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LAND USE AND PHYSICAL HYDROLOGY OF THE SOUTH NJOMBE CATCHMENT, SOUTHERN HIGHLANDS OF TANZANIA

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This study examines the effect of changes in land use and vegetation cover on water yield from the Ruhudji catchment in southern Njombe. An evaluation was also made to assess the effect of afforestation on water yield. Land use vegetation covers were determined from topographic maps produced by the government of Tanzania in 1963 and 1967. More recent aerial photos were also used. Rainfall and runoff patterns were identified, and 3- and 5-year means were used to test any variation. Using correlation techniques, the relationship between rainfall and runoff was tested; the result showed very little correlation between the two variables. Some indications are provided for future research and management practices needed in the field.

INTRODUCTION

The environmental effects of man's actions are of concern throughout the world. These effects can be immediate or delayed, and local or regional in their occurrence and extent. The complexity of process interactions in natural systems makes it difficult to isolate differences due to land use change; for example, the interactions occurring before and after afforestation. However, the need to develop a better understanding of the implications of land use on water resources and the environment as a whole remains. Studies that focus on a small area within regions that have undergone or have experienced significant land use change can contribute to this improvement in understanding.

Figure 1. Map showing location of Njombe District.

The southern highlands of Tanzania, particularly the Njombe district, have undergone land use change on a large scale and have been considered for this study.

- In 1949, 13,400 ha of land was planted with black wattle (*Acacia mearnsii*) and Pines (*Pinus patula*) by the Tanganyika Wattle Company, a subsidiary of the Commonwealth Development Corporation (CDC). Since then, tree planting has became increasingly popular with individual farmers unconnected with CDC activity.

- In 1950 the government decided to allow cultivation of cash crops and local people started to do so, planting in particular pyrethrum, tea, coffee, and tobacco. There was an expansion of land under plantation crops and increased land clearance for agriculture.

Introduction of hybrid maize in 1970 in the Njombe district by the Tanganyika Wattle Company resulted in commercialization of maize production in the area creating further demand for land.

Little work has been done to evaluate land use change in the region, and how they have affected the hydrology of the area. This study is an effort to determine the impact of land use change on water yield, and focuses on the Ruhudji, the largest river in Tanzania and the product of many rivers that originate from the southern highlands.

Different land use patterns produce different hydrologic effects. Monitoring of research into catchment land use is important, so that a record of surface cover characteristics is available to predict the quantity and timing of water yield. This study has two objectives:

- to identify land use changes in the southern Njombe region in Tanzania from topographic maps and aerial photos, and

- to asses the effect of land use change on the hydrological cycle with particular respect to the effect of reforestation on water yield.

Site Description

The Njombe district lies at an elevation of 600-1500 m, mostly above 1000 m with fairly low temperatures. Annual mean temperature varies from 18^{o}C at the higher altitude to about 28^{o}C in the lower and drier part of basin. Minimum and maximum average monthly temperatures vary from 5^{o}C to 28^{o}C. It has a rainfall of between 600-1600 mm/yr.

The Ruhudji catchment in the Njombe district which defines the area of this study has an area of 500 km^2 and is located between 9^{o}15'-9^{o}30'S and 34^{o}30'-34^{o}55'E. There are two sub-catchments; the Hagafilo (150 km^2) and the little Ruhudji (350 km^2). The rivers are perennial or intermittent and the specific mean annual runoff is low, varying from 1.5 to 7 l/km.

Land use

Although large areas of the region are now cultivated, the vast majority of the land is still covered by natural vegetation (Hasen, 1992). The predominant natural vegetation is Miombo woodland. The main cultivation areas include maize, beans, bananas, and cash crops including tea, tobacco, pyrethrum, wattle, coffee, citrus fruits and pines. The other land uses in the area include vinyungu cultivation (growing of vegetables along the river banks), and livestock grazing.

MATERIAL AND METHODS

Land use process

Land use changes during the period 1959-1974 were examined through comparison of topographic maps and air photos. Four 1:50,000 (Government of Tanzania 1969,1967) topographic map sheets were used.

