CHALLENGES AND RAINWATER HARVESTING IN SEMIARID AREAS

COLLECTE DES EAUX DE PLUIE ET DÉFIS QUE POSENT LES REGIONS SEMIARIDES

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ABSTRACT

Establishing economically efficient permanent plant cover through active rural participation is a way to control water induced soil erosion, promote further vegetation growth and facilitate moisture conservation, all of which improve villagers' life. The other way to augument water resources in water-scarce and low rainfall areas is to harvest some part of the rainfall when it occurs. In the present study, long-term rainfall data of the Zanjan meteorology station were analysed and rainfall frequencies of various depths were worked out. Runoff harvesting plots with 3 different surface treatments namely, impeded, semi-impeded and un-impeded (natural condition) in a completely random blocks design and replicated 4 times were established at the Garacharyan Researches Complex situated 35 km west of the Zanjan city. The runoff from all the plots were recorded. Statistical analysis of the data showed that the treatments hade significant differences at 1% level. The threshold values of daily rainfall for runoff occurrence in impeded, semi-impeded and un-impeded plots were 1, 4 and 7 mm, respectively, and the corresponding runoff coefficients were 44, 12.1 and 3 percent. These findings indicate that impermeable land induced higher runoff fro rainfall. This runoff can be stored and used through a suitable distribution system for successful agriculture.

Key words: *daily rainfall frequency, piedmont, runoff coefficient, water harvesting plot.*

RESUME

L'établissement de la couverture végétale permanente efficace de manière économique par la participation rurale est un moyen de contrôler l'érosion du sol causée par l'eau, de promouvoir la croissance de végétation et de faciliter la conservation d'humidité. Tous ces facteurs aident à améliorer la vie rurale. La collecte de certaine partie des eaux de pluie est d'autre moyen d'augmenter les ressources en eau dans les régions affectées par la pénurie d'eau ou le niveau bas de précipitation. L'étude actuelle analyse les données de précipitation

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à long terme de la station météorologique de Zanjan et met au point les fréquences de précipitation de diverses profondeurs. On a établit des champs pour collecter l'écoulement avec 3 différents traitements de surface, à savoir « impeded, semi-impeded, et un-impeded (condition naturelle) » selon la conception de bloc randomisé avec quatre répétitions au Complexe de Recherche de Garacharyan qui est situé à 35 km ouest de la ville Zanjan. On a noté l'écoulement de tous les champs. L'analyse statistique des données a montré que le traitement avait des différences significatives au niveau de 1%. Les valeurs de seuil de la précipitation quotidienne de la présence d'écoulement dans les champs « impeded, semi-impeded, et un-impeded (condition naturelle) » étaient de 1, 4 et 7 mm respectivement et les coefficients d'écoulement correspondants étaient de 44, 12.1 et 3 %. Ces résultats indiquent que la terre imperméable provoque un niveau élevé de l'écoulement de la précipitation. Cet écoulement peut être stocké et utilisé par un réseau approprié de distribution dans l'agriculture.

Mots clés : *Fréquence de précipitation quotidienne, piémont, coefficient d'écoulement, champ de la collecte d'eau.*

1. INTRODUCTION

Water is perpetually in shortage in arid and semi-arid regions (Prinz, 2001). Naturally, agriculture in such areas is dependent upon rainfall. If the land slope is steeper than 5%, soil erosion occurs when runoff water flows over the land. The land gets degraded gradually and loses their ability to produce crops. Rehabilitation of such lands to restore their production potential will be very useful to the local population. One of the approaches towards this is adoption of rainwater harvesting system and use the harvested rain water to irrigate plants (Samuel and Satapathy, 2008). Another approach is to allow (and facilitate) rainwater absorption into the soil to increase soil moisture, which the plants can take up. However, either of the two must be simple, should not require large finances and should be compatible with water requirement of crops to be grown. Successful rainwater harvesting endeavours ward off deficit water stress to the plants due to uncertainties of rainfall occurrence and its magnitude.

Several investigators have explored rainwater harvesting systems specifications all over the world. For instance Hanson (2008) has studied the statistical nature of daily rainfall and the Storage-Reliability-Yield behavior of rainwater harvesting systems in the United States and concluded that Pearson Type-III (P3) probability distribution fitted the full record of daily precipitation data remarkably well. They also found that the Kappa (KAP) distribution best described the observed distribution of wet-day daily rainfall, and so a regional regression modeling approach demonstrated that by combining system parameters (daily yield, collection area, reliability) with climatic variables, a generalized regression model could be developed to predict required storage capacity. Palla et al., (2011), based on for non-dimensional design parameters and performance assessment of rainwater harvesting systems, have concluded that 30 years of daily rainfall data are sufficient to assess the rainwater harvesting and storage systems performance. Vishwanath (2001) has reported that several issues remain to be addressed with rooftop rainwater harvesting. Foremost among them are the issues of quality, occasional acid rain and water contamination due to the presence of dust and bird droppings on the rooftop.

