

RUNOFF GENERATION AND SOIL EROSION UNDER THREE DIFFERENT LAND USES IN THE DRY ZONE OF SRI LANKA

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ABSTRACT

Large quantities of runoff is produced during the main rainy season in the dry zone of Sri Lanka, which is collected in a system of tanks both small and large, for the purpose of irrigating crops. All such small village tanks command an area equivalent to 15% of the total extent of paddy lands in the country. Surface runoff from micro-catchments is the main source of water supply to these tanks. As water is the most limiting resource for agricultural development, surface runoff plays a vital role in rural agriculture sector.

Catchment runoff yield is determined by rainfall and catchment characteristics such as land use, soils, slopes and catchment dimensions. In the dry zone micro-catchment, land use plays a dominant role in determining catchment runoff, because it varies from year to year, whereas other factors remain constant. Therefore, the influence of land use namely chena (cleared land), scrub and forest, on surface runoff and soil erosion was evaluated, for the purpose of making recommendations on the allocation of lands for different uses in a micro-catchment.

In chena land runoff was found to have a linear relationship with the daily rainfall ($r = 0.93$). Chena land generated 36 to 55% of the rainfall received in the maha season as runoff, whereas the other two land uses produced less than 2%. During maha 87/88, soil loss in chena land exceeded the locally accepted allowable limit of 9000 kg/ha/year by 17%. But soil loss was negligible in the other two land uses.

KEY WORDS : Chena land, Runoff generation, Soil erosion

INTRODUCTION

In the dry zone of Sri Lanka, where the landscape is a composite of micro-catchments, rainfall is seasonal. High intensity rainfalls occur during the main rainy season. Both landscape and rainfall characteristics contribute to the generation of substantial quantities of catchment runoff during rainy seasons.

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In the region, rainfall is erratic and uncertain. Poor distribution of rainfall and lack of other water resources had been the main constraints to agricultural development. Hence, a water conservation system, commonly referred to as village tanks had been developed to collect the catchment runoff by early settlers in order to irrigate paddy, the principal staple food crop of the people of this country.

Presently, about 8000 village tanks are in use in the island (Ratnatunga, 1979). Nearly 102,000 ha are cultivated with paddy under them, which is 15% of the total area developed for paddy cultivation in the island. These tanks collect water both from catchment yield and direct rainfall. In maha nearly 65% is received from runoff whereas, in yala it does not exceed 33% and the balance is contributed by direct rainfall (Somasiri, 1979).

Catchment runoff is largely influenced by factors such as catchment size, topography, soil type and land use. Unlike other factors, land use is subjected to many changes arising from agricultural and other development activities and these affect tank water collection. Therefore, quantification of runoff generation and its relationship with the rainfall pattern under different types of land use are useful to determine the suitable land use composition for a catchment to generate the appropriate runoff amount with a certain degree of balance and stability. Unlike in more stable, settled wet areas, in the dry zone the extent of forest, scrub and chena (cleared land), the most dominant land uses, are subject to changes when farmers shift from one tank micro-catchment to another for traditional 'slash and burn' cultivation. With changes in extent of chena the extents of scrub and forest are also altered and these appear to have an influence on runoff generation.

It is also well known that soil erosion is enhanced by high runoff generation, which creates many problems due to siltation and land degradation. Therefore, soil loss measurements under different land uses would be equally useful in recommending catchment conservation and management measures.

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This paper discusses the results of an experiment carried out in the Nachchaduwa catchment from 1987 to 1989 to evaluate both runoff generation and soil erosion under three different land uses, chena, scrub and forest.

MATERIALS AND METHODS

Description of the study area

This study was carried out at Maradankadawala (8° 5'N, 80° 34'E) in the Nachchaduwa catchment. This lies in the agroecological region DL₁ (Agroecological Map of Sri Lanka, Land and Water Use Division, Peradeniya, 1976).

