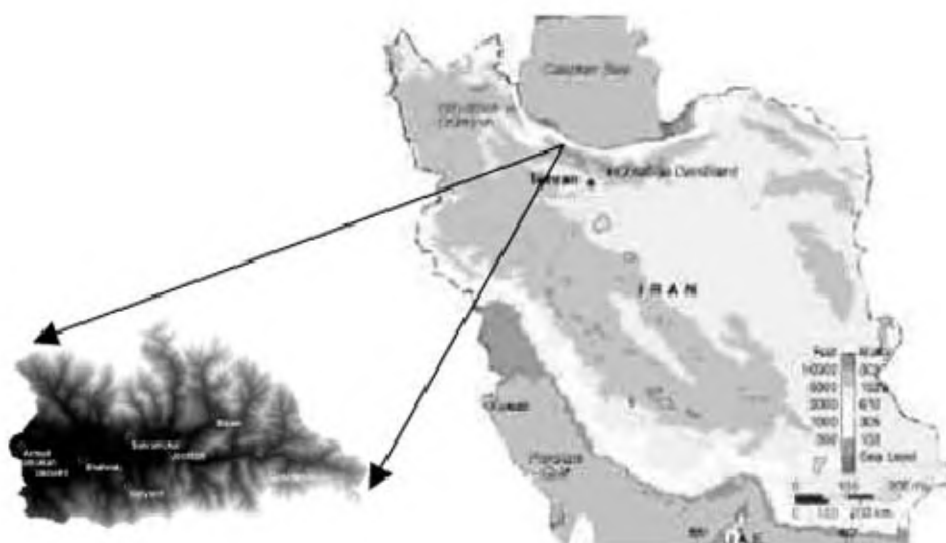
The Taleghan basin is located in the southern part of Alborz, about 100 km from Tehran. This watershed is bounded in the north by the Alamoot basin, in the south by Zeyaran and Samgh Abad, in the east by a part of the Karaj basin and in the west by the Shahrood basin. This watershed is located between the two northern latitudes of 36°31'5" and 36°23'37" and between the two eastern longitudes of 50°21' and 51°1'16". The mean annual precipitation of this region is 591 mm. The area of the

Taleghan basin is about 1135 km<sup>2</sup>. Figure 1 shows the location of the Taleghan basin.

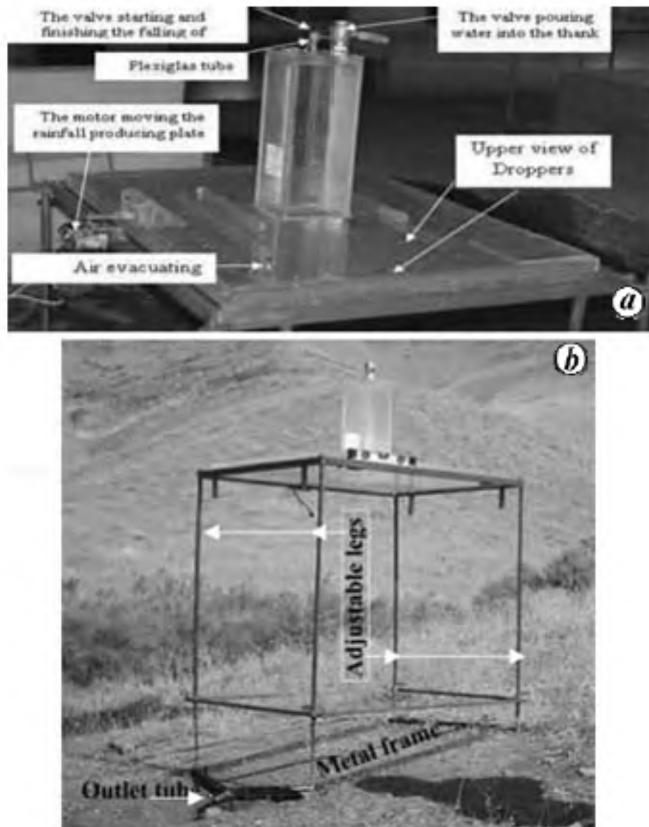
### *Rainfall simulator specifications*

The rainfall simulator used is a portable non-pressurized type made of Plexiglas, with dimensions of 120 cm × 89 cm and with adjustable legs of 1.5 m height, which can be used on various slopes. This rainfall simulator with 51.6 l storage tank can produce rainfall for different duration. For uniform distribution of raindrops over the experimental plots, an electro-motor was fitted on the metal framework of the rainfall storage tank to shake the plate horizontally. Raindrops without initial speed fall freely through the dropper under gravitational force. The raindrop-producing plate has 216 perforations serving as the dropper.

