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INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 5, Issue, 06, pp.1609-1613, June, 2013

ISSN: 0975-833X

RESEARCH ARTICLE

RUNOFF CHARACTERISTICS OF BARE MICRO CATCHMENTS IN A SEMI ARID AREA, KENYA

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ARTICLE INFO

Article History:
Received 02nd March, 2013
Received in revised form
19th April, 2013
Accepted 11th May, 2013
Published online 15th June, 2013

Key words:
Curve number,
Bare micro catchments,
Paved surfaces,
Runoff, Calibration.

ABSTRACT

The main objective of the study was to investigate the runoff characteristics of bare micro catchments using the Natural Resources Conservation Service Curve Number (NRCS CN) method. The study was carried out on three rectangular and two triangular bare runoff plots of area 10 m^2 constructed on a natural slope of 5% and a typical loamy sand soil. It involved measurement of rainfall and surface run off on storm basis. The curve numbers in the NRCS CN method were first obtained through calibration using observed rainfall and surface runoff data. The calibrated curve numbers were found to be between 97.16 and 99.37 with mean of 98.54. Based on the mean curve number and the soil hydrologic group B, it was found that the bare micro-catchments could be treated as paved surfaces. The treatment of bare runoff plots as paved surfaces was later validated using a different set of rainfall and runoff data. A comparison between computed and observed surface runoff from the runoff plots revealed a close fit (R^2 = 0.971). Based on the results, it was concluded that the NRCS CN method could be used to compute surface runoff from bare micro catchments if treated as pave surfaces.

INTRODUCTION

In arid and semi arid areas, rainfall varies considerably in time. Most rainfall is lost through evaporation or as runoff due to unfavourable rainfall characteristics and soil surface properties such as crusting. The availability of water in arid and semi arid areas can be achieved through rainwater harvesting techniques. Rainwater harvesting is defined as a method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions (Boers and Ben-Asher, 1982). One method of rainwater harvesting involves use of micro catchments. Micro catchments have been used in arid and semi arid lands (ASAL) to harvest runoff for both crop production and domestic water. In micro catchment water harvesting systems there are two parts, namely the runoff producing (catchment) and runoff receiving areas. The present study concentrated on the runoff producing area.

"Estimation of runoff from micro catchments is important for the design of appropriate storage structures and determining size of runoff receiving area. According to Bruins *et al.* (1986), the relationship between the size of the runoff producing and runoff receiving areas is of paramount importance in the design of micro catchments. The volume of runoff from micro catchments in arid and semi arid regions depends on rainfall characteristics (amount, intensity and distribution), micro catchment characteristics (size, slope, antecedent soil moisture condition) and the water spreading properties of the soil (Sharma, 1986)".

One of the methods that have been used to estimate runoff is the Natural Resource Conservation Service Curve Number (NRCS CN). The NRCS CN method was designed for determining runoff from storm rainfall (Hjelmfelt 1991; Svoboda, 1991) in small catchments of 8 km2 or less where the storm durations vary from about 3–24 h (Schwab *et al*., 1993). The NRCS CN method computes the volume of direct runoff as a function of curve number (CN), which, in turn, depends on soil-vegetation-land use complex. In practice the CN is obtained from published tables (SCS, 1985) but exact match is the major challenge. According to Hawkins (2010) handbook table values of CN give guidance in the absence of better information, but incorporate only limited land cover and conditions and are often untested. With increasing user sophistication, coupled with the awareness that the runoff calculation is more sensitive to CN than to rainfall, interest in determining local CNs from local rainfall-runoff data has grown (Hawkins, 2010). In the present study there was no land cover description that matched the bare micro catchments. In addition, the curve number method computes direct runoff (combination of surface runoff and interflow) while in water harvesting micro catchments only surface runoff is of interest. Therefore, the focus of the study was to obtain curve numbers through calibration process using observed rainfall and runoff data. From the calibrated curve numbers, an equivalent land cover in handbook was determined and then the NRCS CN method evaluated for applicability in surface runoff estimation from bare micro catchments.

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Natural Resource Conservation Service Curve Number (NRCS CN) Method

The NRCS CN method is usually represented by the equation below:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \qquad (1)$$

Where Q = direct runoff depth (mm), P = rainfall depth (mm), S = potential maximum retention after runoff begins. From the study of many catchments an empirical relation I_a = 0.2S was developed. By substituting I_a = 0.2S, equation (3) becomes:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad (2)$$

The storage S is related to a dimensionless Curve Number (CN) as follows:

$$S = \frac{25400}{CN} - 254 \qquad (3)$$

The curve number is established based on the information on hydrologic soil group, land cover and the antecedent soil moisture condition. Values of CN vary from 0 to 100 and are well documented in most hydrologic texts (Chow *et al*., 1988; Schwab *et al*., 1993; McCuen, 1989).

