"THE EFFECTS OF ENVIROMENTAL DEGRADATION ON STREAM FLOW. VOLUME AND TURBIDITY IN THE ITARE SUB-CATCHMENT WITHIN THE LAKE VICTORIA DRAINAGE BASIN , IN KENYA".

BY

John Moenga Nyangaga

BSc . Hons, MSc. (UON)

POSTGRADUATE PROGRAMME IN HYDROLOGY

Department of Geography and Environmental studies,
School of Physical Sciences,
University of Nairobi

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DECLARATION

This is my original work and has not been presented for award of a degree in any other university.

John M. Nyangaga

(candidate)

This thesis has been submitted for examination with our approval as University supervisors.

Eng. Dr. W .O. Ogembo

(Supervisor)

Prof. J.O Barongo

(Supervisor)

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Abstract

Land use changes that accompany economic development and population growth leads to alteration of natural vegetation and downstream hydrological function. This work examines the land use changes which have occurred in the Itare sub-catchment and their possible effects on water quantity and water turbidity over time.

The study begins by characterizing in general terms the relationship that governs the linkages between land use and stream flow and turbidity variation in a humid tropical catchment. The emphasis is on how hydrological functions (water yield, turbidity variations, seasonal flows), are related to changes in land use. Review of the literature suggests that, information on this subject is sparse and hence less understood, especially in tropical environments. However, considerable interest is emerging in studies which attempt to evaluate the effects of land use changes on the complex interrelationship between hydrological regimes and changes in land use. The objectives of the study were: To examine river flow variations over time and space, determine the rate of deforestation in the sub catchment over time and space, investigate the effect of land use changes on base flow and water turbidity, investigate the concentrations and fluxes of turbidity and sediment load in the sub-catchment, correlate land use changes and water volume changes, identify the major causes of environmental degradation and recommend possible interventions.

Kenya's water supply index is currently 647m^3/capita/year against the internationally accepted figure of 1700m^3/capita/year, and by the 2025, this figure is projected to fall to 235m^3/capita/year due to catchment degradation.

The south western Mau forest which is the source of the Itare River has declined by about 27 % from an estimated 95,356 hectares in 1932 to 81,840 hectares in 2001.

The methodology used in the study included remote sensing, global positioning (GPS) technologies to provide and display baseline data. Satellite image interpretation and analysis on time series of lands at thematic images of 1986 and 2000 was done to show land use changes over the period. This was supplemented by aerial photo interpretation. Stream flow data for the years 1953-2004, and rainfall for the years 1950-2004 data was collected from two regular river gauging station 1JC13 Timbilil, 1JA02 Kiptiget and two rainfall stations which had consistent data.

Data analysis methods included trend analysis, regression, and other statistical tests. A hydrological data base system HYDATA was used in hydrograph separation and subsequent estimation of total runoff, direct runoff, base flow runoff and calculation of base flow index (BFI).The same system was used to draw the various hydrological graphs and other presentations of data.

Results indicate that, there has been a tremendous change in land use in the catchment, with more conspicuous being the reduction in forest cover by 33% and increased land under the various uses such as urbanization, development of road network, provision of social facilities, agriculture and settlement.

There is an increase in total flow and base flow, but a reduction in direct flow over time. Dry season flow has reduced while wet season flows have increased as evidenced by high flood flows. The water quality in the catchment has deteriorated as indicated by high turbidity. This is due to changes in land use which increased soil particles and sediment in the water. In conclusion, the changes in land use have reduced dry spell flows; sometimes leading to water shortages, but with a marked increase in total flow, and has affected the general quality of the water in the catchment.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Improper land use often results in adverse environmental impact for both surface and ground water systems and their spatial- temporal patterns and trends are of much interest to water resource manager's world over. Over the years, water demands for various uses have been steadily increasing although available quantities continue to shrink due to various reasons such as catchment degradation and land use changes. Water ranks high among a country's important resources and effective water resource management has to consider the effects of land use changes within the basins as they affect the availability of water resources. This includes present effects on the existing flow regimes as well as future effects relating to expected land use changes. It is only then that effective water availability can be quantified and future water management options assessed.

Considerable interest is emerging in studies which attempt to evaluate the effects of land use changes on the complex inter-relationship between environmental degradation and hydrological regimes of the catchments. Effects of land use and land cover change on water resources of the catchments is a major issue. It has attracted newspaper, television and radio programmes featuring politicians, water engineers, hydrologists, academicians, administrators and the general public as they talk about the effect of shrinking water resources which sometimes has led to serious social conflicts. Catchment degradation is evident in Kenya. For instance, Kenya's forests have been reduced from a bountiful green belt to a handful of isolated oases in an arid land. Against a global forest cover of 21.43% and an average for Africa of 9.25%, Kenya's forest cover stands at a critical 1.7 % (Kenya Forest Group (KFG), 2003), compared to 77 % and 27 % respectively.

