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NOTE

EFFECT OF VEGETATION COVER, SLOPE, AND RAINFALL INTENSITY ON RUNOFF IN SOME WATERSHEDS OF CHAHARMAHAL AND BAKHTIARY PROVINCE

S. F. MOUSAVI AND R. RAISIAN[1]

Department of Irrigation, College of Agriculture, Isfahan University of Technology, Isfahan, I.R. Iran.

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ABSTRACT

Surface runoff is an important component of the hydrologic cycle. Runoff and water losses may be influenced by the watershed management strategies. The amount of surface runoff depends on precipitation and physiographic characteristics of the watersheds. The main objectives of the present study were to investigate the effects of vegetation cover, slope, and rainfall intensity on runoff in Chaharmahal and Bakhtiary Province. The experiments were performed in Baba-Haidar (3,000 ha), Dareh-Zanioni (18,000 ha), and Hadj-Kohva (2,000 ha) regions located in Behesht-Abad catchment. Three natural cover conditions (poor, fair, and good), three slope classes (10-15%, 15-20%, and 25-30%) and different rainfall intensities (14-91.4 mm h^{-1}) were considered. A rainfall simulator, with 1 m^2 of cover area, was designed to make the rains. This rainfall simulator was installed over the plots to shed the rain drops. The results showed that for slope class of 15-20% and poor vegetation cover, rainfall intensity of 50 mm h^{-1} and duration of 180 min produced 77.7 mm of runoff. The same

1. Associate Professor and former Graduate Student (now at Research Center for Animal Science and Natural Resources, Shahrekord) College of Agriculture, Isfahan University of Technology, Isfahan, I.R. Iran, respectively.

slope class and rainfall intensity but with fair vegetation cover produced 39.7 mm of runoff (a 48.9% decrease). For slope class of 10-15% and poor vegetation cover, rainfall intensity of .50 mm h^{-1} and duration of 180 min produced 60.6 mm of runoff. Increasing this slope to 25-30% caused 78.4 mm of runoff to run (a 29.4% increase). Changing the vegetation cover to fair condition, the slope class of 25-30% produced only 57 mm of runoff. So, improving the vegetation cover caused the greatest reduction in runoff. The rainfall intensity of 91.4 mm h^{-1}, when lasted for 63 min, resulted in sediment concentration of 24.46 g l^{-1} in runoff water, while rainfall intensity of 14 mm h^{-1} when lasted for 143 min resulted in sediment concentration of 4 g l^{-1}.

Key Words: Rainfall intensity, Rainfall simulator, Surface runoff, Vegetation cover.

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تاثیر پوشش گیاهی، شیب و شدت بارندگی بر رواناب در چند حوضه آبخیز استان چهار محال و بختیاری

سید فرهاد موسوی و روانبخش رئیسیان

به ترتیب دانشیار و دانشجوی سابق کارشناسی ارشد (اکنون در مرکز تحقیقات امور دام و منابع طبیعی چهار محال و بختیاری، شهر کرد) دانشکده کشاورزی، دانشگاه صنعتی اصفهان، اصفهان، جمهوری اسلامی ایران.

چکیده

رواناب سطحی یکی از اجزای مهم چرخه هیدرولوژیک است. رواناب و هدر روی آب ممکن است تحت تاثیر راهبردهای مدیریتی حوضه های آبخیز قرار گیرد. مقداررواناب سطحی بستگی به بارندگی و خصوصیات فیزیوگرافیک حوضه های آبخیز دارد .هدف اصلی این تحقیق بررسی اثرات پو شش گیاهی، شیب و شدت بارندگی بر رواناب در چند حوضه آبخیز استان چهار محال و

