POTENTIAL OF EPISODIC FLOWS IN SOME FOUR REPRESENTATIVE NON-PERENNIAL RIVER FLOW CATCHMENTS IN SEMI ARID LAIKIPIA DISTRICT, KENYA

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Abstract. The purpose of this study was to establish the water resources of the non-perennial streams in providing supplementary water needs in Laikipia district. This district has undergone remarkable land use changes resulting in water use stress of perennial river abstractions and groundwater exploitation in the semi arid environment.

Over a three year period extending from January 1989 to December 1991, hydrological variables were monitored in four non-perennial flow catchments within the district. These catchments have been shown to have potential of about 8000 m^3/km^2/year except for long dry spells during the observation period and high sediment losses and evaporation rates calling for proper conservation measures in order to exploit productively the water resources potential of such catchments.

Key words: hydrological variables, non-perennial streams, semi-arid hydrological variables, water use stress

1. Introduction

Of the available water resources in most semi-arid basins, non-perennial flows have received least attention in Kenya. These could contribute to the water supply through reservoir storages, but there is lack of adequate information on the hydrology of catchments with non-perennial flows which could be used for effective long term planning, management and exploitation of the available water resources. This information would include temporal characteristics of surface runoff and sediment transport.

Studies on semi-arid catchments have shown well defined relationships between sediment loads and runoff (Weaver, 1980). Steep rising and falling limbs for semi-arid flow hydrographs have been observed by Yair and Lavee (1976) and Pilgrim *et al*. (1989) have attempted modelling of semi-arid hydrological information. Van Sickle and Bescheta (1983) have also presented results on non-perennial flow characteristics in semi-arid parts of South Africa with well developed relationships between flows and suspended sediments. Other studies on semi-arid catchments include those by Edwards and Blackie (1981), Herald (1989), Berger (1989), Decurtins *et al*. (1988), Lane *et al*. (1978), Renard and Lauresen (1975) and Murray and Gorgens (1983) among others.

In this study, four catchments were investigated for potential of episodic flow to supply various needs. The evaluation was done for a number of observed storms in the representative catchments within the semi-arid Laikipia district.

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2. Location and Characteristics of the Study Area

Laikipia district is situated to the west of Mt. Kenya and to the North West of the Nyandarua ranges. The district extends between latitude 0°46′ North and 0°18′S longitude 36°15′E and 37° 17′E and has an area of 9720 km^2 lying in an altitudinal range of about 1500–2000 m.a.s.1. The location of the non-perennial catchments representative of Laikipia semi-arid district is shown in Figure 1. having been chosen on the basis of hydrological homogeneity, Ondieki (1993). A brief account of the chosen catchments is given.

2.1. NGENIA CATCHMENT

This catchment is located in latitude 0° 05′N and longitude 37° 12′E and has a catchment area of 2.04 km^2. It slopes in an East-West direction with a slope varying from 3–6%. Geologically, the catchment is underlain by Mt. Kenya volcanics and its soils are developed from colluvial materials derived from the volcanic rocks and are well drained. The land use is largely cultivation of maize, beans, potatoes, and wheat with small portions left for grazing. The climate of the catchment may be described as semi-humid to semi-arid with rainfall ranging from 600–750 mm and mean annual evaporation rates ranging from 1500–1600 mm. Figure 1d shows the hydrometric network of the catchment.

2.2. SIRIMA CATCHMENT

The catchment is located on latitude 0° 05′S and longitude 36° 49′E and covers an area of 3.65 km^2. With an altitudinal range of 1910–2100 m above mean sea level. It slopes in a NW–SE direction with slopes ranging from 2–5% in the foot slopes and 8–16% on the upper catches. The catchment is covered by igneous rocks of mixed volcanic formations of miocene to pleistocene age consisting of phonolites and basalts. The soils are mostly friable to firm clay with vertic characteristics in most parts of the catchment where vertic luvisols exist. The land use is mainly livestock grazing with limited subsistence cultivation of maize and beans. The climate is semi-humid to semi-arid with mean annual rainfall ranging from 600–750 mm and annual evaporation rates ranging from 1600–1700 mm. Figure 1c shows the hydrometric network at the catchment.

2.3. MUKOGODO CATCHMENT

Mukogodo catchment is located on latitude 0° 23′N and longitude 37° 04′E and covers an area of 2.52 km^2 sloping from West to East, the altitude ranges from 1820–1990 m above mean sea level with slopes of 2–16% with topography consisting of undulating rolling uplands with rock out-crops and valleys are greatly incised with gullies and rills. The catchment is underlain by the Basement complex with metamorphic rocks of Precambrian age which consists of gneisses and migmatites.