In semiarid areas substantial rainwater collection is feasible when the water contributing areas have high runoff coefficient (Wang et al., 2009). Li et al., (2004) showed that runoff and runoff efficiency of the earthen surface treatments were closely related to the rain intensity, while runoff from the asphalt fiberglass, plastic film, gravel-covered plastic film, and concrete surface treatments was more governed by the amount of the rainfall. Asphalt fiberglass had the highest average annual runoff efficiency of 74–81%, followed in decreasing order by the plastic film (57–76%), gravel-covered plastic film (56–77%), concrete (46–69%), cleared loess slope (12–13%), and natural loess slope (9–11%). Antecedent rainfall had an obvious effect on the runoff yield for the cleared loess slope, natural loess slope, and concrete. The threshold rainfall was 8.5, 8.0, and 1.5 mm for the natural loess slope, cleared loess slope, and concrete treatments, respectively without antecedent rainfall effects and 6.0, 5.0, and 1.2 mm, respectively, with antecedent rainfall effects. Due to the impermeable surface, antecedent rainfall had little effect on the runoff yield for the asphalt fiberglass, plastic film, and gravel-covered plastic film treatments, which had threshold rainfalls of 0.1, 0.2, and 0.9 mm, respectively.

In this paper, we have analyzed and discussed the frequency of different intensities of 24h rainfalls based on the data recorded at the meteorological observatory at Zanjan city, which is a representative of semiarid regions in Iran; and their abilities to produce runoff from variously surface treated plots.

2. MATERIALS AND METHODS

The experimental plots are located at the Garacharyan Researches Complex (48° 20’ E, 36° 55’ N), 35km west of Zanjan city. The climate is cold semiarid with MEAN annual temperature and precipitation of 100C and 300mm, respectively. The seasonal distribution of precipitation is 34% in spring, 4% in summer, 31% in autumn and 31% in winter. Rainfall data of 45 years at Zanjan city were used to analyze the frequency and temporal distribution of daily rainfall (Table 1).

Table 1. Average monthly precipitation of Zanjan’s meteorological station (Les précipitations mensuelles moyennes de la station météorologique de Zanjan)

Months mm	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Ann mm**
Average mm	29.68	28.03	43.31	40.82	53.03	15.4	4.63	3.66	2.67	17.26	29.39	27.42	295.3

The 4m x 5m size experimental plots with 3 treatments and 4 replications were established on hillside (slope: 16-25%) in a completely random blocks design. Plots’ surface treatments were (1) impediment (gravel covered by plastic), (2) semi impediment (cleared of vegetation) and (3) undisturbed (natural condition). Figure 1 and Table 2 give the details of the treatments. At the downstream end of every plot two barrels were installed to collect and measure the volume of runoff. Measurements were taken during May to November of 2008. A total of 52 pairs of rainfall-runoff events were used for developing regression models and determining threshold rainfall for runoff to occur from variously treated plots.

Treatment						Replications
			Semi imp. A2 slope 15.50%	Natural A3 Slope 16.25%	Impediment A1 slope 15.25%	**First**
Semi imp. B2 Slope 19.12%	Impediment B1 slope = 16.12%	Natural B3 slope = 16.20%				**Second**
			Impediment C1 Slope 19.56%	Natural C3 Slope 19.12%	Semi imp. C2 Slope 18.62%	**Third**
Natural D3 Slope 22.75%	Impediment D1 Slope 22.25%	Semi imp. D2 Slope 24.75%				**Fourth**

Fig. 1. Rainwater harvesting plots arrangement on hillside (L'eau de pluie arrangement de récolte des parcelles à flanc de colline)

Table 2. Specifications of natural plots (Caractéristiques des parcelles naturelles)

Replication	Soil texture	Canopy%	Litter%	Pebbles%	Bare soil
A3	clay	10	15	25	50
B3	Sandy clay	25	12	23	40
C3	Sandy clay	30	40	10	20
D3	Clay	42	10	35	13
Average	-	26.75	19.25	23.25	30.75

For every treatment, a linear regression was developed between runoff depth as dependent and 24h rainfall depth as independent variables. Frequency of daily rainfall recorded at Zanjan meteorological observatory with depth of more than 1, 5 and 10mm for months of May to November were worked out. The linear regression models of 24h rainfall and runoff depths of different treatments were used to estimate runoff. By application of SAS software the differences of blocks and treatments were investigated. The means were compared by using Duncan's method.