بختیاری بود . آزمایش در مناطق باباحیدر (با وسعت ۳۰۰۰ هکتار)، دره زانیونی (با وسعت ۱۸۰۰۰ هکتار) و حاج کهوا (با وسعت ۲۰۰۰ هکتار) در حوضه بهشت آباد انجام شد. سه حالت پوشش گیاهی طبیعی (کم، متوسط و خوب)، سه کلاس شیب (۱۵٪-۱۰، ٪۲۰-۱۵ و ٪۳۰-۲۵) و شدت های مختلف بارندگی (۱۴ تا ۹۱/۴ میلی متر در ساعت) درنظر گرفته شد. یک شبیه ساز باران، با مساحت تحت پوشش یک متر مربع، برای ایجاد باران، طراحی و ساخته شد. این شبیه ساز باران برای ایجاد باران با شدت های مختلف روی پلات های آزمایشی قرار داده شد. نتایج نشان داد که برای کلاس شیب ٪۲۰-۱۵ و پوشش گیاهی کم، شدت بارندگی ۵۰ میلی متر در ساعت و مدت ۱۸۰ دقیقه، ۷۷/۷ میلی متر رواناب ایجاد کرد. همین شیب و شدت بارندگی، اما با پوشش گیاهی متوسط ۳۹/۷میلی متر رواناب تولید کرد (٪۴۸/۹ کاهش). برای شیب ٪۱۵-۱۰ و پوشش گیاهی کم، بارندگی ۵۰ میلی متر در ساعت و مدت ۱۸۰ دقیقه فقط ۶۰/۶ میلی متر رواناب ایجاد کرد. افزایش این شیب به ٪۳۰-۲۵، باعث ایجاد ۷۸/۴ میلی متر رواناب شد (یعنی افزایش ٪۲۹/۴) . با تغییر پوشش گیاهی به حالت متوسط، شیب ٪۳۰-۲۵، ۵۷ میلی متر رواناب تولید کرد. هنگامی که بارندگی با شدت ۹۱/۴ میلی متر در ساعت برای ۶۳ دقیقه ادامه یافت، غلظت رسوب در رواناب ۲۴/۴۶ گرم در لیتر شد، در حالی که بارندگی با شدت ۱۴ میلی متر در ساعت و دوام ۱۴۳ دقیقه باعث غلظت رسوب ۴ گرم در لیتر در رواناب گردید.

INTRODUCTION

Surface runoff in watersheds is one of the most important components of the hydrologic cycle. It usually causes erosion and silting of reservoirs, irrigation canals, and drainage ditches. Runoff and water losses are mainly due to improper use of the watersheds and could be reduced with proper management. Surface runoff resulting from precipitation is a function of rainfall amount and intensity, vegetation cover, soil characteristics, evapotranspiration, land use and topography (8, 10). Estimation or measurement of runoff has wide application in hydrologic studies.

A major objective in watershed management is protection of topsoil, which contains crop coverage and plant nutrients, from removal by runoff and preventing deposition of sediments in reservoirs and canals. Erosion and deposition are related to surface runoff, and the soil surface cover is of prime importance in controlling the runoff. Obtaining a representative distribution of rainfall intensities and quantities for quantitative evaluation of the effects of rainfall intensity, slope and vegetation cover on infiltration or runoff processes under natural events usually requires many years of data collection. This is time consuming and requires a network of instrumentation in each area.

Because of such difficulties, rainfall simulators are used instead. Rainfall simulators are designed to apply water in a form similar to natural rainstorms. The rainfall simulators are more rapid, more efficient, more controlable, and more adaptable than natural rainfall (8). But the cost and time required to construct a suitable simulator and related pieces of equipment and the personnel needed to operate an effective simulated rainfall research program are generally the greatest drawbacks.

Different types of rainfall simulators exist. Swartzendruber and Hillel (17) used a Purdue-Wisconsin sprinkling simulator on plots of 1 m^2 to test runoff and infiltration equations on a loamy sand soil subjected to constant intensity simulated rainfall. A rotating boom simulator was used to evaluate the effects on infiltration and runoff of removing cattle from a native shortgrass rangeland site in the Central Great Plains (7), or to investigate infiltration process (14). Rotodisk rainfall simulator and tank drip-type rain simulator were used to study infiltration and erosion (10, 16).

Rainfall simulators have been used to evaluate infiltration and runoff under different conditions. Radcliffe *et al.* (12) used a rainfall simulator to determine infiltration on bare and straw covered tilled loamy sand soil. Final infiltration rates were significantly lower in the bare soil because of surface sealing. These seals were formed due to surface compaction and disruption by raindrops. If enough rainfall and climatic data are available, mathematical rainfall-runoff models may also be used to estimate runoff (3, 4).

The objectives of this study were: 1) to design an economic and simple tank drip-type rainfall simulator; 2) to quantitatively evaluate runoff characteristics on natural slopes by combining detailed rainfall intensity information and surface characteristics in some watersheds of Chaharmahal and Bakhtiary Province in central Iran.