"The study was conducted in Chepareria Division of West Pokot County in Kenya. West Pokot County is situated along Kenya's western boundary with Uganda. From north to south, the county stretches from 2°40'N to 1°7'N. From west to east it is located between 34°37'E and 35°49'E. The rainfall in the division varies from 600 mm to 1100 mm per year with high evapotranspiration rates of up to 1800 mm. Rainfall is poorly distributed within the year consisting of high intensity storms of short duration that usually result in high runoff generation. The annual mean temperature in the division is 21°C with mean maximum temperature of 27°C and mean minimum temperature of 15°C. Most parts of the division have typical semi arid climate with the economic activity being livestock keeping. The division is mainly occupied by CHROMIC LUVISOLS (well drained, very deep, yellowish to dark reddish brown, friable, coarse loamy sand to sandy clay loam) (Hendrix, 1985). The soils in the division have a general tendency to form crusts and hence generate high amounts of runoff which ends up in the ephemeral streams".

"The research site was located near the chief's camp in Kipkomo location of Chepareria Division (Figure 1). The overriding factors in the choice of the site were security and the semi aridity condition. The police officers at the chief's camp ensured the security of the instruments installed at the research site.

plots have same slope, soil and vegetal features to minimize within variations. The plots were initially cleared of grass so as to leave a bare ground. Thereafter, herbicides were used to control weeds so as to maintain the runoff plots bare throughout the rain season. The soil at the site varied from loamy sand (0-20 cm) to sandy loam (20-40 cm). Walls made of bricks were constructed round each runoff plot to a height 0.20 m and dug to a depth of 0.10 m to prevent water from entering or leaving the plots. At the end of each plot was a 15 cm diameter plastic pipe that led the surface runoff to plastic buckets of capacity 30 litres put in excavated pits. The inlet of each pipe was covered with fine gravel so as to reduce the amount of sediments reaching the collecting buckets. A deep cutoff drain was also dug upstream of the runoff plots to prevent inflow of runoff from outside the research site. The entire experimental site was fenced off so as to prevent livestock from entering. Both automatic and manual rain gauges were installed within the experimental site. Rainfall and runoff events were measured during the rain season which extends from March to May with consistency. The arrangement of the runoff plots is shown in Figure 2".

Rainfall and Runoff Measurement

Rainfall and runoff data were obtained during the rainy season in the months of March to May 1997. Rainfall was measured using both autographic and manual rain gauges. The volume of surface runoff was collected in plastic buckets at the lower end of each runoff plot and measured on storm basis, mainly for the daytime storm events. The runoff volume was converted to depth and tabulated against the corresponding rainfall depth.

Determination of Curve Numbers

The soil at the site belonged to soil group B (Chow *et al*., 1988). However, no land cover type described in the above text and published curve number tables fitted the bare runoff plots.