Aerial photographs

Aerial photographs used for evaluation of land use pattern were 1959 and 1974 black and white cover, obtained from the map division office in Dar-es-Salaam, Tanzania. Individual frames are as listed in Table 1.

Grouping of the land use types

The major categories identified in this study are cultivated land, forest and woodland, settlements and other land uses (Table 2).

Table 1. Flight Lines and Photo Numbers

Year of Flight	Flight line	Images
1959	15 tan 8	09, 011, 013, 015, 011, 042, 044, 046
	15 tan 9	031, 082, 084, 086, 088, 090, 118, 120, 121, 123
	15 tan 20	014, 016, 018, 020
	15 tan 27	011, 013, 015
1974	ROLL 12 L4	
	ROLL 12 L5	
	ROLL 12 L6	
	ROLL 13 L6	
	ROLL 15 L5	

Land use trend analysis

The area for land use evaluation was determined as follows:

Nine sample strips were located randomly in the catchment area using a grid sheet system. Squares of size 2 x 2 km were drawn on the catchment area. They were then numbered in ascending order, five numbers were taken to produce nine samples. A 1 km by 5 km strip was drawn from each point, the strips were then located and marked on the photos and topographic maps available for interpretation The 1959 and 1974 interpretation was based on the aerial photos and the 1969 interpretation was based on the topographic maps.

Interpretation of land cover types

Using a pocket stereoscope and a low magnifying microscope, four land use cover types were identified, settlements, roads, total trees, and total cultivation. The extent of these cover types was estimated. Graph paper with 1 mm x 1 mm squares was used for area determination after reproducing maps of each strip at a fixed scale (1:50,000). Trend areas of each land use type is summarized by assessment year (Table 3).

Table 2. Detailed Description of Land Use Categories Used

Land Use Category	Description
1. Cultivated land	this is land which includes arable crops, horticulture crops, and semi natural vegetation
2. Woodland	a stand of tree 18m high with canopy cover equal to more than 20% grass herbs and shrubs dominated the undergrouth
3. Water surface	large bodies i.e. streams, river and lakes
4. Settlement	includes land close to houses, industries, prisons and hospitals

Land use cover change

The land use/cover trend of sample strips in the catchment are presented in Tables 4, 5, and 6 obtained by a strata method. A more general picture is provided in Figures 4 a, b, and c. The area under

Table 3. Total Land Trends

Year	Land Use			
	Settlement %	Roads %	Total tree %	Total cultivation
1959	37	25	4	49
1969	12	25	44	-
1974	51	50	52	51

roads is lower in the estimate based on the 1974 photos than on the 1969 map, it is not clear why. Possibly some trends were not distinct on the photos or the maps may have retained roads from overdue maps which had actually gone out of use before 1959. Since there was a road development in progress under a regional Development Programme over the 1969-1974 period, an increase would be expected. Comparing photos for 1959 and 1974 confirms an overall increase for 15 years.

HYDROLOGICAL CHARACTERISTICS AND PROCESS

Data on rainfall and hydrological history of the area were obtained from the Meteorological Department (Ministry of Energy in Dar-es-Salaam), and supplemented with information from other bodies involved in management of water resources, including DANIDA (Danish International Development Assistance), and HIMA (Hifadhi Mazingira). There are seven rain gauges in the catchment and two (09934001 and 099340022) were taken for this study as they had a running time of more than 15 years. Stream flow data for the Ruhudji and Hagafilo rivers for gauges IKB 18 and IKB 19 were extracted. The river flow data are in m^3/sec and the total discharge is monthly in millions of cubic meters.