MATERIALS AND METHODS

Study Area

Chaharmahal and Bakhtiary province, with an area of 16,533 km^2, is located in central Iran. It is a mountainous area with the highest point of 4,221 m and lowest point of 800 m above mean sea level. Average annual rainfall is estimated as 695 mm for this province. On annual basis, about 8.5 and 0.9 billion cubic meters of overland runoff water of this province discharges into Karun and Zayandehrud rivers, respectively.

The research area about 3860 km^2 is located in Behesht-Abad catchment, in the northern part of the province. Three study regions namely Baba-Haidar (in Sarab sub-basin, 3000 ha), Dareh-Zanioni (in Gorgak sub-basin, 18000 ha), and Hadj-Kohva (in Kharaji sub-basin, 2,000 ha) with mean elevation of 2180, 2280, and 2420 m above mean sea level, respectively, were selected in the catchment. Their long-time average rainfall are 393, 446, and 925 mm. They are located about 5, 15, and 55 km from the center of the province (Shahrekord), respectively. The average annual temperature of the nearest station (Shahrekord) to the regions is 11.9 °C. The natural vegetation cover in these regions is mainly *Astaracantha adscendens* Boiss, *Phlomis persica* Boiss, *Scariola orientalis* (Boiss) Sojak, and *Cousinia bachtiarica* Boiss & Hausskn, which according to Raunkiaer system of classification (11) are microphanerophyte (shrub), hemicryptophyte (herbaceous perennials), chamaephyte (bush), and hemicryptophyte (herbaceous perennials), respectively.

Plot Design

Since characteristics of watersheds have a wide variability, studying the effect of one factor on runoff production needs a homogeneous and uniform environment. So, as the smaller plot size is selected, this uniformity is attained easier and the results are more accurate. However, extrapolating data to large and diverse areas would be erroneous. It is good to have a large plot to include the variability, but coverage area of rainfall simulator is the limiting factor. Difficulties in supplying water for conducting the experiments in the elevated area of the watersheds, transport of the pieces of equipment and expense of constructing a big rainfall simulator are among other factors which limit selecting large plots. On this basis, 1 m^2 plot size was selected. Swartzendruber and Hillel (17) used 1 m^2 and Morin and Kosolovsky (10) used 1.5 m^2 runoff plots.

Rainfall Simulator

Figs. 1 and 2 show the simple tank drip-type rainfall simulator designed and constructed by the authors (13). This equipment is cheap and easy to carry to elevate watersheds. The water supply is by a cylindrical graduated tank, mounted on a tripod. Mariott-bottle mechanism is used in the tank to keep a uniform outflow rate. Water passes through a hose from the tank to 11 interconnected polyethylene pipes, each 105 cm long, and then sheds from 384 drippers arranged in a spacing of 5×5 cm. An aluminium frame of 105×107.5 cm and three cross-bars prevent the curvature of the water pipes, specially when they are full of water.

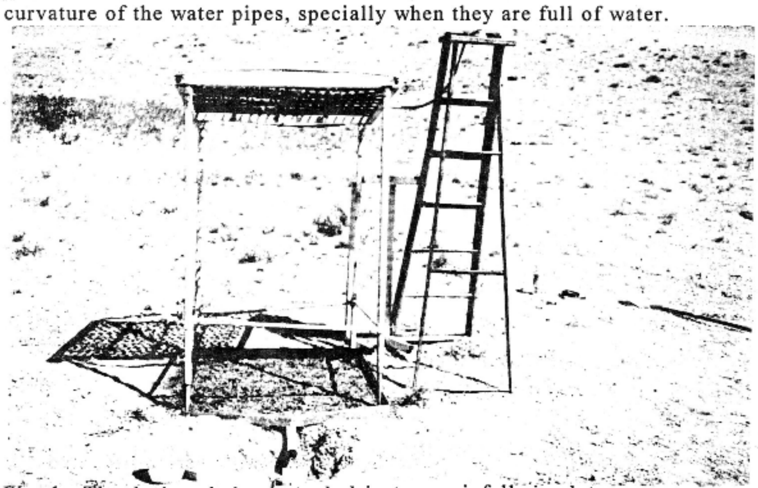

Fig. 1. The designed simple tank drip-type rainfall simulator.