The rainfall here is bimodal with an average annual total of about 1200 mm. Only 20% of this rain is received in the yala season, between March and June. Not enough water is collected in the tank system in yala to provide for irrigation. The remaining 80% of the annual rainfall is received in the maha season, usually starting in October with high intensity thunderstorms; the intensities may reach even up to 100mm/hr. These high intensity storms are followed by north-east monsoon rains in November and last until mid-January. Maha is the main water contributing season for the tank system.

The dominant topography in this region varies from flat to rolling (0 to 16% slope). Lands with higher slopes are found occasionally in isolated hills and ridges. Forest cover still remains on lands with slopes over 8%. Other land uses, such as shifting cultivation, homestead garden, teak forest and abandoned chena are in flat to undulating lands (0 to 8% slope). The soils comprise of Reddish Brown Earths (RBE) in uplands and Low Humic Gley (LHG) soils in valley bottoms (De Alwis, and Panabokke, 1972). Paddy cultivation and village tank systems have been confined to the valleys, usually with slopes less than 2.5%. All these land uses are in a mosaic as shown in Fig. 1. The land use distribution of the Nachchaduwa catchment area is given in Table 1.

Runoff plots

Three plots with overflow divided tank system to collect runoff water and eroded soil particles were constructed in each selected land use. The length of each plot was 22.13m, while plot widths were changed to minimize errors arising from possible water dripping from tree branches out of the plot. Neither runoff nor soil erosion from a unit area is affected by the plot width, but rather by the slope length (universal soil loss equation). Furthermore, it is an accepted principle in studies involving large catchments to select catchment of different sizes; therefore in this study different plot sizes were adopted to suit the local condition. Moreover, the larger widths for forest and scrub, were expected to reduce errors of measurement. Thus plot widths of 5.49 and 7.31 m were used for scrub and forest lands respectively, to accommodate the larger canopies. The plots under chena lands had a width of 1.8 m. Except for land use and plot width the other factors were kept uniform by the experimental design. The soils, the slope and the surface of the plots were same for all treatments. A well-drained RBE site on a 1.5 to 3% slope was selected for this study as most shifting cultivation sites are in similar land categories. The same plots were used to obtain the data for the second year.

Rainfall and runoff

Rain gauges were kept in an open space close to the site to measure daily rainfall. Daily throughfall was measured by keeping rain gauges inside the plot area and on the brim of runoff collecting tanks. This plot runoff estimation was corrected by deduction of throughfall volume from the total water collection in the tank, as the tanks were not covered.

Soil loss

Runoff water collected into the tank was stirred and five water suspension samples were taken. From each sample the soil content was measured after drying in the oven at 105°C.

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RESULTS AND DISCUSSION

Runoff

The runoff generation in micro-catchments of the study area is discussed mainly with reference to total seasonal rainfall and seasonal runoff as determined by the land uses under study. The rainfall intensity factors have not been considered for runoff evaluation or in the assessment of soil loss, because the application of such information would be limited by non-availability of rainfall intensity data for the dry zone in general. The data also show that seasonal total runoff depends largely on land use rather than on the absolute quantities of rainfall (Table 2). In spite of different rainfall quantities received on these different land uses, the runoff generated from chena plots remained always greater than from other plots. Furthermore, in this region overall rainfall intensity calculations do not appear to vary much from place to place, although on a given day it can be highly variable.

The chena land runoff generation was greater than that of the scrub and forest; but the difference in runoff between scrub and forest was negligible (Table 2). Chena with unprotected soil surface during maha planting time is directly exposed to the early intermonsoon high intensity rains, with the result the bare land surface is converted to a high runoff generating surface. Furthermore, the destruction of soil aggregates by the impact of rain drops and slaking causes surface sealing while repeated cultivation of Alfisols compacts soil layers by particle translocation (Pathak *et al.*, 1983). Both these enhance runoff generation. In these chena lands, as water infiltration is low, initial crop growth is retarded; hence surface remains bare for a longer duration, thereby generating greater runoff (El-Swaify *et al.*, 1983).