Table 4. 1959 - Area (ha) of Land Use Categories in Strips

Strip. No. (location) SW corner	Area Land Categories (ha)								Linear Features (km)	
	Vegetation					Tree crop		Settlement	Roads	Rivers
	Grass&Scrub	Scattered trees	Bamboo	Woodland	Cultivation	Wattle	Pine			
1. ($9^0$28.14', $34^0$37.70')	340			7	10			5	3.85	1
2. ($9^0$26.27', $34^0$42.59')	321	17			49			3	7.5	5.55
3. ($9^0$23.89', $34^0$44.05')	349	34			19			7	5.55	7
4. ($9^0$23.89', $34^0$36.97')	382				13				7.75	6
5. ($9^0$22.35', $34^0$39.48')	416	8			24				1.75	4.25
6. ($9^0$26.27', $34^0$43')	306	12			32				8	8.25
7. ($9^0$20.20', $34^0$44.90')	256				9		4	4	6.5	8.25
8. ($9^0$18.81', $34^0$44.32')	330	6			30		5	15	4.75	7.75
9. ($9^0$17.05', $34^0$50.24')	337	19			10			6	3.85	1.2

Table 5. 1969 - Area (ha) of Land Use Categories in Strips

Strip. No. (location) SW corner	Area Land Categories (ha)							Linear Features (km)	
	Vegetation				Tree crop		Settlement	Roads	Rivers
	Grass&Cultivation	Scattered trees	Scrub	Woodland	Wattle	Pine			
1. ($9^0$28.14', $34^0$37.70')	426	5	6		24		1.5	3	10.9
2. ($9^0$26.27', $34^0$42.59')	355	11		1				7.25	6.05
3. ($9^0$23.89', $34^0$44.05')	363	12.5					7.5	5.25	6.25
4. ($9^0$23.89', $34^0$36.97')	340	15						5.25	9.25
5. ($9^0$22.35', $34^0$39.48')	227	15.5	19.5		79			7.5	8.45
6. ($9^0$26.27', $34^0$43')	367	36						11	9.75
7. ($9^0$20.20', $34^0$44.90')	354	24.5	2				1.5	11.2	11.5
8. ($9^0$18.81', $34^0$44.32')	207	55.5					3	11.5	12.3
9. ($9^0$17.05', $34^0$50.24')	365	27.5						55	10.5

Table 5. 1974 - Area (ha) of Land Use Categories in Strips

Strip. No. (location) SW corner	Area Land Categories (ha)							Linear Features (km)	
	Vegetation					Tree crop	Settlement	Roads	Rivers
	Grass&Scrubb	Scatted trees	Bamboo	Woodland	Cultivation	Wattle	Pine		
1. ($9^0$28.14', $34^0$37.70')	353				18	27		3	2.75	7.35
2. ($9^0$26.27', $34^0$42.59')	382				24				6.25	3.15
3. ($9^0$23.89', $34^0$44.05')	398				13	5	6		3.3	5
4. ($9^0$23.89', $34^0$36.97')	388				22				2.35	6.7
5. ($9^0$22.35', $34^0$39.48')	275		6		53	80		5	4	4.75
6. ($9^0$26.27', $34^0$43')	344				15			18	6.75	5.6
7. ($9^0$20.20', $34^0$44.90')	368				29			21	6.75	3.35
8. ($9^0$18.81', $34^0$44.32')	381	3			16		6	5	4.75	4.5
9. ($9^0$17.05', $34^0$50.24')	385				14			3	0.25	9.55