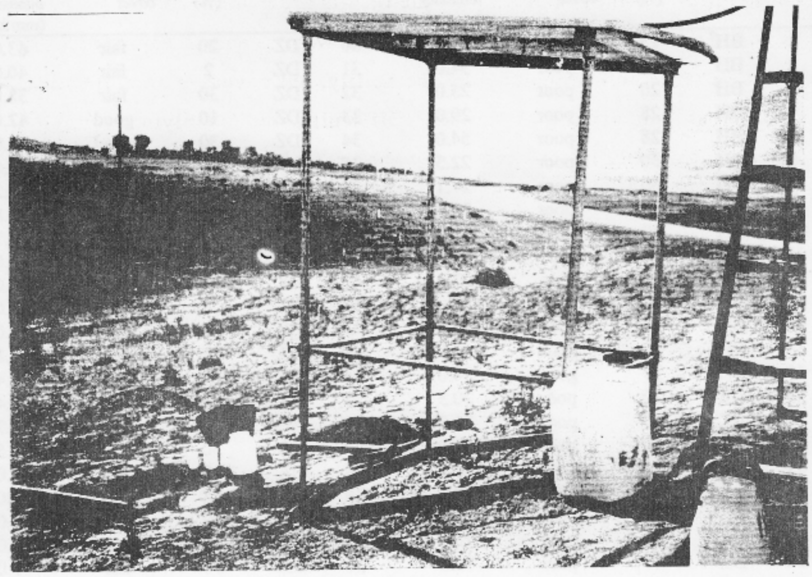

Fig. 2. Another view of rainfall simulator at work.

To raise the water pipes and drippers to the required elevation, 4 adjustable vertical bars (with a length of 165 cm) are screwed to the frame. This system works very well in sloping lands. As it is known, the impact of water droplets from the rain or overhead sprinklers can cause a seal to form on the soil surface. This feature is very common in arid and semiarid regions, and has a prominent effect on reduction of infiltration and inducing runoff and soil erosion (1, 2). We expect that not much sealing occurs from water droplets falling from a height of 165 cm, specially when the soil surface is covered by vegetation.

To bound the experimental plots, a metal quadrant of 1 m × 1 m was used and surface runoff was channeled into a pit where outflow runoff volume was measured with a wide-mouth graduated jar. The runoff volume was then converted to runoff depth. Different rainfall intensities were simulated by adjusting the drippers. Simulated rain was continued for 3 hours in all the experiments. Table 1 shows the intensities applied on the experimental plots.

Table 1. Characteristics of the experimental plots.

No	Region	Slope (%)	Vegetation cover	Rainfall intensity (mm h^{-1})	No.	Region	Slope (%)	Vegetation cover	Rainfall intensity (mm h^{-1})
1	BH†	13	poor	59.0	30	DZ	20	fair	43.0
2	BH	15	poor	54.0	31	DZ	2	fair	40.0
3	BH	20	poor	25.0	32	DZ	30	fair	38.0
4	BH	28	poor	29.0	33	DZ	10	good	42.0
5	BH	28	poor	54.0	34	DZ	30	good	35.0
6	BH	30	poor	22.5	35	HK	10	poor	16.0
7	BH	30	poor	27.1	36	HK	10	poor	41.2
8	BH	30	poor	32.0	37	HK	10	poor	64.8
9	BH	30	poor	33.0	38	HK	10	poor	86.7
10	BH	20	fair	17.6	39	HK	20	poor	14.0
11	BH	28	fair	27.0	40	HK	20	poor	20.0
12	BH	20	fair	33.0	41	HK	20	poor	50.0
13	BH	20	good	36.0	42	HK	20	poor	62.0
14	BH	30	good	40.0	43	HK	25	poor	25.8
15	BH	30	good	54.0	44	HK	27	poor	91.4
16	DZ	10	poor	20.3	45	HK	28	poor	34.4
17	DZ	10	poor	21.7	46	HK	28	poor	56.7
18	DZ	10	poor	30.2	47	HK	30	poor	61.5
19	DZ	10	poor	36.0	48	HK	18	fair	51.0
20	DZ	20	poor	17.0	49	HK	18	fair	64.0
21	DZ	20	poor	20.1	50	HK	20	fair	18.0
22	DZ	20	poor	29.4	51	HK	20	fair	23.0
23	DZ	20	poor	31.2	52	HK	30	fair	15.0
24	DZ	20	poor	33.0	53	HK	30	fair	15.2
25	DZ	20	poor	39.5	54	HK	30	fair	23.0
26	DZ	25	poor	33.1	55	HK	30	fair	42.8
27	DZ	30	poor	25.7	56	HK	30	fair	52.0
28	DZ	30	poor	29.8	57	HK	30	fair	78.4
29	DZ	20	fair	37.2					

† BH= Baba-Haidar, DZ=Dareh-Zanioni, and HK=Hadj-Kohva regions.