3. RESULTS

Daily rainfall frequency analysis of Zanjan's meteorological station for a period of 45 years (1956-2000) showed that with increasing depth of daily rainfalls their frequency decrease and was least in warm (plant growth) months. Average frequencies of daily rainfall events with depth of more than 1 and occurred in July, August and September at nearly one per year and one per 3 years, respectively. The critical month is August and frequencies of daily rainfalls with depth of more than 0, 1, 5 and 10mm for every year were 2.22, 0.96, 0.27 and 0.04, respectively (Table 3). Generally, the decrease of all daily rainfall frequencies in May onwards were sharp. Only 30 percent of daily rainfall events occurring in May actually occurred in Jun and 50 percent of June occurred in July.

Table 3. Frequencies of daily rainfalls with depths of more than 0, 1, 5 and 10mm in Zanjan's meteorological station (Les fréquences des pluies quotidiennes avec des profondeurs de plus de 0, 1, 5 et 10 mm de la station météorologique de Zanjan)

month	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
limit	More than zero mm											
sum	491	443	566	586	512	195	112	100	100	293	347	434
mean	10.91	9.84	12.58	13.02	11.38	4.33	2.49	2.22	2.22	6.51	7.71	9.64
limit	More than 1mm											
sum	291	273	391	399	327	99	55	43	47	182	223	252
mean	6.47	6.07	8.69	8.87	7.27	2.2	1.22	0.96	1.04	4.04	4.96	5.6
limit	More than 5mm											
sum	98	99	156	177	126	33	17	12	10	80	97	84
mean	2.18	2.2	3.47	3.93	2.8	0.73	0.38	0.27	0.22	1.78	2.16	1.87
limit	More than 10mm											
sum	36	30	69	83	54	12	3	2	5	27	42	34
mean	0.8	0.67	1.53	1.84	1.2	0.27	0.07	0.04	0.11	0.6	0.93	0.76

Mean estate number of events to that month for every year

Statistical analyses showed that there were no significant differences among blocks. But the treatments differed at 1% level (Tables 4, 5).

Table 4. Analyses of variances of blocks and treatments (Analyse des écarts de blocs et de traitements)

Source	DF	SS	MS	F	$P_{0.01}$
Blocks	3	3.65	1.216	0.39	0.7676
Treatments	2	586.94	93.02	93.02	0.0001

Table 5. Test of means of runoff depths at treatments (Test de moyens des profondeurs d'écoulement à des traitements)

Treatments	Sample count	Average rain, mm	Duncan's grouping
Impediment	52	5.2682	A
Semi insulation	52	1.9985	B
Undisturbed (natural)	52	0.6749	C

The analysis of the developed linear regression equations revealed that threshold of daily rainfalls to produce runoff at treatments of impediment, semi impediment and undisturbed (natural) were 1, 4 and 7mm, respectively (Table 6). In other words, occurrence of daily rainfalls less than the above indicated values them will not produce runoff from the corresponding treated plots.

Table 6. Regression equations of daily rainfall-runoff (Les équations de régression de pluie-débit journalier)

Treatment	Regression*	Daily rainfall-runoff threshold	Average runoff coefficient	Determination coefficient (R^2)	Sig. level %
Impediment	R = 0.5349 p – 0.6035	1.13	43.9	0.8158	1
Semi Impediment	R = 0.2917 p – 1.1994	4.11	12.5	0.666	1
Undisturbed (natural)	R = 0.1519 p – 1.0429	6.87	3.04	0.4221	1

* P and R are daily rainfall and runoff, respectively

4. CONCLUSIONS AND DISCUSSION

Comparison of the averages of monthly rainfalls (Table 1) with frequencies of daily rainfalls of depth greater than 0 and 1 mm in warm months including July, August and September (Table 3) showed that generally in semiarid climate, depths and frequencies of daily rainfalls were too little to generate runoff under the natural condition of the land, i.e., with vegetation and litters. Further, in semiarid areas the frequencies of daily rainfall events and time distribution are such that surface treatment to make them fully or partially impermeable would be essential to induce measurable and useable runoff in the warm months. The Regression equations indicated that runoff coefficient increases from natural to impediment surface and the daily threshold rainfall decrease (Table 6). On the other hand, for natural surfaces only daily rainfalls with depth of more than 6.87mm are able to generate runoff but their occurrence probability is very low in the warmer months.

Surface treatment of the plots made significant changes in the runoff producing potential of the land (Table 6). The treatments however are to be further investigated for their cost-effectiveness based on a longer period of field trials.

Based on the study it was concluded that the key factor for consideration in the design of rainwater harvesting system is the climate, particularly in terms of rainfall amounts, frequencies and temporal distribution during the plant growth months. Surface treatment to make it partially or fully impermeable is needed to induce runoff from the meager rainfalls in the regions of semi-arid and arid climate.

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