In contrast, scrub and forest lands with protected soil surface maintain high water infiltration capacity. This is further enhanced by rapid moisture depletion due to evapotranspiration by deep-rooted vegetation (Sharma *et al.*, 1987). Thus, under scrub and forest runoff is drastically reduced.

A rapid decline in runoff percentage from 36 to 1.3 was subsequently observed in 1990 when chena land was abandoned for one year. This observation also supports the view that surface cover enhances infiltration while reducing surface runoff.

Although the water supply to village tank system can be from both surface runoff and sub-surface flow, the more important component appears to be the surface runoff because much of the infiltrated rainfall is consumed by the deep-rooted vegetation. Even if some sub-surface flow occurs, there is nothing to prevent such flow continuing beyond the tank down the valley. To estimate the sub-surface flow component of the catchment yield, it is essential to determine the soil moisture balance and evapotranspiration of the natural vegetation (Gee, 1978). The other studies (unpublished data) indicate that sub-surface flow does not contribute as much as surface runoff for the tank water supply. Therefore, the chena lands and similar surfaces appear to provide the main component of the tank water supply.

The runoff during the yala season remained low compared to the runoff in the maha season for all three land use categories, and the percentage of the rainfall that was produced as runoff was also low (Table 2). Rapid moisture depletion by evapotranspiration between intermittent rains during the yala season, probably would have enhanced the water infiltration into the soil leaving less amounts for runoff generation. The antecedent moisture condition, as determined by frequent rains in the maha season is a prominent factor that may encourage greater runoff generation.

The regression analysis between runoff and rainfall showed a simple linear relationship for the three land uses (Table 3) and the steady increase in runoff generation on chena lands with the increasing rainfall is significant ($P=0.01$) as shown by a high 'a' value of 0.615 (Table 3). A similar analysis carried out by Pepper (1985) in Western Australia for treated plots gave a linear relationship at low rainfall condition. However, the relationship appeared to be quadratic at high rainfall events.

The regression analysis shows that runoff generation initiates in the order, forest, scrub and chena lands. This is an apparent contradiction to the normal behaviour of land surface cover on rainfall-runoff generation. However, when residual effect of the previous day's rainfall or the following day's rainfall-runoff is taken out, the runoff initiation occurs first in chena plots, followed by scrub and forest plots. This observation

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suggests that under forest and scrub after a rainfall event, surface remains too wet for a longer time than on chena plots allowing less surface absorption than on a drier chena surface. After a heavy rainfall on the previous day or two, forest and scrub produced runoff even with a little rainfall of about 4 mm, whereas in chena plots runoff occurred only after a rainfall of 10 mm. Analysis of isolated rainfall events illustrates that about 38 mm of rainfall is needed to fill up this storage capacity of forest or scrub before the initiation of runoff. Nevertheless, more important factor is that runoff increases very rapidly in chena plots with increases in the day's rainfall than in other types of plots.

Soil loss

The soil loss was higher in chena lands compared to scrub or forest lands. The soil loss from chena lands exceeded the allowable limit of 9000 kg/ha/year by 17% in maha 87/88. However, in maha 88/89 the soil loss was low due to the unusual low rainfall (Table 2). It is well established that soil loss is negligible from soil surfaces protected by vegetation and the present observations are in agreement with this general rule. Fig. 2 shows the soil loss rate for the rainfall in the maha season. The peak losses coincide with the initial intermonsoonal period, at which time land is bare as it is prepared for maha planting and is without any protection to withstand the disruption caused by high intensity storms. Further the soil losses occur due to the rapid flow conditions arising from high runoff generation on chena lands. This is consistent with the results reported by Pathak *et al.* (1983) for Alfisols in Central India.

CONCLUSIONS

In chena lands runoff generation steadily increased with the increasing rainfall but in case of forest and scrub, increments were small.