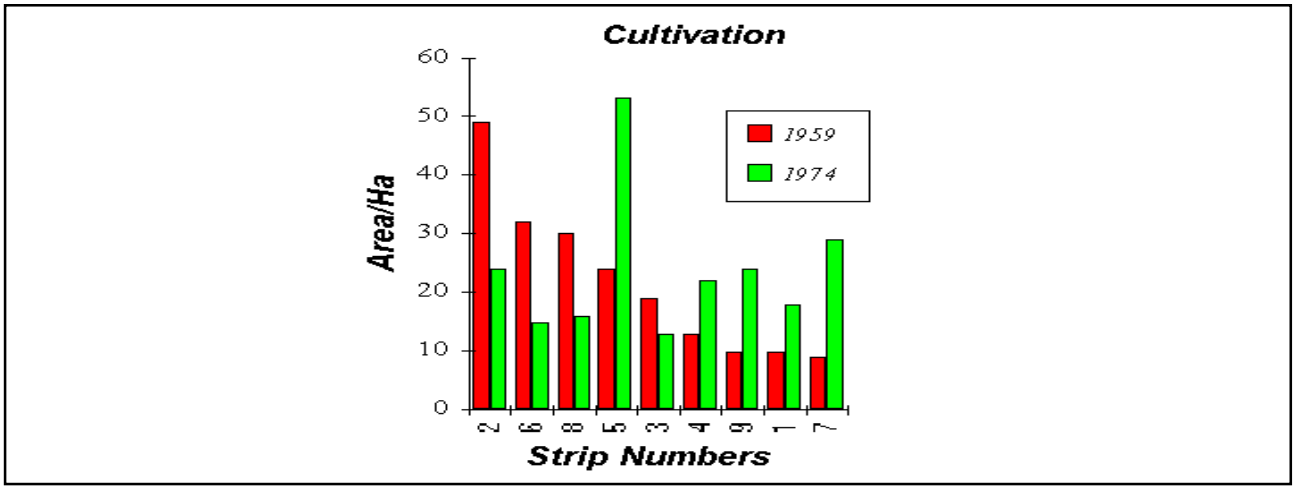

Figure 4a.

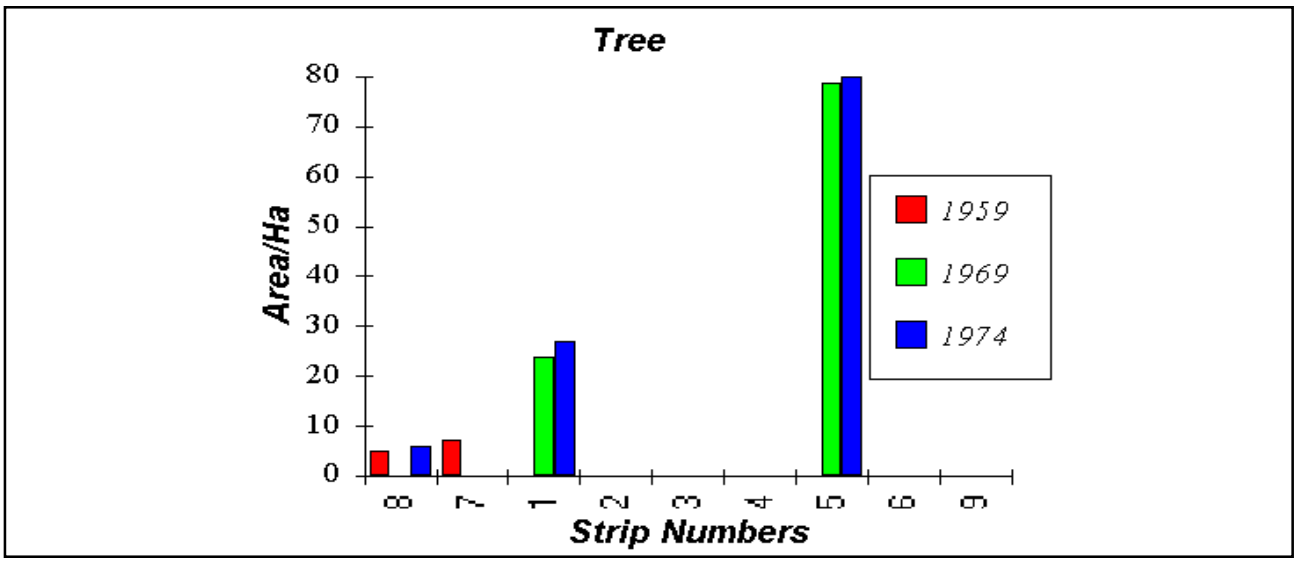

Figure 4b.