Data Analysis

The relationship between rainfall, runoff, and infiltration in small plots is commonly represented by the following equation (10):

$$I(app) = P - (R + S_t) \quad [1]$$

where: I(app)= apparent infiltration (mm), P= precipitation (mm), R=runoff (mm), and S_t=surface storage (mm). What is important in the recent research is the amount (depth) of surface runoff resulting from different simulated rainfall events.

Linear regression analysis is performed between runoff and rainfall intensity. The relationship is of the following type:

$$R = A + BI \quad [2]$$

where, R = runoff (mm), I = rainfall intensity (mm h^{-1}), and A and B = coefficients.

Slope and Cover

Three land slope classes of 10-15%, 15-20%, and 25-30%, and three natural vegetation cover conditions of Poor (<25% cover), Fair (40-60% cover), and Good (>75% cover) were considered in the study regions. The slope was measured with a surveying level and rod and the vegetal cover percentage was determined directly on the plot. Table 1 shows the slope and vegetation cover in the three regions.

Some of the physical properties of the soils in the research regions are shown in Table 2. As it is seen, the soils are all clay with different gravel percentages. The soil of Baba-Haidar region has the greatest and that of Dareh-Zanioni has the least amount of gravel. This difference in texture may cause some differences in the runoff production. In each of the above regions, a limited number of sediment measurement was performed in the runoff water from the plots.

Table 2. Some physical characteristics of the soils in the research regions.

Region	Soil depth (cm)	Initial moisture content (%)	Porosity (%)	Particle size distribution (%)				Soil texture
				Clay	Silt	Sand	Gravel	
Baba-Haidar	100	5.2	54	47	29	24	24	clay
Hadj-Kohva	50	4.4	54	49	34	17	18	clay
Dareh-Zanioni	50	6.1	48	41	31	28	7	clay

RESULTS AND DISCUSSION

In each region, different rainfall intensities were simulated and the resulting runoff volume was measured by collecting it in a jar. The 25-year rainfall intensities for 0.5, 1, and 2 hour rainstorms in the study area are 30, 20, and 15 mm h^{-1}, respectively. The selected range of simulated rainfall intensity in this research (14-91.4 mm h^{-1}) covers both the low and high values (15 and 30 mm h^{-1}) of actual intensities. The very high intensities were simulated for very intense storms.

Tables 3 to 8 show the results of runoff production for different conditions. Table 3 shows the runoff produced for slope class of 10-15%, poor natural vegetation cover, rainfall intensities of 16-86.7 mm h^{-1}, and different rainfall durations of 30 to 180 min. As it is seen, in all the studied regions, for each rainfall duration, increasing the rainfall intensity increases the runoff. This result is in accordance with Morin and Kosolovsky (10), who state that apparent infiltration rates increase at higher rain intensities. For rainfall duration of 30 min, there was no runoff until the intensity exceeded than 36 mm h^{-1}. Also, for rainfall intensity of 16mm h^{-1}, there was no runoff until 90 min after the start of the rain. The range of runoff for 30 min duratin was 16.8 mm (0 to 16.8 mm), while for 180 min it was 167.3 mm (1.8 to 169.1 mm). In HK region, for rainfall intensity of 86.7 mm h^{-1} and duration of 30 min, 38.8% of the rain became runoff over the land, while for duration of 180 min, 65% of the rain became runoff.

Table 3. Effect of rainfall intensity and duration on total runoff (mm) for slope class of 10-15% and poor vegetation cover.