Runoff generated under different land uses are distinctly different from each other. From chena lands a greater fraction of the rainfall received (36 to 54%) was removed as runoff, whereas in scrub and forest lands, this was less than 2%. The year to year variation of runoff from chena lands was observed to be quite high while the variations are very low in scrub and forest lands.

Much of the rainfall appear to infiltrate into the soil, while some part of the rainfall is held by the canopy of the forest and scrub of plots under these two land use categories. However, the rainfall infiltrated in the vegetated catchments will be used up for evapotranspiration and any balance will end up as sub-surface flow. The sub-surface flow contribution into the tank system cannot be evaluated without determining the water consumption by the perennial vegetation during the rainy season.

Soil loss on chena lands exceeded the allowable limit of 9000 kg/ha by 17% in maha 87/88 and the losses were greater during the high intensity inter-monsoonal rains, whereas soil losses from forest and scrub were less than 1.5% of the allowable limit. During the early part of the maha season, unprotected soil surface in chena lands provides greater opportunities for soil loss.

In order to integrate soil degradation and other environmental damage due to soil erosion and deposition elsewhere, it is important to follow soil and moisture conservation practices in dry zone agriculture.

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Table 1. Distribution of land use units in the Nachchaduwa catchment area (1987)

<i>Lands use units</i>	<i>Area (ha)</i>	<i>Area (% of total)</i>
Forest	24,217	41.0
Scrub (abandoned chena)	7,707	13.1
Chena	3,325	5.6
Village/homestead	4,895	8.3
Stabilized dry land farms	1,943	3.3
Teak	3,276	5.6
Paddy	8,508	14.4
Village tanks (No. 293)	4,878	8.3
Others	195	0.3
Total	58,944	

Prepared using 1933 air-photos and revised with field observation in 1987.

Table 2. Rainfall, runoff and soil loss under three different land uses in the Nachchaduwa catchment

<i>parameters</i>	<i>Chena</i>		<i>Scrub</i>		<i>Forest</i>	
	<i>maha</i>	<i>yala</i>	<i>maha</i>	<i>yala</i>	<i>maha</i>	<i>yala</i>
<i>1987/88</i>						
Rainfall (mm)	802	382	558	275	727	413
Runoff (mm)	292	73	7	4	8	0
Soil loss (kg/ha)	10334	215	88	20	66	0
Runoff (%)	36.4	19.1	1.3	1.5	1.1	0
<i>1988/89</i>						
Rainfall (mm)	342	165	587	338	323	243
Runoff (mm)	188	27	2	1	3	0.3
Soil loss (kg/ha)	3273	484	78	4	21	1
Runoff (%)	54.9	16.4	0.5	0.3	0.7	0.1