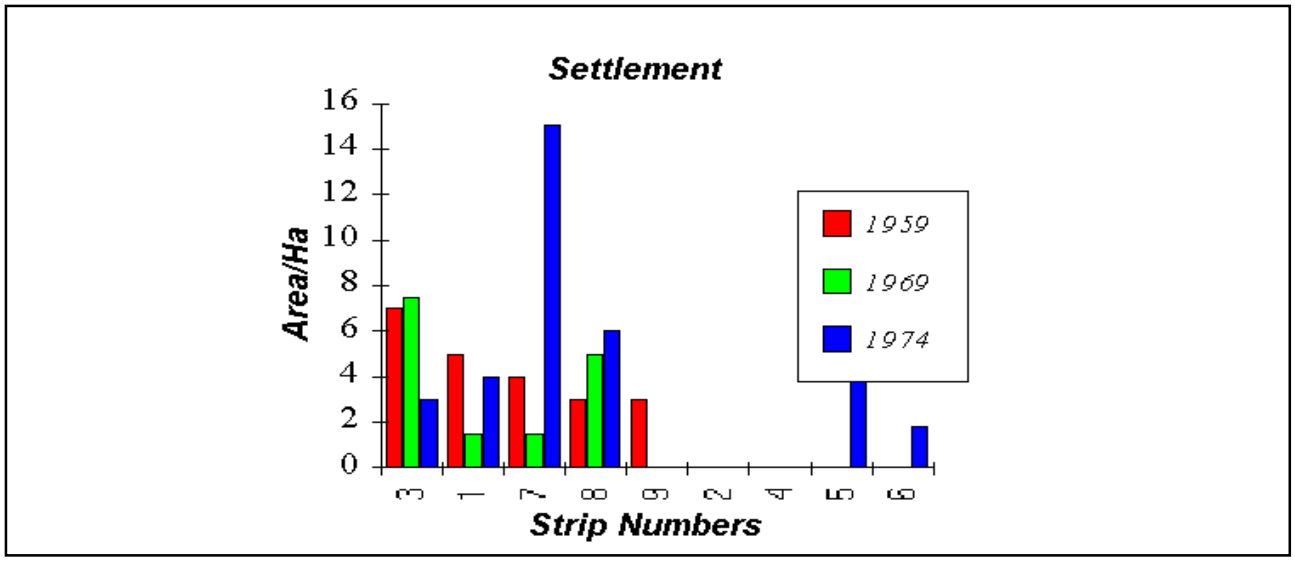

Figure 4c.

Rainfall

The rainfall trends were sought in the data using three and five year running means, Figures, 5a and b, show trends for the two stations. The graphs indicate that there is a slightly upward trend of periodic variation. For example, on 5-year periods, rainfall values seem to be increasing slightly for the period after 1953, and again markedly increasing after the 1980's. Downward trends occur between 1984-1994. The expected trend was not clear due to strong seasonality for the study area.

Evapotranspiration

Evapotranspiration figures in the study are from pans and Penman estimates. The pans are of the class "A" type modified according to recommendations from the former East African Meteorological Department with black and white paint in the interior and covered with a wire mesh.

Annual values ranged from about 1300 mm to about 1900 mm with an average of roughly 1500 mm across Mbeya , Iringa and Ruvuma (Woodhead, 1968 and Coheme, 1969).