Region	Rainfall intensity (mm h^{-1})	Rainfall duration (min)					
		30	45	60	90	120	180
HK	16	0.0	0.0	0.0	0.3	0.8	1.80
DZ	20.3	0.0	0.0	0.0	0.8	4.1	9.70
DZ	21.7	0.0	0.2	0.7	2.4	5.0	11.4
DZ	30.2	0.0	0.3	1.4	4.8	8.0	18.1
DZ	36.0	0.0	0.5	2.2	7.9	13.2	26.4
HK	41.2	0.2	1.6	3.6	11.2	18.8	42.0
BH	54.0	3.5	7.2	14.0	26.6	42.5	69.0
BH	59.0	4.7	9.2	16.8	31.8	49.8	80.4
HK	64.8	8.6	15.0	23.0	42.1	61.2	99.5
HK	86.7	16.8	28.7	44.3	75.4	106.6	169.1
	A	-6.14	-10.22	-15.20	-23.82	-31.61	-44.77
	B	0.221	0.384	0.600	1.027	1.456	2.268
	R^2	0.830	0.866	0.902	0.937	0.952	0.965

† BH= Baba-Haidar, DZ=Dareh-Zanioni, and HK=Hadj-Kohva regions.

The A and B coefficients along with the coefficients of determination (R^2) are shown in Table 3. All the R^2 values are greater than 0.83 and are significant at 5% probability level. This shows a good relationship between rainfall intensity and runoff amount in these watersheds.

When the slope class changed to 15-20%, the runoff increased slightly (Table 4). For example, for rainfall intensity of 50 mm h^{-1} and duration of 180 min, Table 3 showed 60.6 mm of runoff (by interpolation), and Table 4 showed 77.7 mm of runoff (a 28.2% increase). Comparing Tables 4 and 5 showed that when the vegetation condition changed from poor to fair, rainfall intensity of 50 mm h^{-1} and 180 min produced only 39.7 mm of runoff (Table 5), which was a decrease of 48.9%. So, improving vegetation cover had a prominent effect on runoff production, and vice versa. Grazing and trampling the vegetation cover of the watersheds increased erosion and soil loss (5). Tables 6 and 7 showed the runoff production for slope class of 25-30% and vegetation cover conditions of poor and fair, respectively. In Table 6, there was no runoff for rainfall intensity of 22.5 mm h^{-1} and duration of 45 min. Rainfall intensity of 50 mm h^{-1} and duration of 180 min produced 78.4 mm of runoff. Thus, doubling the slope (as compared to Table 3) did not double the runoff, but increased it by 29.4%.

Table 4. Effect of rainfall intensity and duration on total runoff (mm) for slope class of 15-20% and poor vegetation cover.

Region	Rainfall intensity (mm h^{-1})	Rainfall duration (min)					
		30	45	60	90	120	180
HK	14.0	0.0	0.0	0.0	0.1	1.1	3.6
DZ	17.0	0.0	0.0	0.3	3.1	4.2	7.8
HK	20.0	0.0	0.3	1.0	4.1	6.0	10.3
DZ	20.1	0.0	0.3	1.0	4.2	6.3	10.8
BH	25.0	0.0	0.5	1.7	5.3	8.2	14.8
DZ	29.4	0.3	0.9	2.6	6.6	10.6	19.8
DZ	31.2	0.8	1.9	4.2	8.7	13.4	25.3
DZ	33.0	1.0	4.3	8.2	14.6	20.5	32.2
DZ	39.5	2.2	5.4	9.6	19.5	29.2	48.9
HK	50.0	4.8	10.1	15.9	31.4	46.8	77.7
HK	62.0	9.8	16.6	25.1	44.9	64.7	105.5
	A	-4.24	-7.09	-9.99	-15.81	-22.50	-35.06
	B	0.192	0.374	0.526	0.927	1.344	2.176
	R^2	0.855	0.920	0.948	0.958	0.962	0.968

† BH= Baba-Haidar, DZ=Dareh-Zanioni, and HK=Hadj-Kohva regions.

By changing the cover condition to fair, the slope class of 25-30% produced only 57 mm of runoff for 50 mm h^{-1} rainfall intensity (Table 7), which was about 27.3% less than 78.4 mm of Table 6. The R^2 values of Table 6 were all above 0.975 and this showed a very good relationship between rainfall intensity and runoff depth for this slope and vegetation cover condition. Sharifi *et al.* (15) found a good correlation between rainfall amount and runoff depth, too.

Again, when vegetation condition of Table 6 was changed to fair, the total runoff was reduced (Table 7).