A Plexiglas tube was inserted into the storage tank (through a hole on the roof) in such a way that one end (input) with a plastic cap stands out of the tank on the upper surface and the other end rests on the floor of the tank. The tube plays the role of a starter and regulator in the rainfall simulator. After filling the tank with water through the fixed input and evacuating the air inside, which was done properly when the device was sufficiently levelled, the water input valve, the air-evacuating valve and the cap of the regulating tube (Plexiglas tube) were closed immediately to prevent the tank from being emptied. In this case, after a few seconds no drops fell out of the dropper. In order to have the designed rainfall intensity, the regulating tube (Plexiglas tube) was placed at the calculated height and when the cap of the tube was removed, rainfall began. The rainfall intensity depends on the distance of the lower end of the regulating tube (Plexiglas tube) from the tank floor. Different components and a general view of the rainfall simulator are shown in Figure 2.



**Figure 1.** Location of the Taleghan basin in Iran.



**Figure 2.** Components (a) and general view (b) of the rainfall simulator.

In this study, rainfall of 24.5 and 32 mm/h intensity with 30 min duration was produced using the rainfall simulator on plots with 120 cm × 95 cm dimension in a range of slopes with different antecedent soil moisture contents in some areas of the Taleghan basin. During and at the end of each of the 145 experiments, certain parameters such as run-off rate were measured.

#### *Characteristics of the experimental plots*

To achieve the objectives of the present study, the necessary data were collected and reviewed through field survey and library studies of topographic maps of scale 1/50,000; the satellite images of the watershed were also collected. After preparing the location map of the area, the experiments were conducted using maps of soil, vegetation cover and roads. Also, field experiments using a portable rainfall simulator were conducted in plots of the watershed for determining run-off rate.

Making use of the available maps, i.e. soil, slope and vegetation cover from the study area, the locations of the experimental plots on the rangelands of the watershed were determined. The following conditions were considered in the selection of independent field variables:

1. Slopes in two classes, i.e. 12–20 and 20–30%.

2. Rangelands with poor (9–24%) and medium (24–49%) vegetation cover.
3. Locations with a well-balanced distribution in soils with light, medium and heavy texture.

The amount of soil moisture as an independent variable was measured using a Time Domain Reflectometry (TDR) device before starting each experiment. The given independent variables and the amount of run-off caused by the simulated rainfall intensity were recorded in the prepared forms for each experiment. Finally, the recorded results were analysed.

#### *Statistical analysis*

The correlation matrix and multi-variable regression method were used to determine the degree and type of relationship between the variables such as slope, vegetation cover, sand, clay, silt and antecedent soil moisture content with run-off rate and to present the relationship between the given independent variables with run-off rate and coefficient at two rainfall intensities of 24.5 and 32 mm/h. Backward method was used to examine the regression relationship between the dependent variable and the measured variables. Data on descriptive statistics model, ANOVA, and dependent variables were used to select the appropriate model among the developed ones.

### **Results and discussions**

In this study, a rainfall simulator was used to examine the effect of slope, vegetation cover, clay, sand, silt and antecedent soil moisture content on run-off yield. Rainfall with 24.5 and 32 mm/h intensity was simulated on 145 experimental plots in the Taleghan watershed and the run-off yield was measured from each experimental plot. The following results were obtained from the study.

#### *To examine the effect of variables on run-off rate*

The graphs of independent variables (clay, sand, silt, slope, vegetation cover and antecedent soil moisture content) and run-off rate for rainfall intensity of 24.5 and 32 mm/h were prepared. Visual interpretation of distribution graphs obtained from the results of the experiments for the above rainfall intensities indicated that there is high correlation between clay and run-off rate for rainfall intensity of 24.5 mm/h, whereas for rainfall intensity of 32 mm/h, high correlation is observed between antecedent soil moisture content and run-off. In order to determine the degree and type of relationship of each one of the variables, i.e. slope, vegetation cover, sand, clay, silt and soil moisture with run-off rate for the above-mentioned rainfall intensities, the correlation matrix between the given variables was prepared (Table 1).

**Table 1.** Correlation matrix between run-off and independent variables (%)

Rainfall intensity (mm/h)	Parameter	Area of slope (%)	Vegetation cover (%)	Antecedent soil moisture (%)	Clay (%)	Silt (%)	Sand (%)
24.5	Pearson correlation	0.144	-0.903*	0.584*	0.449**	0.154	-0.331*
	Sigma (two-tailed)	0.225	0.000	0.000	0.000	0.193	0.004
32.0	Pearson correlation	0.058	-0.872*	0.662*	0.184	0.551**	-0.702*
	Sigma (two-tailed)	0.631	0.000	0.000	0.121	0.000	0.000

\*Correlation is significant at the 0.01 of confidence level (two-tailed test).