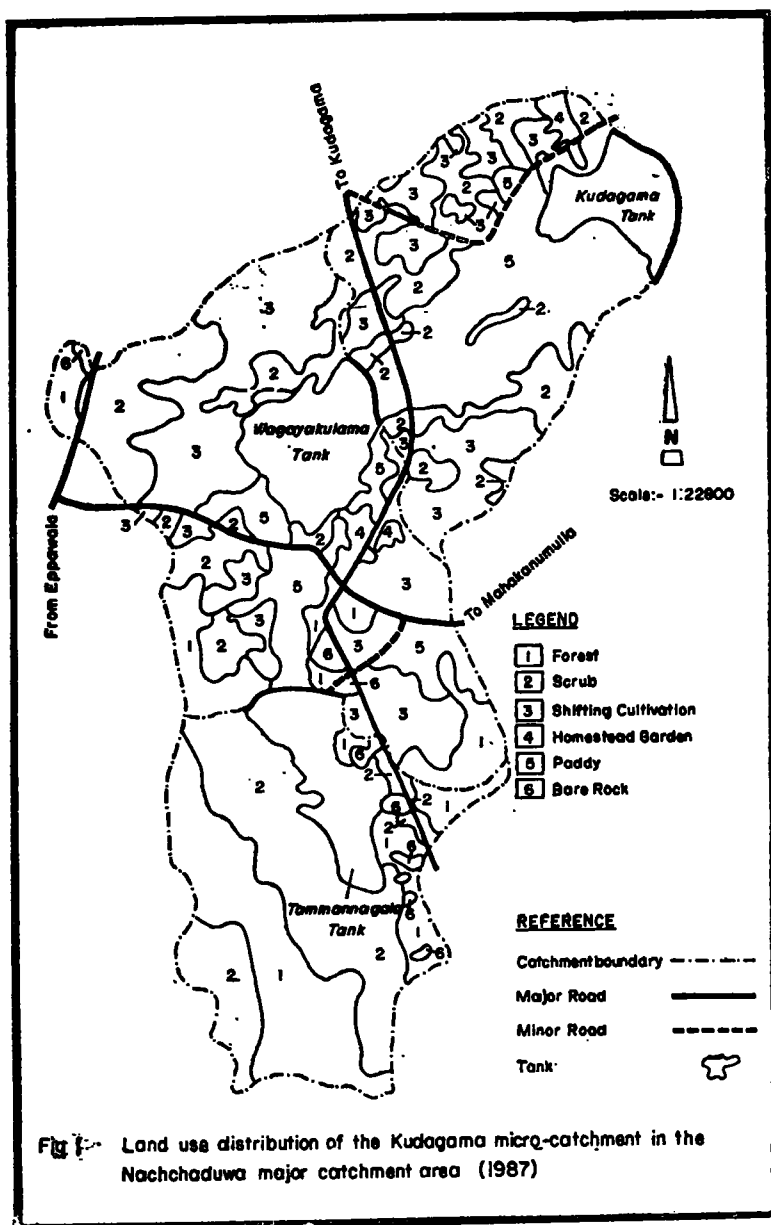
Table 3. Regression analysis ($Y=a+bx$), between rainfall (X) and runoff (Y) under 3 different land uses in the Nachchaduwa catchment (August 1987-July 1989)

<i>Land use</i>	<i>n</i>	<i>a</i>	<i>b</i>	<i>r</i>
Chena	41	-9.310	0.615***	0.93***
Scrub	21	-0.169	0.019*	0.49*
Forest	22	-0.123	0.022**	0.47*

***p = 1%, **p = 2% and *p = 5%

n = number of observation, r = correlation coefficient a and b = constants

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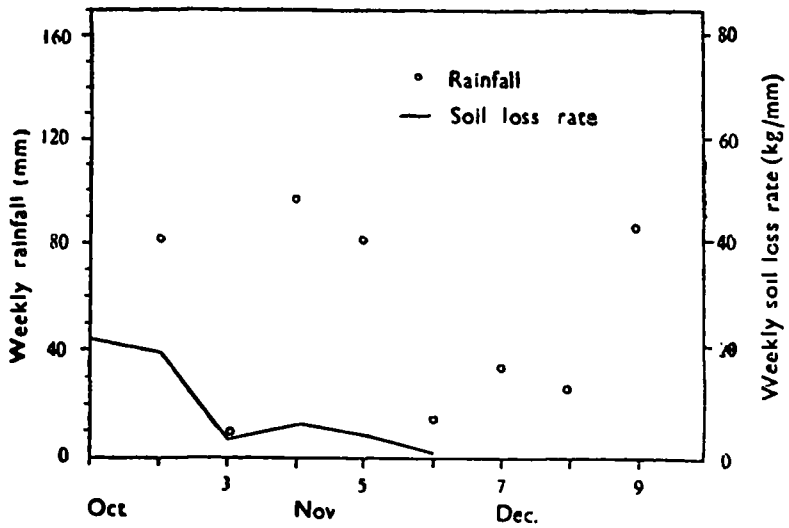


Fig. 2. Weekly soil loss rate and weekly rainfall in Chena lands of the Nachchaduwa catchment during maha 87/88.