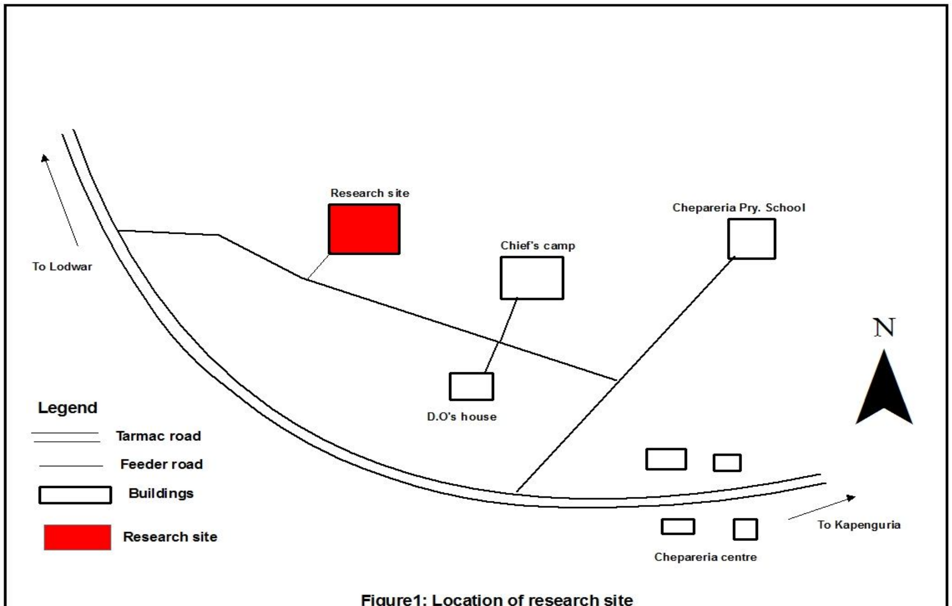

Figure1: Location of research site

MATERIALS AND METHODS

Experimental Layout

The study involved measurement of rainfall and surface runoff on storm basis. The research site provided a suitable environment to install rain gauges and runoff plots. A piece of land on a prevailing slope of 5% and of a major soil type permitted the construction of three rectangular and two triangular runoff plots of area 10 m^2 with flow distance of 5 m each. The plots were constructed such that they could accommodate statistical comparison, which required that all

A calibration process was done using a portion of the data to find the curve numbers corresponding to observed rainfall and runoff data and close fitting land use type. Based on the close fitting land cover, the other portion of data was used for validation, during which curve numbers were obtained based on the antecedent moisture condition. The curve numbers obtained were used to compute runoff values using Eqs. 2 and 3. The computed surface runoff values were compared with observed surface runoff values using the coefficient of determination about the 1:1 line (R^2) and mean error of estimate (ME) expressed as:

$$R^2 = \frac{\sum (Q_{pi} - Q_{mp})^2}{\sum (Q_{oi} - Q_m)^2} \quad \text{...(4)}$$

$$ME = \frac{\sum (Q_{pi} - Q_{oi})}{n} \quad \text{...(5)}$$

A comparison of the surface runoff values from the five plots using an F-test showed insignificant differences at 5% level of significance ($F_{calculated}$ = 0.014 and $F_{critical}$=2.479). From the results, it could be interpreted that surface runoff values from the five plots of equal area under identical slope and soil type were similar regardless of the shape. The results showed that shape did not have effect on the amount of surface runoff from the plots used in the study.

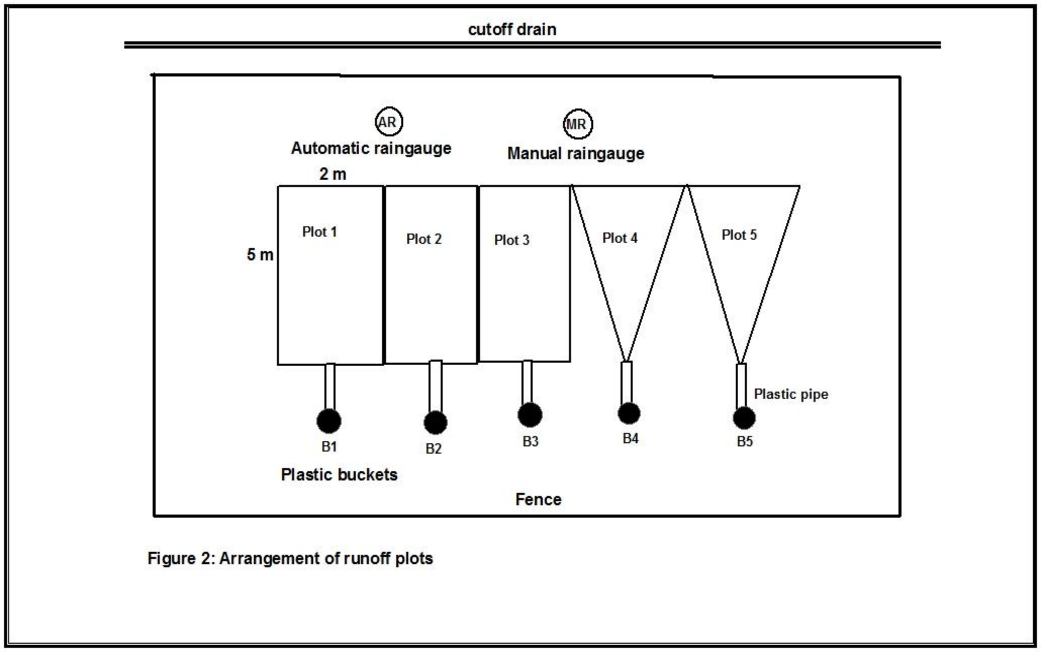

Figure 2: Arrangement of runoff plots

Where Q_{oi} is the observed runoff of event i (mm), Q_{pi} is the computed runoff of event i (mm), Q_m is the mean of all observed runoff values, Q_{mp} is the mean of all computed runoff values and n is the number of surface runoff values. A high value of R^2 indicates a close fit between computed and observed values while the value of ME should be close to zero.