Table 5. Effect of rainfall intensity and duration on total runoff (mm) for slope class of 15-20% and fair vegetation cover.

Region	Rainfall intensity ($mm\ h^{-1}$)	Rainfall duration (min)					
		30	45	60	90	120	180
BH	17.6	0.0	0.0	0.0	0.0	0.0	0.0
HK	18.0	0.0	0.0	0.0	0.0	0.0	0.0
HK	23.0	0.0	0.0	0.8	2.9	4.6	7.7
BH	33.0	0.3	0.6	2.4	4.9	7.9	15.1
DZ	37.2	0.5	1.8	3.5	5.9	10.1	18.2
DZ	43. 0	1.1	3.0	5.8	10.4	15.9	29.5
HK	51. 0	3.2	5.1	8.1	15.9	23.9	41.2
HK	64.0	4.7	8.1	12.3	22.2	39.9	64.2
	A	-2.33	-3.85	-5.29	-9.15	-16.10	-25.66
	B	0.099	0.172	0.262	0.472	0.806	1.329
	R^2	0.855	0.926	0.975	0.968	0.954	0.975

† BH= Baba-Haidar, DZ=Dareh-Zanioni, and HK=Hadj-Kohva regions.

Table 6. Effect of rainfall intensity and duration on total runoff (mm) for slope class of 25-30% and poor vegetation cover.

Region	Rainfall intensity ($mm\ h^{-1}$)	Rainfall duration (min)					
		30	45	60	90	120	180
BH	22.5	0.0	0.0	0.4	1.6	3.6	8.3
DZ	25.7	0.1	0.7	1.8	4.1	6.7	11.9
HK	25.8	0.1	0.8	1.9	4.2	7.0	12.3
BH	27.1	0.3	1.2	2.7	5.9	9.0	15.2
BH	29.2	0.4	1.5	3.3	7.1	10.7	17.9
DZ	29.8	0.6	2.7	5.2	11.0	16.5	28.6
BH	32.0	1.2	3.6	6.9	14.2	22.2	37.2
BH	33.0	1.9	4.0	7.8	15.3	22.7	37.9
DZ	33.1	1.9	4.1	7.9	15.5	22.5	38.2
HK	34.4	2.2	4.4	9.0	18.2	31.3	53.0
BH	54.0	6.8	12.6	22.0	35.5	52.1	84.9
HK	56.7	7.3	13.8	24.9	38.8	56.8	92.7
HK	61.5	11.3	19.1	29.6	46.0	67.4	102.7
HK	91.4	21.6	38.7	57.7	94.6	133.2	209.0
	A	-8.42	-13.93	-19.51	-28.63	-38.60	-57.37
	B	0.312	0.543	0.817	1.281	1.802	2.792
	R^2	0.975	0.979	0.993	0.984	0.984	0.981

† BH= Baba-Haidar, DZ=Dareh-Zanioni, and HK=Hadj-Kohva regions.

Table 8 shows the mean of runoff values for different classes of slope, natural vegetation cover, and mean rainfall intensity. It is obvious from this table that improving vegetation cover is very effective in runoff reduction.

The experiments performed on plots with good vegetation cover condition (in BH and DZ regions) showed that even with the rainfall intensity of 90 mm h^{-1} and slope of 25-30% there was no runoff until 145 min and continuing this test for 180 min produced only 1.5 mm of runoff.

There was no runoff for slope classes of 10-15% and 15-20% even when the tests lasted for 180 min.

Table 7. Effect of rainfall intensity and duration on total runoff (mm) for slope class of 25-30% and fair vegetation cover.

Region	Rainfall intensity ($mm\ h^{-1}$)	Rainfall duration (min)					
		30	45	60	90	120	180
HK	15.0	0.0	0.0	0.0	0.0	0.0	1.1
HK	15.2	0.0	0.0	0.0	0.0	0.1	1.1
HK	23.0	0.0	0.0	0.0	0.3	0.7	1.3
HK	27.0	0.0	0.3	0.3	1.5	2.8	5.9
DZ	38.0	0.0	2.2	2.2	4.9	12.4	21.5
DZ	40.0	0.5	3.1	3.1	8.8	17.4	27.5
HK	42.8	1.2	6.3	6.3	13.6	19.1	30.6
HK	52.0	2.5	11.4	11.4	26.8	39.5	67.3
HK	78.4	7.8	27.6	27.6	49.4	75.1	119.9
	A	-2.89	-9.90	-9.90	-17.38	-25.41	-39.40
	B	0.115	0.422	0.422	0.790	1.194	1.894
	R^2	0.806	0.878	0.878	0.911	0.937	0.936

† BH= Baba-Haidar, DZ=Dareh-Zanioni, and HK=Hadj-Kohva regions.