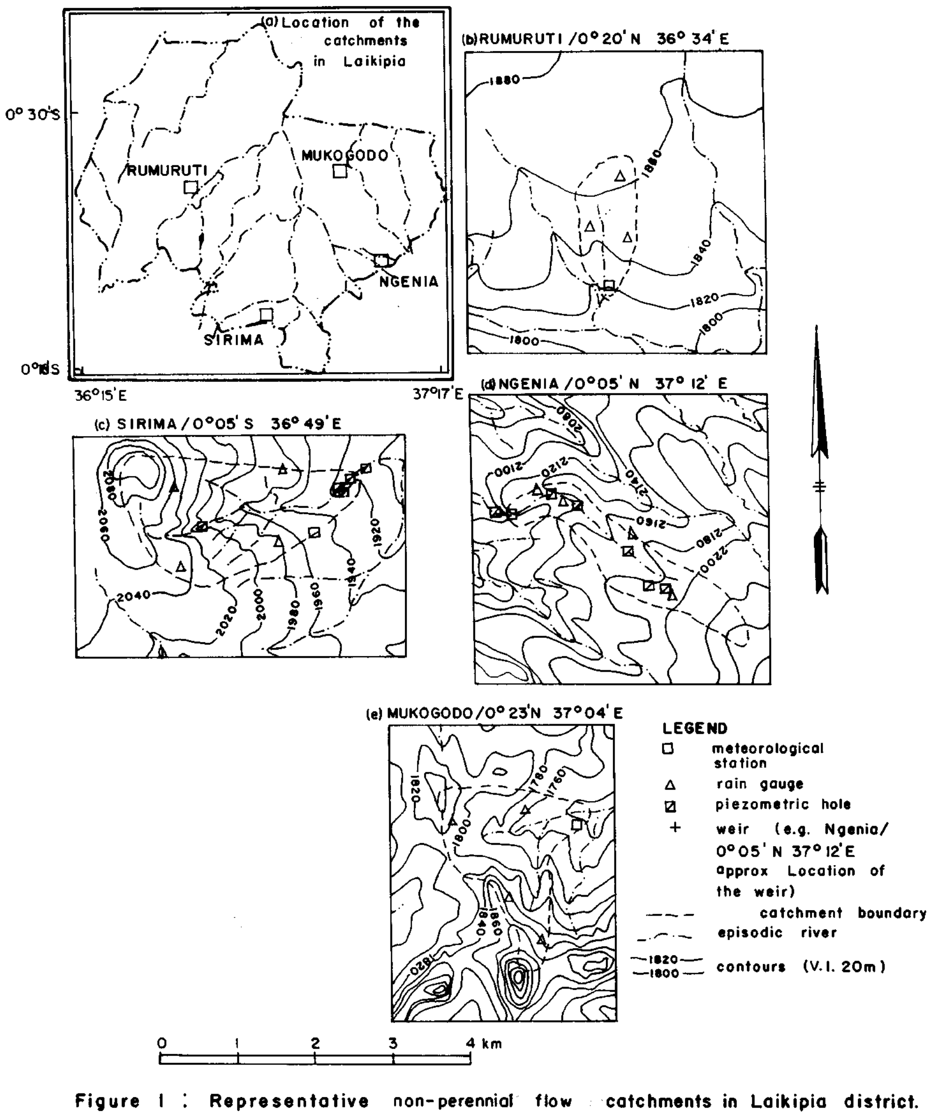

Figure 1. Representative non-perennial flow catchments in Laikipia district.

The soils are developed on the metamorphic rocks and are well drained red friable gravely sandy clay mainly luivisols and lixols intertwined with stones and boulders. The land use is mainly communal pastoral grazing with no single settlement within the catchment whose vegetation cover is mainly thorny acacia bushes with minor annual grasses. The climate in this catchment is semi-arid with annual rainfall ranging from 450–600 mm and annual evaporation rates ranging from 1750–1950 mm. Figure 1e shows the hydrometric network.

2.4. Rumuruti catchment

This catchment is located on latitude 0° 20′N and longitude 36° 34′E and covers an area of 1.14 km^2. The catchment slopes in a West-East direction with an altitudinal range of 1818–1865 m above mean sea level with a mean catchment slope of 2.8%. The catchment is underlain by volcanic rocks ‘with soils developed from phonolites and colluivial material derived from volcanic rocks. The soils are well drained and range from luvic phaeozems in the upper catches to eutric cambisols at the footslopes. The land use is mainly grazing with sparse thickets and grass species. The climate is semi-arid with annual rainfall ranging from 500–700 mm and annual evaporation rates between 1750–1950 mm. Figure 1b shows the hydrometric network of the catchment.

3. Methodology

The techniques which were used to acquire the various hydrological data in each of the catchments during the experimental period are given.

Point rainfall amounts and intensities were obtained by both standard raingauges and Hellman autographic rainfall recorders. Four to five standard raingauges and one autographic rainfall recorder were used in each catchment. The Thiessen (1911) averaging technique using each catchment network was adapted in computing the areal rainfall depth on daily time means as per the relationship

$$P = \sum_{i=1}^{n} W_i d_i \tag{1}$$

where

$$W_i = \frac{A_i}{\sum_{i=1}^{n} A_i}$$

is defined as the weighting coefficient for any given station,

A_i = is partial area covered by that station and;

d_i = is point precipitation depth of station i.