According to the Food and Agricultural Organization (FAO), (1996), any country with less than 10% of its land area covered by forests is environmentally unstable. Kenya having only 1.7 % of the forest cover is therefore environmentally unstable. Over the years, Kenya has continued to lose most of its forest cover and this loss is estimated to be about 5,000 ha per year (International Union for the Conservation of Nature (IUCN), 1996). The Itare catchment has undergone remarkable land use changes in the last five decades primarily due to a combination of unsound forest management practices, such as illegal excisions of gazetted state forests, illegal encroachment, illegal logging for timber, charcoal, poles, settlement, urbanization, industrialization and effects from natural and artificial fires. Majority of these changes is taking place in the forest areas considered to be the water towers like the Mau forest which is the catchment area for the Itare River.

Table 1.1 below indicates that 154,415 ha. of forest cover had been excised by the year 1999 and 23,515 ha, were proposed for further excision. This rate of loss of forest cover is of great concern to the environmentalists as it contradicts the government policy on the catchment protection and conservation.

Table 1.1: Summary of Forest Reserves Excised/Proposed for Excision

Year	Total Excisions (ha)	Proposed Excisions (ha)
1963-1969	90,716	45
1970-1979	12,272	12,201
1980-1989	44,067	4.593
1990-1994	6,659	1,433
1995-1999	701	5,243
Total	**154,415**	**23,515**

Source: Kenya forestry group (KFG), 2003

The Sessional Paper No. 6 of 1999 on environment and development states that: "The Government will endeavour to introduce measures to protect and preserve forests that are rich in biodiversity, have aesthetic and cultural value, serve as water catchment areas and are particularly important for biodiversity conservation, for example, south west Mau, and Mount Kenya forest".

Kenya's water supply index is currently 647m^3/capita/year according the Ministry of Water and Irrigation (MWI 2004). This falls far below the internationally accepted figure of 1700m^3/capita/year. The present water supply index is projected to fall to about 235m^3/capita by the year 2025 due to catchment's degradation (MWI. 2004). The water demand for this country currently stands at about 3,900 million m^3 per annum and this is projected to increase to about 5,800 million m^3/annum by the year 2010 (MWI .2004).

Surface Water covers 130,000km^2 (23%) of the country's total area of 583,000km^2 Kenya's renewable water resources is estimated to be 20.2 billion m^3/year, where 19.6 billion m^3 / year is surface water and 0.62 billion is ground water (MWI 2004).The Lake Victoria drainage basin covers only 8% of the country but holds 50% of the country's fresh water; hence the need for research based conservation of the catchments in the basin.

Public awareness on the effect of land use changes on water resources is minimal and only few attempts have been made to study this phenomenon. The study analyses the temporal variability of annual stream flow time series covering 15-50 years of record for two regular river gauging stations and seventeen rainfall stations within the Lake Victoria drainage basin.

The overall emerging picture is that, the Itare sub-catchment has undergone some physical and chemical degradation that has affected the stream flow and the water quality. The catchment has experienced tremendous land use change from 1950 to the present primarily due to spontaneous deforestation to create space for various land uses. The hydrological consequences of these changes has resulted in the reduction of the surface runoff, increased the baseflow and total flow in the catchment. This study presents the results obtained from a three-year study of river discharge variation dynamics in the 705 km^2 of Itare sub-catchment area due to land use changes and subsequent environmental degradation.

1.2 Location, Size and Human Activities

The Itare sub-catchment area covers about 705km^2 and occurs in the upper catchment of the Sondu Miriu river catchment within the larger Mau water tower. The Itare river is one of the two tributaries of the river Sondu Miriu, the other one being Kipsonoi river. The Itare catchment is within the Lake Victoria drainage basin in western Kenya. The river Itare and its major tributaries Kiptiget, Soasa, Timbilil, Marmar, Kimugu and Itare itself drains Nakuru, Bomet, Kericho and Buret Districts in Rift Valley province. Geographically, it is situated between latitudes 35^0 02' and 35^0 40'E and between the equator and latitude $0^0$23'S (Figure 1.1).

The study area is said to have been covered fully by forest and woodland before the impact of man. Forest clearance and intensive settlements in the catchment is said to have started in 1970s and continued to date. The people who initially settled in the area were the Laibon (Kalenjin subtribe) who depended on hunting and honey harvesting but were later displaced by farming communities consisting of the Kipsigis, the Kisii and the Kikuyu.