Based on the correlation matrix in Table 1 which confirms the visual interpretation of distribution graphs of the independent and dependent variables, the effective variables on run-off rate in rainfall intensity of 24.5 mm/h are respectively, vegetation cover, antecedent soil moisture content, clay, sand, silt and slope percentages in their order of importance, while for rainfall intensity of 32 mm/h vegetation cover, sand, antecedent soil moisture content, silt, clay and slope are the most import effective factors.

As seen from these results, the correlation coefficients of all the above variables except sand and vegetation cover are positive, which indicates an increase in run-off rate when these variables are increased. In other words, when antecedent soil moisture content, silt, clay and slope increase, the run-off yield also increases which testifies to the logical relationship between these variables and the run-off rate. On the other hand, considering the negative correlation coefficient of sand and vegetation cover with run-off rate, with an increase in these variables, the run-off yield will decrease.

Based on the values of their correlation coefficients, the degree of correlation of the examined independent variables with the run-off rate for rainfall intensities of 24.5 and 32 mm/h can be interpreted as follows: the correlation coefficients between slope, silt and sand with run-off rate for rainfall intensity of 24.5 mm/h are 0.144, 0.154 and 0.331 respectively. For rainfall intensity of 32 mm/h, the correlation coefficients between slope and clay with run-off rate are 0.058 and 0.184 respectively. Though the given coefficients are statistically significant, they are low. The results presented regarding correlation matrix for rainfall intensity of 24.5 mm/h, soil moisture and clay with correlation coefficients of 0.584 and 0.449 respectively, and for rainfall intensity of 32 mm/h, silt with correlation coefficient of 0.551 with run-off rate in 0.01 level of confidence are significant. The variables for which their correlation coefficients fall within the range 0.35–0.65 by integrating with other variables can be used to predict run-off with acceptable error. For rainfall intensity of 24.5 mm/h, vegetation cover with correlation coefficient of -0.903 and for rainfall intensity of 32 mm/h, vegetation cover and sand with correlation coefficients of -0.872 and -0.702, respectively have a significant relationship with run-off rate at level of 0.01. The variables which their correlation coefficients fall

within 0.65 to 0.85 can be used in high accuracy of predictions.

### *Correlation between the considered variables and obtained run-off rate*

One of the fundamental goals in statistical investigations is to find a relationship between two or more variables. These relationships can be used to estimate the values of dependent variables for different conditions of existing independent variables, based on the established relationship. As run-off yield resulting from two applied rainfall intensities of 24.5 and 32 mm/h were measured separately in 73 and 72 experimental plots, the stepwise and backward methods were used to determine the relationship between the considered variables, including slope, vegetation cover, antecedent soil moisture content, clay, silt and sand with the measured run-off rate for the above rainfall intensities. The results for the above rainfall intensities are as follows.

**Rainfall intensity of 24.5 mm/h:** The backward method presents four models between independent variables and run-off rate. By examining the descriptive statistics and magnitude of the significance degree in the ANOVA table prepared for the models of both methods, model number 1 of the backward method with significance degree of Fisher test equals to 0.000, which is statistically significant at 99% and with  $R^2 = 0.907$ , indicating that 90.7% of the observed distribution of the dependent variables is justified by five independent variables. The value of  $R = 0.953$ , which implies its proper predicting capability, was the reason for it to be selected as an appropriate model for predicting the run-off yield for rainfall intensity of 24.5 mm/h for different values of the above independent variables. Descriptive statistics, ANOVA table and regression coefficients of the selected model are presented in Tables 2, 3 and 4 respectively.

To examine the regression relationship between the dependent variable and the calculated variables, a linear relation between them was developed. Correlation coefficients between run-off rate and variables, such as slope, vegetation cover, antecedent soil moisture content, clay and sand are given in Table 4. Using the data from Table 4,

**Table 2.** Descriptive statistics of the selected model (rainfall intensity = 24.5 mm/h)

<i>R</i>	<i>R</i> <sup>2</sup>	Adjusted <i>R</i> <sup>2</sup>	Standard error of the estimate	Change in statistics				
				<i>R</i> <sup>2</sup> change	<i>F</i> change	<i>df</i> 1	<i>df</i> 2	Sigma <i>F</i> change
0.953	0.907	0.900	0.366886	0.008	5.800	1	67	0.019

Predictors: (Constant), sand (%), area of slope (%), initial moisture (%), vegetation cover density (%), clay (%).