15 minute rainfall values recorded by the Hellman recorder were used to determine hourly rainfall intensities at the individual catchment locations for the storm events.

3.1. Water discharge

Sharp crested weirs were constructed at suitable catchment outlet sites as per the British standards, 3680 (1980). A relationship between water discharge and water level measured at the upstream by a water level recorder and staff gauge was obtained by using a current meter at various verticals within the cross section as per the mid-section method (Young, 1950; Thornes and Somers, 1969) using the formula:

$$Q_m = \sum_{i=1}^{n} V_i b_i d_i \tag{2}$$

where

V_i = mean velocity at vertical i (m/s);

d_i = depth at vertical i(m) and;

b_i = sum of half the width from adjacent verticals for which partial discharge (m^3/s), $b_i v_i d_i$ is calculated and n is the number of verticals.

For situation of extreme flows where a weir could be topped, the slope-area method of Manning (Tate and Benson, 1967), was used to indirectly determine the discharge. The equation which involves channel characteristics, water surface profile and roughness or retardance coefficient is written as

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \tag{3}$$

where

Q = discharge (m^3/s);

A = cross sectional area (m^2);

R = $\frac{A}{P}$, the hydraulic radius (m);

P = wetted perimeter (m);

S = Frictional slope of the water surface;

n = Manning roughness coefficient, which is a function of bed material, cross-sectional irregularities, depth of flow, vegetation and channel alignment.

The water level records confined to the weir levels were rated and their discharges were easily obtained. During the runoff event, there was that portion during the rising and falling stage of the hydrograph where the flows exceeded the weir levels. The flood marks were manually recorded on the stilling well pipe with respect to time and the cross-section levelled after the flow receded and thus the whole hydrograph was now available for volume computation for the runoff event. The highest flood marks were obtained by pegging at both banks and using some three cross-sections; upstream, at weir site and downstream the appropriate discharges were computed using the Slope-Area method.The runoff volume for each of the events was then obtained through an integration of the discharge time graph over small time intervals which with the planimetered catchment area, event runoff values (mm) could be obtained.

Simple relationships between runoff and rainfall were then sought through simple linear regression relationships of the form:

$$R_i = \alpha(P_i - \delta) \tag{4}$$

where

R_i = storm runoff (mm);

P_i = rainfall (mm);

α = runoff coefficient;

δ = threshold rainfall value (mm).

The simple relationship, also used by Diskin (1970), and Frasier (1975) was used in an attempt to measure the relative catchment response to storm rainfall.

3.2. Suspended sediment loads

Water samples taken from the centre of the gauging sites were taken for suspended sediment load using a calibrated device lowered and raised such that the sampling device almost filled during the submergence time during rising and falling stages of the hydrograph. Details of this procedure are discussed in Ondieki (1993, 1995), Riggs (1969) and Flaximan (1975) and will not be highlighted here.

3.3. Evaporation

Pan A was used to obtain the evaporation rates for each of the catchments. This value is an integration of temperatures, winds, humidities and solar insolation within the catchments.

3.4. Episodic flow potential

In order to establish the water resources potential of the episodic flows in the catchments, the demand was first considered. The demand was computed on the basis of 0.05 m^3/day per livestock unit, domestic consumption of 0.35 m^3/ day per family and 86.4 m^3/ha/day irrigation needs as per the rural Kenyan standards for water use (Tams, 1979). A scenario of 50 families, each settled on a 2 ha plot and having two livestock units was assumed to be the population supplied from a vicinity of 1 km^2 area of reservoir site consistent with the situation in the already settled area. The reservoir was also assumed to be on a non-perennial channel at a point of 1 km^2 area outlet and for purposes of catchment comparison, the reservoir was considered to be the only source of water supply. The agricultural demand by irrigation was excluded from the above scenario since this demand alone far exceeded the yield supply. The seasonal fluctuations of the demand were also assumed to be insignificant and uniform draft over an average year was used. Using the total annual demand based on domestic and livestock needs, a value of 8218 m^3 was obtained. Defining the annual surplus as the deficit between annual flow supply and annual demand, this value was also equally spread over the months of the year. Compared with demand, the difference in magnitudes between this and the surplus would show the relative potential. Of necessity any prescribed demand would be assigned.