RESULTS AND DISCUSSION

Rainfall and Surface Runoff Data

Table 1 shows the rainfall and surface runoff depths collected during the study. Therefore, the average surface runoff values from the plots were used to compute runoff efficiencies (Table 1) and for the rest of the study. The runoff efficiencies varied between 34 % and 95% with 75% of the rainfall events having runoff efficiencies greater than 50% (Table 1). The high runoff efficiencies were associated with high intensity storms and those storms which fell immediately after other storms had wetted the surfaces of the plots.

Results of Curve Number Calibration

Ten observed rainfall and runoff events were used for calibration of curve numbers. The calibrated curve numbers were between 97.16 and 99.37 with mean of 98.54 (Table 2). Based on the mean value of

Table 1. Rainfall and surface runoff depths (mm)

Date of storm	Rain (mm)	Plot1 (mm)	Plot2 (mm)	Plot3 (mm)	Plot4 (mm)	Plot5 (mm)	Average (mm)	Runoff Eff. (%)
28/4/97 (1)	7	5.63	5.16	5.08	5.51	5.37	5.35	76.43
27/4/97 (2)	1.5	0.56	0.47	0.48	0.51	0.48	0.50	33.33
5/5/97	11	8.20	7.75	8.07	8.77	8.24	8.21	74.64
7/4/97 (4)	20	14.78	13.08	11.63	13.34	13.23	13.21	66.05
31/3/97	15	13.44	13.36	12.36	13.24	12.60	12.93	86.20
4/4/97	12	9.36	8.88	8.48	8.52	8.04	8.66	72.17
1/5/97 (2)	31	30.25	29.59	27.64	30.71	28.44	29.33	94.61
26/4/97 (2)	7.5	3.75	3.60	3.38	2.88	2.86	3.31	44.13
24/4/97 (2)	21	14.78	15.66	14.63	14.93	15.84	15.17	72.24
20/4/97	35	33.45	32.64	31.86	32.93	32.64	32.68	93.37
30/4/97 (1)	40	35.94	35.21	35.47	36.06	36.26	35.79	89.47
29/3/97	10.5	7.94	7.73	7.63	7.80	8.06	7.83	72.95
21/4/97 (1)	3.5	1.44	1.36	1.29	1.51	1.37	1.39	39.71
10/4/97 (2)	2	0.92	0.85	0.70	0.65	0.60	0.74	37.00
26/4/97 (1)	3.8	2.45	2.24	2.00	2.40	2.22	2.26	59.47
7/4/97 (1)	14	12.80	11.80	11.62	12.76	11.68	12.13	86.64
7/4/97 (3)	2.5	1.80	1.44	1.10	1.30	1.21	1.37	51.20
30/4/97 (3)	6	2.55	3.21	2.80	2.71	2.69	2.79	46.50
30/4/97 (2)	3	2.17	1.96	2.06	2.22	2.00	2.08	69.33
22/4/97	13	12.05	11.44	11.20	11.40	10.91	11.40	87.69
Mean		10.71	10.37	9.97	10.51	10.24	10.36	67.96

Note: Plots 1, 2, and 3 refer to rectangular plots; plots 4 and 5 refer to triangular plots; Runoff Eff. (%) refers to the runoff efficiency which was computed as ratio of

CN of 98.54, the bare runoff plots could be approximated with paved surfaces. This is because for paved surfaces under hydrologic soil group B, the curve number for normal antecedent moisture condition (CNII) is about 98. The behaviour of runoff plots as paved surfaces can be attributed to the tendency of the soils to seal and crust. According to Hardy *et al.* (1983), the presence of a crusted soil surface due to the action of rainfall is a common feature of many soils, particularly in the arid and semi arid regions. The authors found that the structure of the crust was different from the bulk of the soil and affected soil properties such as seedling emergence and water penetration. Hoogmoed and Stroosnijder (1984) noted that in a wet state, the crust reduces infiltration and, when dry, forms a barrier against seedling emergence. Morin *et al.* (1981a and 1981b) studied the infiltration of rainfall into bare soil in the field and laboratory experiments on two soil types. The results indicated that the main governing process in rainfall infiltration was the formation of a crust with a hydraulic conductivity several orders of magnitude lower that of the profile.