**Table 3.** Variance analysis (rainfall intensity = 24.5 mm/h)

Parameter	Sum of squares	<i>df</i>	Mean square	<i>F</i>	Sigma
Regression	88.379	5	17.676	131.315	0.000(a)
Residual	9.019	67	0.135		
Total	97.397	72			

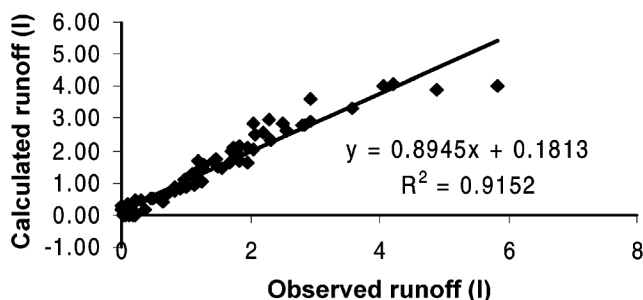
Predictors: (Constant), sand (%), area of slope (%), initial moisture (%), vegetation cover density (%), clay (%).

Dependent variable: Observed run-off rate (l).

**Table 4.** General relationship between coefficients of run-off yield and the examined variables (rainfall intensity = 24.5 mm/h)

Parameter	Unstandardized coefficients		Standardized coefficients		Sigma
	<i>B</i>	Standard error	Beta	<i>t</i>	
Constant	0.787	0.606		10.572	0.000
Area of slope (%)	-0.026	0.011	-0.096	-2.408	0.019
Vegetation cover (%)	-0.044	0.003	-0.664	-13.651	0.000
Initial moisture (%)	0.030	0.004	0.329	7.486	0.000
Clay (%)	-0.053	0.011	-0.562	-4.881	0.000
Sand (%)	-0.025	0.006	-0.568	-4.903	0.000

Dependent variable: Observed run-off rate (l).

**Figure 3.** Relation between calculated and actual run-off (rainfall intensity = 24.5 mm/h).

a linear relationship between the dependent variable of run-off rate and the independent variables, such as slope, vegetation cover, soil moisture, silt and sand has been developed:

$$RU = 0.787 - 0.026SL - 0.044VC + 0.030ASM - 0.053C - 0.025Sa, \quad (1)$$

where RU is the run-off rate, SL the slope (%), VC the vegetation cover (%), ASM the antecedent soil moisture content (%), C the clay (%) and Sa is sand (%).

Considering the results obtained from the eq. (1) and the measured values of run-off rate, a graph between the actual and the calculated run-off rates was plotted (Figure 3). The correlation coefficient between the calculated run-off and the actual run-off was calculated as 0.96 and determination coefficient is equal to 0.91 with significant level  $\alpha = 1\%$ . This means that the eq. (1) can simulate the actual run-off rate with high accuracy.

**Rainfall intensity of 32 mm/h:** Model number 1 of the backward method was selected from the three models presented. The significance degree of Fisher test equals to 0.000, which is statistically significant at 99%. A value of  $R^2 = 0.815$  for this model indicates that 81.5% of the observed distributions of dependent variables is justified by the six investigated variables, i.e. slope, vegetation cover, antecedent soil moisture, clay, silt and sand. The value of  $R = 0.903$  also indicates high capability of prediction of the selected model. Therefore, this model can be appropriate for predicting run-off yield for rainfall intensity of 32 mm/h for different conditions of the given independent variables. Descriptive statistics, ANOVA table and regression coefficients of the selected model for this rain-

**Table 5.** Descriptive statistics of the selected model (rainfall intensity = 32 mm/h)

<i>R</i>	<i>R</i> <sup>2</sup>	Adjusted <i>R</i> <sup>2</sup>	Standard error of the estimate	Change in statistics				
				<i>R</i> <sup>2</sup> change	<i>F</i> change	<i>df</i> 1	<i>df</i> 2	Sigma <i>F</i> change
0.903	0.815	0.797	0.8217	0.815	47.572	6	65	0.000

Predictors: (Constant), sand (%), area of slope (%), antecedent soil moisture (%), vegetation cover (%), silt (%) and clay (%).

Dependent variable: Observed run-off rate (l).