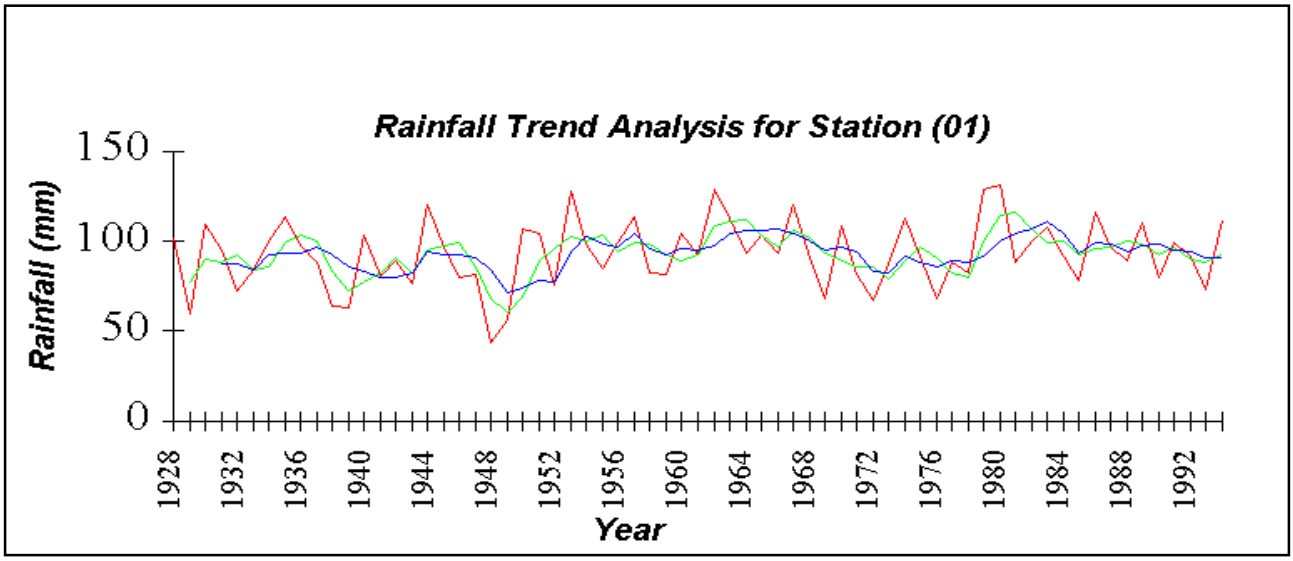

Figure 5a. 3- and 5-year rainfall running means for station (09934001).

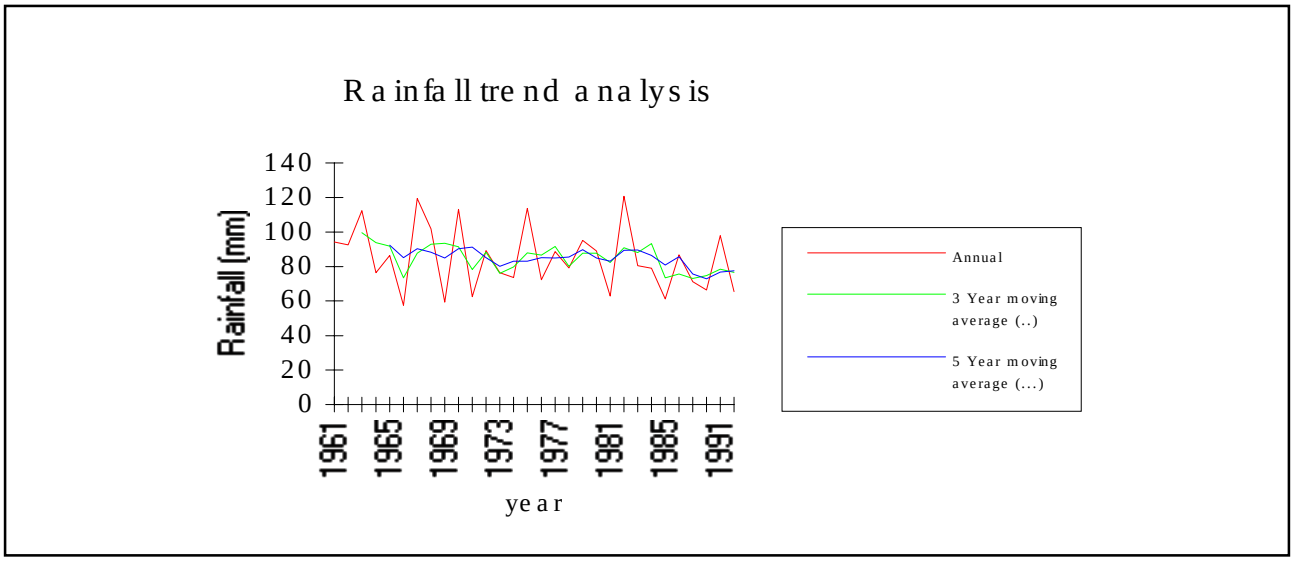

Figure 5b. 3- and 5-year rainfall running means for station (099340022).