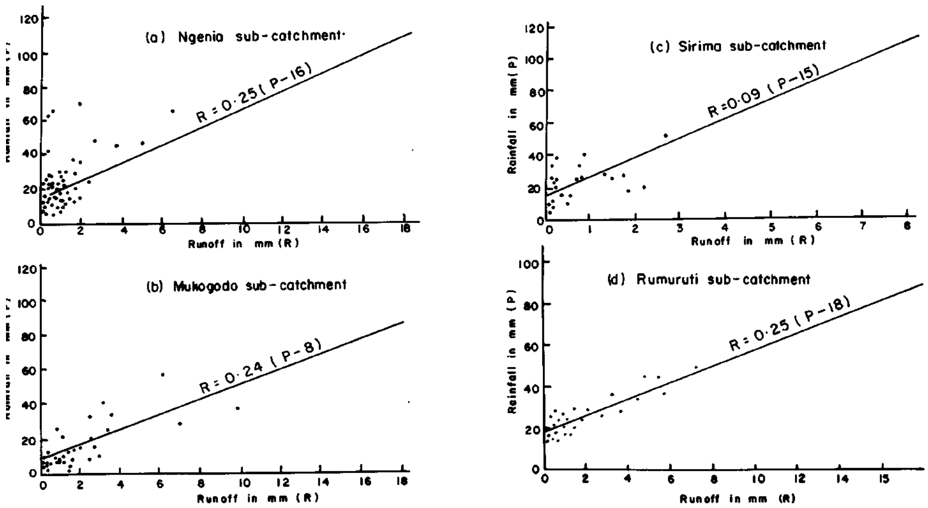

Figure 2. Examples of scatter diagrams of linear regression relationships for sub-catchment rainfall runoff events.

4. Results and Discussion

The seasonal characteristics of the rainfall, discharge, suspended sediment loads and evaporation varied considerably for each of the three experimental years. The monthly rainfall for Mukogodo catchment for example varied by a factor of 6 when the high rainfall year 1989 (April) was compared to the same month for the low rainfall year (1991). For each of the catchments, there were high seasonal rainfall variations associated with the passage of the Inter-Tropical Convergence Zone (ITCZ) and the westerly influx of the Congo/Zaire basin moisture and the Atlantic Ocean.

The rainfall variations were reflected in the corresponding runoff and suspended sediment loads. This would mean that rainfall would have some relationship with the runoff and suspended sediment loads. Indeed, Figure 2 shows the relationship of the rainfall and runoff for the observed storms during the experimental period.

The lowest runoff coefficient of 0.09 was obtained at Sirima catchment while Mukogodo and Rumuruti had relatively high runoff coefficients of 0.24 and 0.25 respectively. The threshold or cut-off values representing initial catchment retention under average conditions for the catchments ranged from 15–18 mm with a low value of 8 mm for Mukogodo catchment. The runoff variances could be explained by 63–68% of the rainfall in three of the catchments with a minimal variance of 40% for Rumuruti. These relatively low values would be attributed to the antecedent catchment wetness at the start of the storm events, individual rainfall intensity characteristics, differences in geology, slopes, soil types and land use cover conditions. Improved regression relationships could be obtained by pos-