The area is the source of several perennial rivers, but now it is prone to serious degradation and consequent deterioration of both water quantity and quality. Large areas of the catchment have been deforested over the decades for agriculture and other land uses. The rural economy is subsistence farming, small- and large-scale tea plantations and other annual crops which provide little protection of the soil from rain drops. The local economy sustains a fairly high population density, hence the need for urgent action to ensure the availability of adequate amount of good quality water for the present and future generations. Most of the inhabitants of this area use surface water, especially from springs which are many and have high quality water. The latter factor is attributed to the fact that the water is collected right at the source before it moves elsewhere where it may get contaminated. Some individual, communal groups and institutions use groundwater from hand dug wells and drilled boreholes. This is common especially in the upstream of the catchment such as Keringet area. Generally, the catchment can be said to be of high water potential because of its geographical location and climatic characteristics. There is very little irrigation in the area as the people rely heavily on rain-fed agriculture.

1.3 Topographical Characteristics

Topographically, the catchment is of steep to gentle slope of about 3% with a gradient of 11.03%. The land slope is towards the west and consequently the rivers drain into that direction. The topography consists of a volcanic plateau with dissected margins, generally consisting of rugged terrain with deep gorges and V-shaped valleys in the upper and middle parts of the catchment. The altitude of the catchment ranges between 1,700 m and 2,860 m above sea-level at the confluence of Kipsonoi/Itare and Ndoinet area, respectively (Figure1.2). These topographic characteristics especially steep slope and gradient, if subjected to poor land use systems; can lead to serious soil erosion, sedimentation of water courses and water supply facilities, and consequently leading to variations in stream flow quantity and turbidity. Topographically the catchment can be divided into three regions: the areas ranging from 2,500 m above sea level (upstream), the area between 2,000 m and 2,500 m above sea level (midstream) and the area between 1,700 m and 2,000 m above sea level (downstream). Figure: 1.2)

Kenya has a total area of closed forest of 1,105,000ha with an annual deforestation rate of 5,000ha and annual a forestation rate of 10,000ha per annum (KFG, 2003). Mau forest alone covers 90,000ha and is a major water catchment area. Vegetation in the catchment consists of natural forest, farm crops, exotic trees and pastureland. The Mau forest which consists mainly of bamboo, *acacia* trees, *macaranga* trees, *caseania fagara*, etc., covers the middle parts of the catchment. Against a global forest cover of 21.43% and an average for Africa of 9.25%, Kenya's forest cover stands at a critical 1.7 %, indicating that the country is environmentally unstable. This situation has serious hydrological implications, especially on the quantity of stream flow.

Tea plantations follow the forest and exotic trees, especially eucalyptus, cypress and pine which are also within the tea plantations to provide energy for the tea factories. The upper and the lower areas of the catchment are covered mainly by farm crops, especially maize, cabbage, kales, etc., leaving only few patches of grassland.

There is evidence of serious encroachment of the forest by the small scale farming communities and large tea plantation owners (e.g., Brooke Bond and African Highland Produce Companies). The replacement of forests by farm crops and exotic trees affects the ability of the vegetation to trap rainfall and influence infiltration rates. This may increase surface runoff which, consequently, will mean reduced ground water recharge as much of the rainfall is wasted as surface runoff which, in turn, causes soil erosion down the sloppy catchment. Therefore, there was need for thorough investigation by the researcher.

Vegetation is known to influence ground water recharge which replenishes the ground water and total river flow. But over the years, the country, and the Itare catchment in particular, has been losing its forest cover due mainly to the following reasons: poor forest management practices, excisions, encroachment, illegal logging of trees for charcoal, timber and poles, settlement, industrialization , urbanization, debarking and forest fires.

1.5 Hydrological Characteristics

The Itare sub catchment with an area of 705km^2 area, occupies only 0.4% of the total area of the lake basin of 184,200km^2. It is generally well drained and has a dendritic drainage pattern which is due to its geological characteristics (Figure 1.3).

Table 1. 2: Drainage Characteristic of the Itare sub-catchment

Sub-catchment	Drainage Area (km^2)	No. of Streams	Total Stream Length (km)	Altitude (m)	Relief Ratio H/L	Basin Length (km)	Channel Length (km)
Kimugu	66	31	113	2500	1.330	35	50
Saosa	38	35	74	2400	1.276	27	34
Timbilil	70	40	88	2380	1.372	44	54
Chepkoisi/marmar	167	84	173	2340	1.315	26	45
Kiptiget	81	90	260	2640	1.450	33	60
Itare	383	135	633	2820	1.659	42	90
Total	**705**	**414**	**1,341**	**2820**	**1.659**	**42**	**90**

Source: Field data 2004

western Mau forest and drains into the Kimugu and Marmar rivers and their tributaries, and finally drains into the Chemosit River. The Taibenai, Tebenik and Cheptebes streams originate from the western Mau forest and from within the tea estates. The Kiptiget subcatchment consists of the Kaptabal, Seretyot, Legumo, and Ngenyibosoin streams. It originates from the western Mau forest. Lastly, the Itare subcatchment consists of streams Michong, Ndonet, Songoi and Sondu which originates from both the western and eastern Mau forests.