Table 2. Results of curve number calibration.

Date of storm	Rain (mm)	Runoff (mm)	Calibrated CN
29/3/97	10.50	7.83	98.95
27/4/97 (2)	1.5	0.50	99.37
7/4/97 (1)	14	12.13	99.33
7/4/97 (4)	20	13.21	97.16
30/4/97 (3)	6.0	2.79	98.33
21/4/97 (1)	3.50	1.39	98.80
26/4/97 (2)	7.5	3.31	97.77
24/4/97 (2)	21	15.17	97.68
20/4/97	35	32.68	99.21
30/4/97 (1)	40	35.79	98.75
	Mean		98.54

Result of Curve Number Validation

The approximation of the bare runoff plots with paved surfaces was validated using different rainfall and runoff events. The computed runoff based on the curve numbers obtained by treating the bare runoff plots as paved surfaces and the observed runoff are presented in Table 3. A comparison of the computed and observed runoff revealed a close fit as shown by the high value of coefficient of determination (R^2 = 0.971) and a low mean error of estimate (ME = -0.485). The results proved that the assumption of the runoff plots being treated as paved surface was acceptable if the soils have surface sealing and crusting tendencies.

Table 3. Comparison of computed and observed runoff with plots as paved surfaces.

Date of storm	Rain (mm)	Observed runoff (mm)	Computed runoff (mm)
28/4/97 (1)	7	5.35	4.88
5/5/97	11	8.21	8.69
31/3/97	15	12.93	12.60
4/4/97	12	8.66	9.66
1/5/97 (2)	31	29.33	28.45
10/4/97 (2)	2	0.74	0.63
26/4/97 (1)	3.8	2.26	2.00
7/4/97 (3)	2.5	1.37	0.98
30/4/97 (2)	3	2.08	1.35
22/4/97	13	11.40	10.64

Figure 3 shows a plot of computed against observed surface runoff about the 1:1 line. It is evident from Figure 3 that the computed and observed runoff values fitted closely, confirming further that the approximation of bare runoff plots as paved surfaces was acceptable. Based on the results of the study it was clear that the curve number method could be used to compute surface runoff with assumption of bare runoff plots being paved surfaces if the soils have a tendency to form crusts. According to Hendrix (1985), the soils in the study area have a tendency to form crusts and therefore the results of the study can be regarded as acceptable.

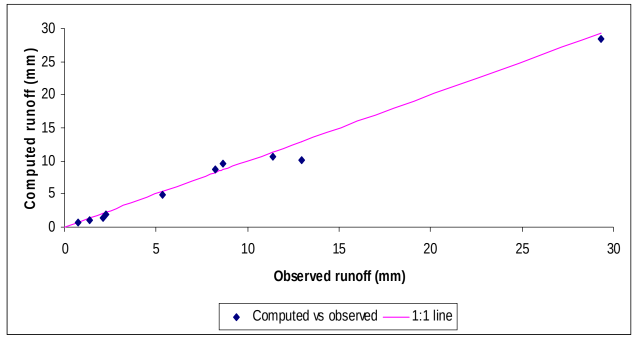

Figure 3. Comparison of computed and observed surface runoff about the 1:1 line.

Conclusions and Recommendations

The study investigated the runoff characteristics of bare micro catchments using observed rainfall and runoff data. The results of the study revealed that the runoff behaviour of the bare micro catchments could be equated to paved surfaces. A comparison between computed and observed surface runoff revealed a close fit, indicating that the curve number method could be used to compute surface runoff from bare micro catchments with acceptable accuracy if treated as paved surfaces. Therefore, it can be concluded that for soils with a tendency to form a surface crust, the NRCS CN method works well with the bare micro catchments being treated as paved surfaces. The NRCS CN method is recommended for computation of surface runoff from bare micro catchments in semi arid areas if the soils undergo surface sealing and crusting.

Acknowledgements

I wish to express my sincere gratitude to the Dutch Government for providing the research funds through collaboration with Moi University. I wish to thank the Chief for Kipkomo location, the District Officer for Chepareria Division and the administration police officers at the chief's camp for ensuring security of the research site during the entire research period. I acknowledge the staff of Kenya Meteorological Department for providing technical assistance and the raingauges used in the research. Lastly, all the staff in the ministry of water development in Kapenguria office are highly appreciated for their support.

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