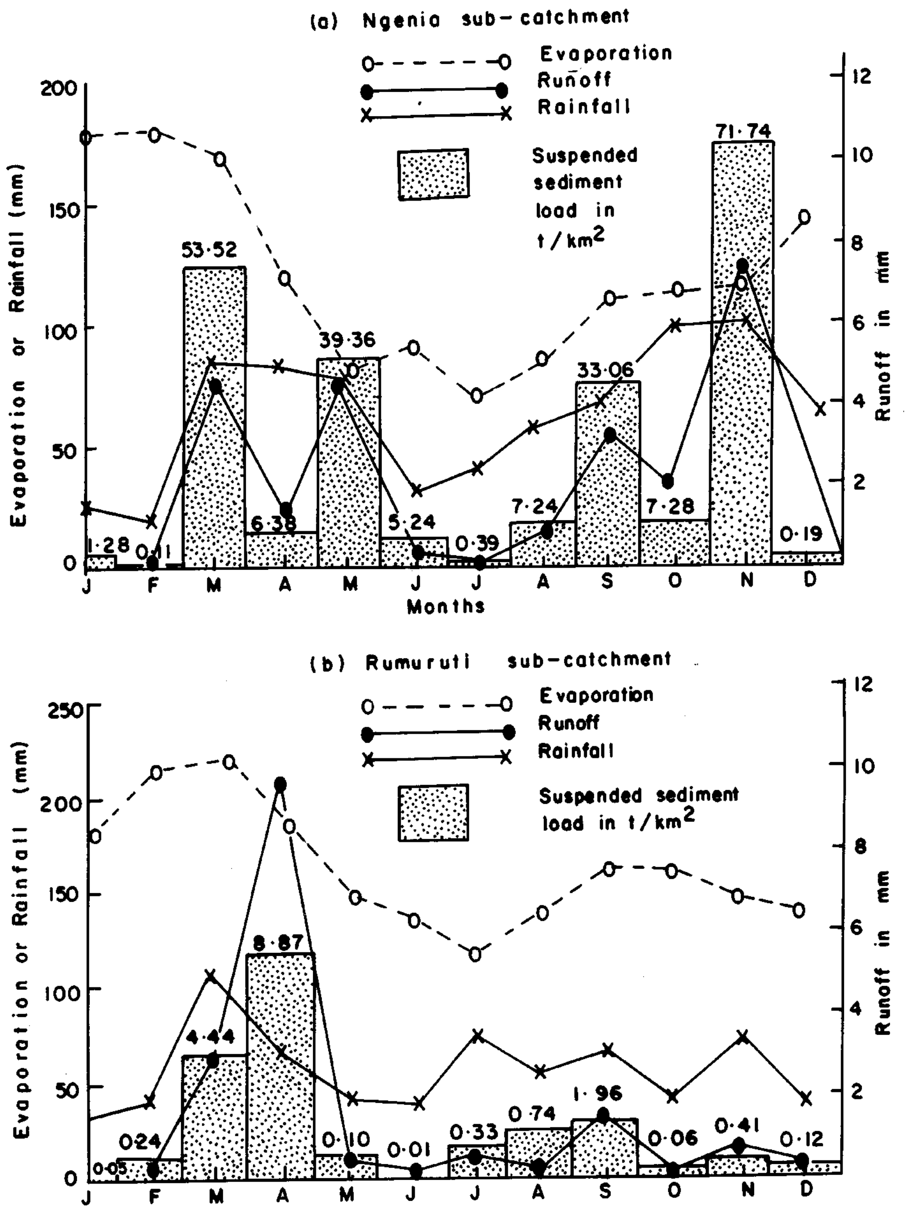

Figure 3. Mean seasonal hydrological variables for Ngenia and Rumuruti sub-catchments.

sibly incorporating the lagged effects of previous rainfall events or treating rainfall events above the mean threshold values and ignoring the lower storm events.

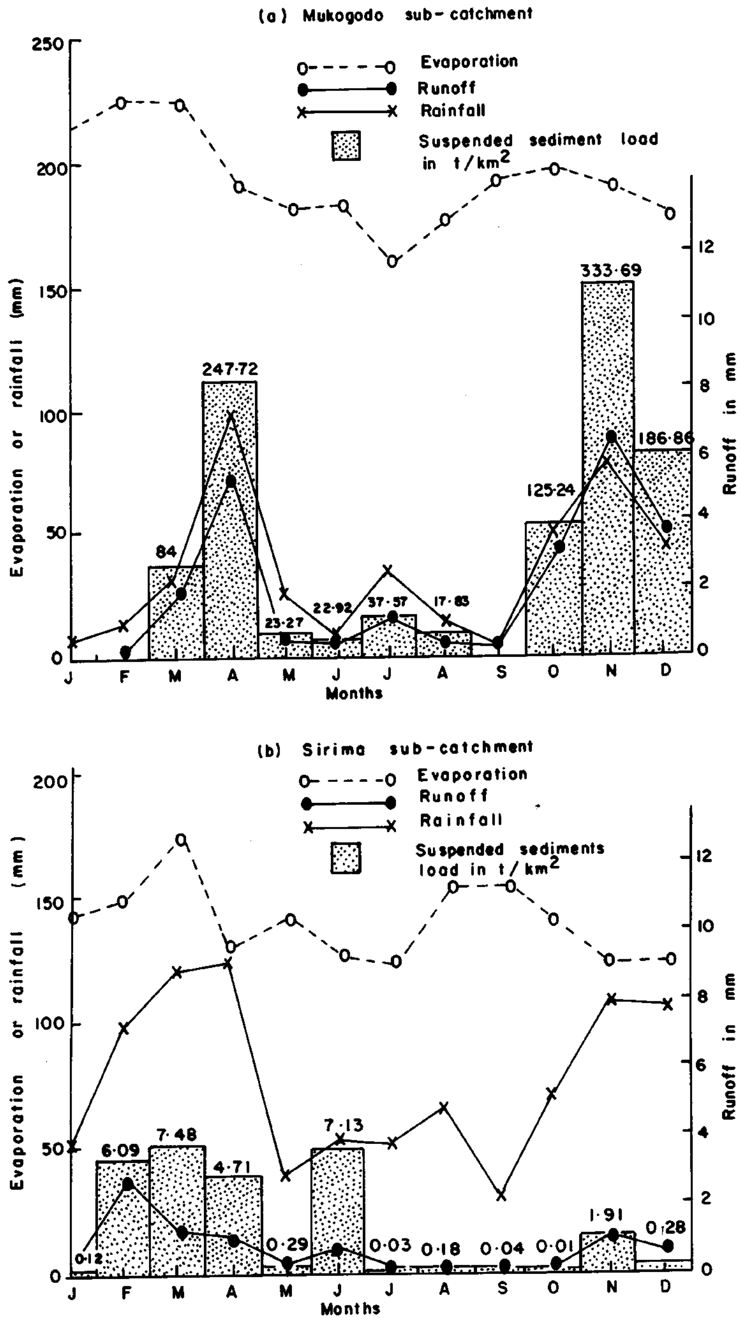

Figure 4. Mean seasonal hydrological variables for Mukogodo and Sirima sub-catchments.