Table 8. Effect of slope, vegetal cover and mean rainfall intensity on total runoff (in mm) for different rainfall durations.

Slope (%)	Vegetation cover	Rainfall intensity ($mm\ h^{-1}$)	Rainfall duration (min)						Mean runoff (mm)
			30	45	60	90	120	180	
25-30	poor	39.7	4.0	7.6	12.9	22.3	33.0	53.5	22.2
	fair	36.8	1.3	3.7	5.6	11.7	18.6	30.3	11.9
15-20	poor	31.0	1.7	3.7	6.3	13.0	19.2	32.4	12.7
	fair	35.9	1.2	2.3	4.1	7.8	12.8	22.0	8.4
10-15	poor	43.0	3.4	6.3	10.6	20.3	31.0	52.7	20.7

The results of collected sediments from eroded soil for runoff plots are shown in Table 9. It is seen that rainfall intensities of 91.4 and 54 mm h^{-1} have produced the largest and rainfall intensity of 21.7 mm h^{-1} the least sediment concentration. Rainfall intensity of 86.7 mm h^{-1} has not produced the same sediment concentration as the 91.4 mm h^{-1} rain because the slopes of the plots were 10% and 30%, respectively. Again, as for runoff production, doubling the slope does not double the sediment concentration (e.g., compare 21.7 and 20.1 mm h^{-1} rainfalls) and also improving the natural vegetal cover decreases sediment concentration (e.g., compare rainfall intensities of 25.8 and 23 mm h^{-1}).

Table 9. Sediment concentration in runoff from experimental plots.

Region	Intensity (mm h^{-1})	Slope (%)	Vegetation cover	Rainfall duration (min)	Runoff volume (l)	Sediment weight (g)	Sediment concentration (g l^{-1})
BH	54.0	28	poor	100	38.9	787.70	20.25
BH	33.0	30	poor	110	2.4	12.30	5.13
BH	32.0	30	poor	106	18.7	112.40	6.01
BH	29.2	28	poor	78	5.6	34.00	6.07
BH	27.1	30	poor	73	4.14	31.00	7.50
BH	22.5	30	poor	140	7.8	59.90	7.68
BH	17.6	20	fair	126	4.2	23.70	5.64
DZ	40.0	26	fair	60	7.94	98.00	12.34
DZ	33.0	25	poor	60	15.2	183.70	12.08
DZ	29.8	30	poor	78	20.27	239.80	11.83
DZ	25.7	30	poor	67	2.2	24.50	11.14
DZ	21.7	10	poor	144	7.3	27.60	3.78
DZ	20.1	20	poor	180	6.7	43.30	6.46
DZ	17.0	20	poor	127	11.5	60.70	5.28
HK	91.4	30	poor	63	45.4	1110.52	24.46
HK	86.7	10	poor	65	41.4	490.10	11.84
HK	34.4	30	poor	75	15.5	240.10	15.49
HK	25.8	25	poor	105	12.6	156.30	12.40
HK	23.0	22	poor	92	4.0	19.00	4.75
HK	20.0	20	poor	99	7.5	41.00	5.47
HK	15.0	30	poor	116	10.5	82.00	7.81
HK	14.5	20	poor	143	2.5	10.00	4.00

CONCLUSIONS

It is concluded that: 1) The designed rainfall simulator is a simple, economic and easy to operate for runoff and erosion research in watersheds, 2) There is a good relationship between rainfall intensity and runoff depth for the slope and natural vegetation cover conditions under the study, 3) Doubling the soil slope does not double the runoff production, other conditions being equal, 4) Improving the natural vegetation cover (from poor to fair or good conditions) has a prominent effect on runoff reduction, and on this basis, it is recommended to keep the vegetation cover of the watersheds in this area at fair level (about 50%), and 5) Poor vegetation cover and high rainfall intensity creates high sediment concentration in runoff water.

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