**Table 6.** Variance analysis (rainfall intensity = 32 mm/h)

Parameter	Sum of squares	<i>df</i>	Mean square	<i>F</i>	Sigma
Regression	192.741	6	32.124	47.572	0.000
Residual	43.892	65	0.675		
Total	236.633	71			

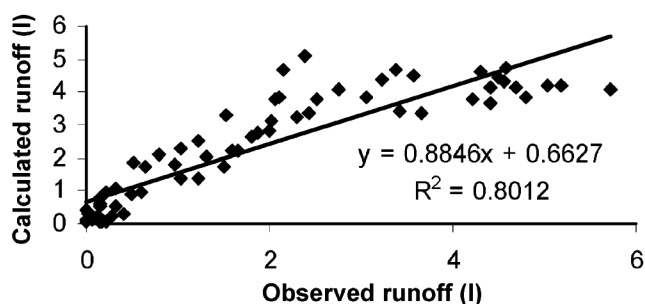
Predictors: (Constant), sand (%), area of slope (%), antecedent soil moisture (%), vegetation cover (%), silt (%) and clay (%).

Dependent variable: Observed run-off rate (l).

**Table 7.** General relationship between coefficient of run-off yield with the examined variables (rainfall intensity = 32 mm/h)

Parameter	Unstandardized coefficients		Standardized coefficients		
	<i>B</i>	Standard error	Beta	<i>t</i>	Sigma
Constant	-12.847	8.325		-1.543	0.128
Area of slope (%)	-0.026	0.022	-0.068	-1.211	0.230
Vegetation cover (%)	-0.076	0.009	-0.985	-8.339	0.000
Initial moisture (%)	0.034	0.015	0.159	2.179	0.033
Clay (%)	0.190	0.083	0.882	2.281	0.026
Silt (%)	0.161	0.083	1.584	1.944	0.056
Sand (%)	0.187	0.085	1.683	2.201	0.031

Dependent variable: Observed run-off rate (l).

**Figure 4.** Relation between actual and calculated run-off (rainfall intensity = 32 mm/h).

fall intensity are presented in Tables 5, 6 and 7 respectively.

The correlation coefficients between run-off rate and independent variables, i.e. slope, vegetation cover, antecedent soil moisture content, clay, silt and sand were also determined (Table 1). A linear relationship was developed between the dependent variable of run-off rate and the independent variables of slope, vegetation cover, antecedent soil moisture content, clay, silt and sand:

$$RU = -12.847 - 0.026S - 0.076VC + 0.034ASM + 0.190C + 0.161Si + 0.187Sa, \quad (2)$$

where RU is the run-off rate (mm), S the slope (%), VC the vegetation cover (%), ASM the antecedent soil moisture content (%), C the clay (%), Si the silt (%) and Sa the sand (%).

Considering the results obtained from eq. (2) and the measured values of run-off, a graph between the actual and the calculated run-off was plotted (Figure 4). Figure 4 shows that the correlation coefficient of calculated run-off and actual run-off is 0.90 and the determination coefficient is 0.80, with significant level  $\alpha = 1\%$ . This implies that eq. (2) simulates the actual run-off rate with reasonable accuracy. The slope of this equation is about 0.88 with  $\alpha = 1\%$  or 99% significant.

## Conclusion

The results of this study compare well with those of other studies<sup>7</sup>, indicate a general coordination and consistency

in the results. Earlier studies have shown that vegetation cover has an effective role in decreasing the amount of run-off. The initial soil moisture with high regression coefficient (0.584–0.662) with run-off increases the amount of run-off. Vegetation cover was considered to have an effect on run-off, indicating a decrease in run-off yield in wet conditions compared to dry conditions. On the other hand, slope had negligible effect on run-off. The results of this study showed vegetation cover and antecedent soil moisture as the most influential factors. Also, for both rainfall intensities used, the slope percentage had a low correlation with run-off.

Due to matrix correlation presented in Table 1 for two different intensities, the relations between run-off and independent variables have logical trend. In regression function numbers 1 and 2, the relation is at variance from binary relation. It seems that the interaction between variables can change the result in function 1 and 2 at two different intensities.

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## MEETINGS/SYMPOSIA/SEMINARS

### 2nd International Conference on Physics at Surface and Interfaces (PSI 2009)

Date: 23–27 February 2009

Place: Puri, India

Topics include: Growth; Structural, electronic and magnetic properties; Surface and interface modifications by energetic particle interactions; Multilayers; Semiconductor heterostructures; Quantum devices; Catalysis; Patterned surfaces using FIB and e-beams; New techniques.

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### National Symposium on Recent Trends and Developments in Analytical Instrumentation and Methodologies

Date: 18–20 March 2009

Place: Hyderabad

Topics include: Mass Spectrometry; Chromatography Techniques; X-ray Techniques; Nuclear Analytical Techniques; Emission, Absorption and fluorescence spectroscopy; Hyphenated Techniques; Environmental Analysis; Separation/Preconcentration Methods; Trace Analysis and Speciation; Analytical Instruments Design and Development; Geochemical/Exploratory Mining Analysis.

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