The mean seasonal patterns of the various hydrological variables for the catchments over the experimental period (89–91) are presented in Figures 3 and 4. It is interesting to note that for all the catchments, the potential evaporation was much higher than rainfall over all the months. The mean potential evaporation was lowest during the month of July and highest during February or March in all the catchments. Mukogodo catchment recorded the highest mean annual potential evaporation rate of 2060 mm over the period while Ngenia recorded an annual mean of only 1540 mm. Although the potential evaporation rates are very high giving an indication of lack of potential for harvestable surface water, during the individual daily episodes, the effective evaporation rates are less marked and harvestable yields can be obtained. The problem only comes in the year round storage on reservoirs. Here the evaporation of water storage may be significant, but the use of Cetyl alcohol may control this.

From Figures 3 and 4, there was an indication of close association of rainfall, runoff and suspended sediment loads. This is clearly evident in the months of April and November for Mukogodo and March and November for Ngenia. Comparable mean monthly rainfall amounts however yielded varying runoff and suspended sediment loads as was the case in April and November in Sirima and Rumuruti. This variability may be explained by the individual event characteristics which contributed to the mean monthly values. A sample of such events behind the above variation are shown in the Table I below. A total of 67 events were recorded in Ngenia, while 45, 44 and 32 events were observed in Sirima, Mukogodo and Rumuruti respectively. Each episodic surface runoff event occurred at localised microscale levels with onsets and amounts being reflective of the antecedent rainfall and cover conditions as already discussed above.

The potential yields for the catchments may be deduced from Figures 5 and 6. The supply in terms of monthly runoff volume has been given as obtained while demand and surplus are assumed constant over all the months of the year. Increased potential supply from the episodic flows is envisaged as peaks over wet periods being stored for use in the dry spells.

Large positive differences between surplus and demand lines (Figure 5) would indicate existance of flows that could meet dead storage in dams, evapotranspiration requirements and downstream ecological needs. When the demand line is far above the surplus potential, then we have negative differences between surplus and demand (Figure 6a). This shows great constraints in the supply potential for the stipulated needs.

When the prescribed demand was expressed as percentage of mean annual flow supply, the catchments which showed high potential yields that would meet the demands over critical periods of a year were Ngenia (29%), Mukogodo (32%) and Rumuruti (43%). Sirima, however showed little promise for the prescribed demand as this required 93% of flow supply to be stored. As stated above, the demand line for this catchment was far above the surplus potential. This low yield would imply