Runoff Analysis

Three and five-year runoffs were obtained and plotted. The plots suggested a rise in river flow from 1971 with both 3- and 5-year periodic means , but later a decrease from 1981 with the 5-year periods and from 1983 with the 3-year periods.

Rainfall-Runoff Relationship

In analyzing long term rainfall and runoff, river discharges were related to variation in rainfall assuming the relationship between the two would be linear. The correlation ($r = +0.442$) was low and the regression line does not show a relationship between the two parameters.

DISCUSSION

It is logical to compare the present findings with the one of Mbwana (1988) in northern Tanzania, Ngowi (1993) in southern Tanzania, and that of Pereira (1973) in Kericho in Kenya (Table 6).

It is clear from these studies that the results were not conclusive on the relationship between

rainfall and runoff. This is probably because there is no straight forward relationship between the two hydrological aspects, just as this study has found. The results suggest that the relationship between rainfall and runoff is difficult to detect.

Though Mbwana found correlation between the two variables, the correlation is too small to be conclusive. The relationship between rainfall and runoff in this study was $R^2 = 0.12$, which shows that 88% of variation in water discharge in the catchment is due to factors other than rainfall. The most

Table 6. Review of Findings from Other Studies in East Africa

	Mbwana (1988)	**Ngowi (1993)**	**Pereira (1973)**	**Present**
Rainfall gange	NOT FOUND	NOT FOUND	NOT FOUND	NOT FOUND
Over period of land use change				
River flow change with time	NOT FOUND	NOT FOUND	NOT FOUND	NOT FOUND
Rainfall, riverflow correlation	0.57	0.42	NOT GIVEN	0.32

likely ones are afforestation, increased settlement, cultivation areas, and an increase in deforestation. A noteworthy change in the catchment in the period since 1959 is the increase in number of roads This has improved accessibility and encouraged settlement, increasing the risk of land degradation. Catchment size may also have contributed to failure to reveal the land use influences on the rainfall/ river flow relationship. Masud (1987) suggested that the effect of land use change on hydrological process are seen more in mesoscale than in small scale work. In the proposal for a conservation program , it was suggested that land degradation was responsible for increased river flow in the study area. However it is difficult to partition the effect between various kinds of land use change or find out how much is directly caused by man's activities. In general it would be expected that land degradation caused by deforestation, cultivation on steep slopes, bush burning and overstocking would result in increase surface runoff (Owen, 1980)

CONCLUSION AND RECOMMENDATION

The concern over land use change of the southern Njombe catchment influencing the hydrological processes appears unfounded. Land use activities practiced by the people of southern Njombe for the last 25 years have not caused any alarming environmental problems. This study found an increase in planted trees over the study period. This is a result of a good response by the people from the leading tree planting campaigner, the MP of the region from the past 30 years (Hon. J.M. Mvangila), together with some environmental organizations and forest divisions. On the other hand there has been very little effort to use tree planting as a mean to protect important catchment areas upstream.

Particular good practices that should be adapted more widely and intensively within the management area are:-

i) To identify land use changes more accurately, regular physical land use surveys are needed to have a clear picture of land use change, and the time they occur in the area. The survey should be done

at a small scale and should be made available at regional and country levels.

ii) To identify which land use changes cause more risk, it is recommended that a wider program of study that evaluates land use practices in relation to management practices should be undertaken. In such studies it is necessary to continue with an approach that is both interdisciplinary and multi-scale so that, for example, results of small studies can be set within a catchment scale framework of water resources in the region.

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