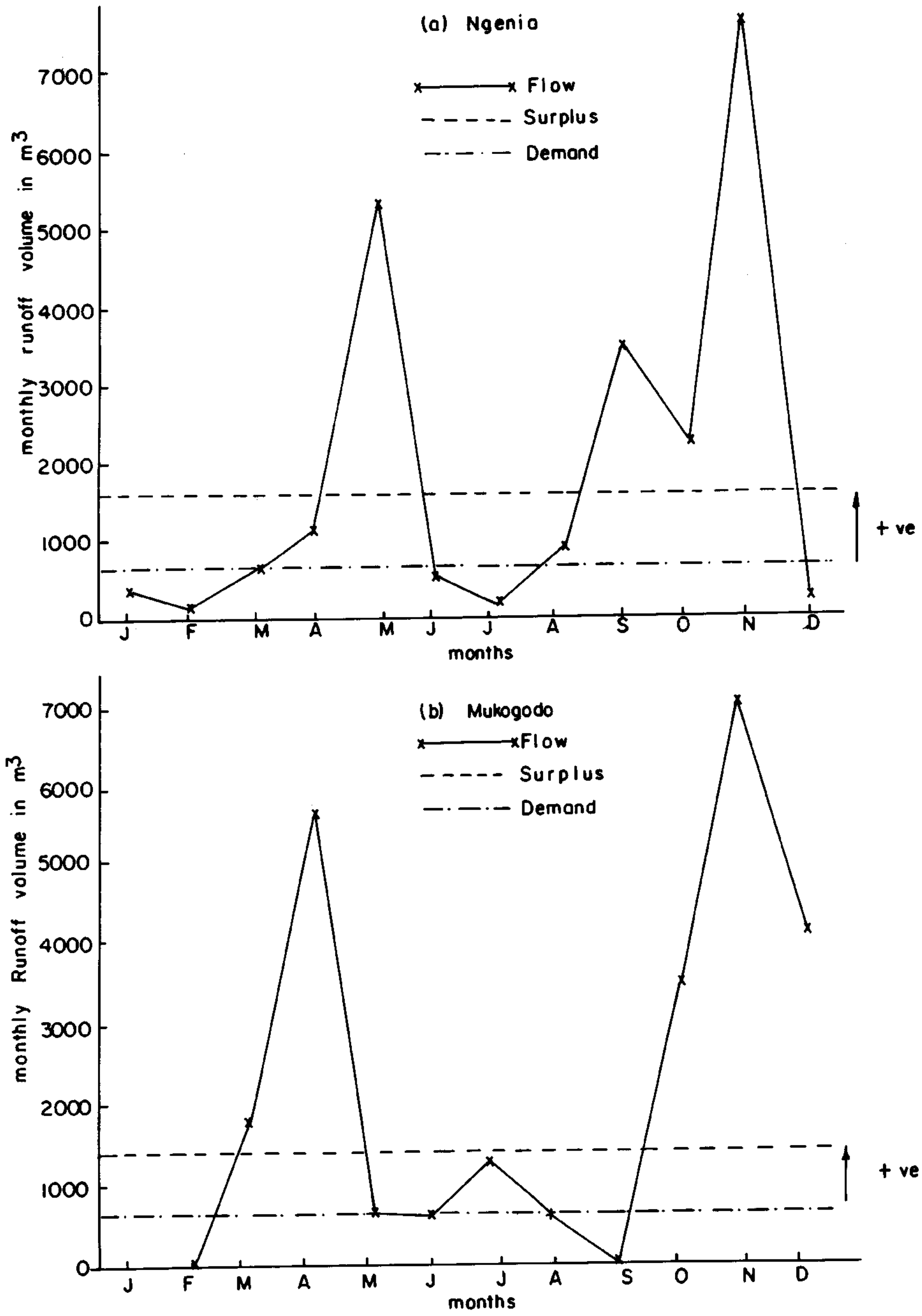

Figure 5. Comparative episodic flow potential yield for Ngenia and Mukogodo sub-catchments.

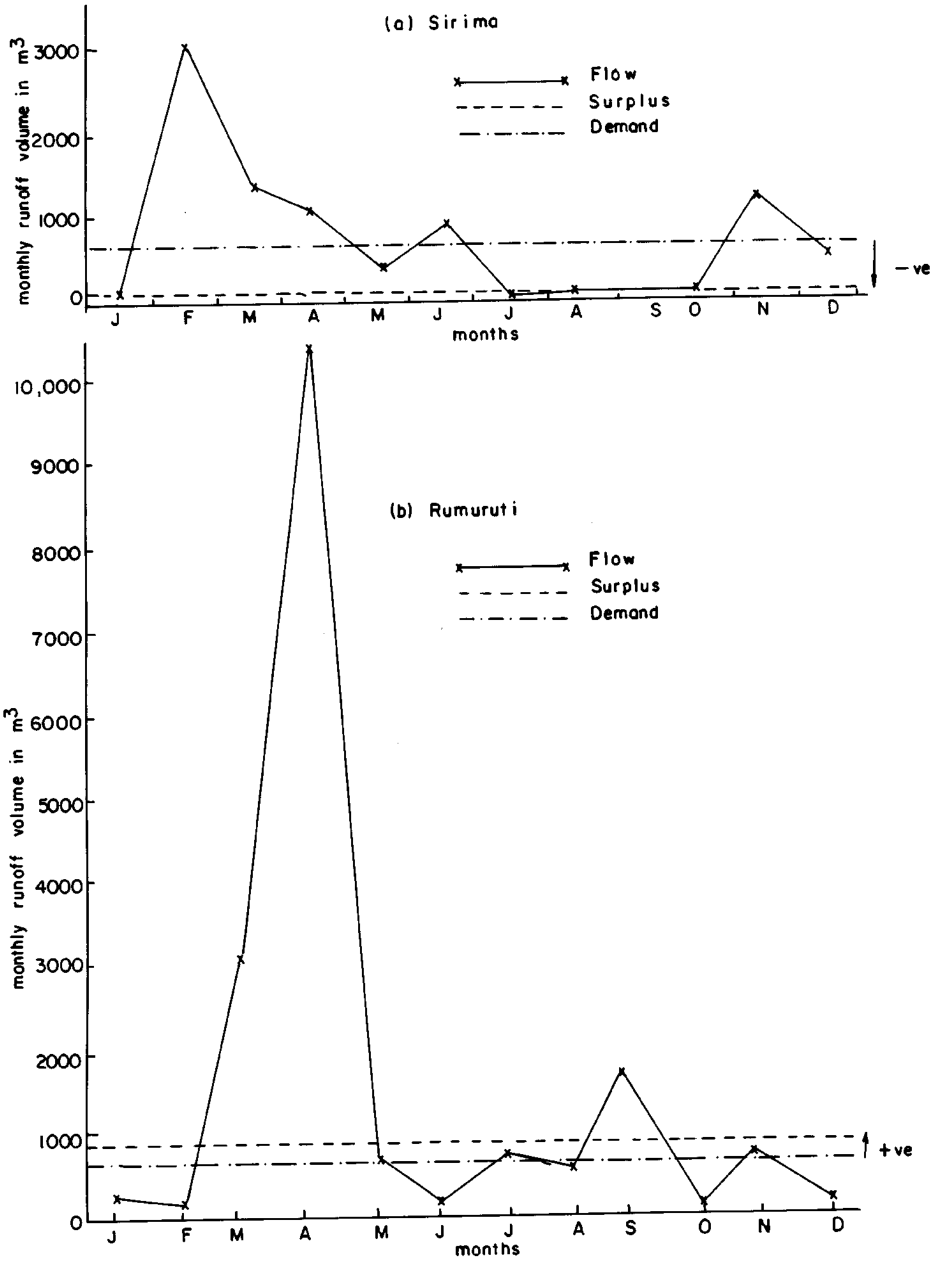

Figure 6. Comparative episodic flow potential yield for Sirima and Rumuruti sub-catchments.

Table I
Individual event characteristics in the catchments

Catchment	Date	Peak	Max	Qvol	Rainfall
		(m^3/s/km^2)	i_{15}(mm/h)	(mm)	(mm)
Ngenia	9.3.90	1.373	66.4	5.10	66.5
	7.11.90	4.363	78.4	17.68	95.3
	5.4.91	0.234	87.2	0.84	20.4
Sirima	10.2.90	1.456	160.0	6.19	110.8
	14.3.90	1.605	36.0	3.59	32.6
	28.4.91	0.169	100.0	0.67	24.0
Mukogodo	13.11.89	6.053	57.2	9.82	36.0
	17.10.90	1.478	52.8	2.35	25.3
	26.3.91	1.034	31.2	3.17	41.0
Rumuruti	4.3.90	1.304	44.0	6.09	68.3
	10.4.90	0.432	6.0	12.52	43.3
	9.7.90	0.331	36.8	0.89	20.5

i_{15} = 15 minute rainfall intensity.
Q_{peak} = Peak discharge.

that only reduced needs may be met. This may mean only livestock or possibly a lower human settlement density.

The major constraints that should be accounted for in harnessing of the episodic flows in reservoirs were the sediment loads and the high evaporation rates. Given the annual sediment loss of 1080 t/km^2 at Mukogodo for example, storage volumes for reservoirs would lose capacity by about 700 mm per km^2 area assuming a sediment bulk density of 1.50 t/km^2 and 90% trap efficiency. Ground water replenishment may also be accomplished by recharge through non-perennial streams. An assessment for groundwater replenishment by ephemeral runoff was however not conclusive.

5. Conclusions

This study has shown that the experimental catchments had high seasonal variability in rainfall which was reflected in the seasonal runoff and suspended sediment loads over the three experimental years. The variations among the different catchments were dependent on the rainfall regimes and other physical characteristics such as soils, land use cover, topography and antecedent conditions.

During any particular runoff event, there existed significant relationships between rainfall and runoff. This rainfall-runoff relationships indicated threshold values of between 8–18 mm with coefficients of determination of between 63 to 68% which could be improved by considering the effect of antecedent moisture for all storms. The runoff amounts and rates were associated to the event rainfall amounts and intensities and the responses in sediment generation could also be influenced by the preceding antecedent conditions.

Most of the experimental catchments have potential for water harvesting. The surface water supply was however not uniform throughout the year. The mean flow patterns showed that about four months in a year are relatively dry. From the mean flow values, using a scenario of future settlement capacity of two hectares per family, the results from the study indicated that some of the demands for water over these periods can be met by storage of the non-perennial flows in reservoirs. In the presence of such storage facilities, the episodic flows of about 8000 m^3 per km^2 per year can serve as supplementary water sources for domestic and livestock needs. The catchments which showed high potential yields were Ngenia, Mukogodo and Rumuruti but Sirima showed little promise for the stated scenario.

Major handicaps which could limit the utilisation of the non-perennial water resources of the semi arid environment included high sediment rates and high evaporation rates as exemplified by the Mukogodo values of 1080 $t/km^2/y$ and 2060 mm respectively. The flush floods may be stored in cemented wells which could be properly protected after appropriate removal of sediments by filtration for use in dry seasons or drought years in the and and semi-arid environments. Sub-surface dams could also be preferred in some areas as a solution to the high sedimentation and evaporation rates.

Appropriate conservation measures and practicing of sustainable land use such as controlled grazing of pastoral areas in ASAL and sustainable agriculture through well organized settlements should be encouraged. This could help in avoiding loss of valuable soils and nutrients by sediment transport. If the non-perennial stream catchments have to supply surface water reasonably to future domestic and livestock needs, settlement patterns must be controlled with suitable carrying capacities in the ASAL areas. Apart from the potential of the non-perennial streams through damming for direct use, the streams may also have potential of replenishing the groundwater systems in the ASAL. This could be accomplished by retarding runoff using small embankments along the non-perennial channels at various stretches, flooding, ditches and percolation through pits. This calls for an overall multi-disciplinary approach of coordinated development involving pasture management, settlement patterns and land use planning

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