The catchment is of order five (5) according to Strauhler (1952), with a total stream length of 315km, basin length of 42km, drainage density of 1.9km/km^2, stream density of 0.65stream/km^2, basin form of 0.4, basin shape of 2.5 and bifurcation ratio of 5.7 (Table 1.3)

Table 1. 3: Basin Parameters of the Catchment

Sub-catchment	Drainage Density (km/km^2)	Stream Intensity (no./km^2)	Basin Form (ratio)	Basin Shape (ratio)	Birfucation Ratio	Order
Kimugu	1.7	0.47	0.05	18.56	11:1	4
Timbilil	1.2	0.57	0.04	27.66	7:1	4
Saosa	1.9	0.92	0.05	19.18	2:1	4
Chepkois/Marmar	1.0	0.50	0.25	4.05	6:1	4
Kiptiget	3.2	1.1	0.07	13.44	7:1	4
Itare	1.6	0.35	0.22	4.61	6:1	4
Catchment	1.9	0.59	0.40	2.50	5:7	5

Source: Researcher, 2004

All these indices, especially drainage density of 1.9km/km^2, according to Horton (1952), indicate that the catchment is a steep and fairly impervious area of high precipitation. High precipitation and relatively low infiltration implies high surface runoff, increased soil erosion, sedimentation together with nutrients into water courses and general environmental degradation. These drainage basin indices hydrologically reflect a well drained catchment with enormous amount of surface water resources (Figure 1.3)

Table 1. 4: Discharges at Outlets of Major Rivers in the Catchment

River	Station	Date	Discharge m³/sec)
Chemosit	*1JD misc	30/9/2002	7.147
Chemosit	*1JD misc	23/7/2003	15.407
Chemosit	*1JD misc	06/6/2004	14.192
Kimugu	1JC 19	22/3/2002	0.279
Kimugu	1JC 19	23/7/2002	5.056
Kimugu	1JC19	1/12/2003	0.801
Kimugu	1Jc 19	06/6/2004	0.994
Timbilil	1JC13	07/6/2004	0.129
Saosa	1JC15	07/6/2004	0.43
Kiptiget	1JA02	17/7/2004	0.437
Ainabkoi	1JD4	21/2/2002	18.723
Yurith	1 JD3	23/3/2002	5.093
Yurith	1 JD3	29/9/2002	12.279
Yurith	1 JD3	23/7/2003	58.99
Yurith	1 JD3	30/11/2003	24.228
Yurith	1 JD3	04/6/2004	34.859

Source: Researcher, 2004

* 1JD misc. stands for unregistered regular gauging station (miscellaneous)

1.6 Geological Characteristics

The geology of the catchment consists of extrusive igneous rocks, mainly *phonolites*, which tend to determine the drainage pattern as already discussed above and also influences the soil characteristics. Therefore, indirectly the geological characteristics influence the land use patterns of the catchment extent of degradation and subsequent hydrological responses.This by the fact that, the geology of a place influences the type of soil and therefore land use,(Figure 1.4).

The extrusive igneous rocks which, as stated above, form the main geological component in the Itare catchment are subdivided into two formations; The Kericho *phonolites* (Losuguta type) and the *phonolitic nephelines* with intercalated tuffs (Binge,1962).

1.6.1 The Kericho Phonolites (Losuguta Type)

This formation covers Kimagu, Marmar, Saosa and Timbilil subcatchments, and extends from the western Mau forest towards the Chemosit River and the Itare river confluence. The *phonolites* are generally *porphyritic* plateau lavas with typical glassy *phenocrysts* of orthoclase and greasy looking greenish *nephelines*, mainly containing various soda-amphiboles, *cossyrites*, *kataphorites*, together with pale greenish pyroxene, magnetite and *pleochroic biotite*. Chemically, the Kericho *phonolites* consist of the compounds listed in Table 1.5.

Table 1. 5: Geochemical Characteristics of the Kericho Phonolite

Compound	Percentage (content)
$Si0_2$	54
Al_20_3	20
Fe_20_3	2
$Fe0$	3
$Mg0$	0.8
$Ca0$	1
Na_20	8
K_20	6
H_20^+	2
H_20^-	0.3
$C0_2$	0.4
$Ti0_2$	0.1
P_20_5	0.6
$S0_3$	Nil
Cl	0.03
F	0.14
MnO	0.21

Source: Binge 1962

1.6.2 The *Phonolitic Nephelinites* with Intercalated Tuffs

These cover the Kiptiget and Itare subcatchments in the upper parts of the catchment. They consist of *phenocrysts* of sphene, apatite and magnetite with increased amount of *porphycritic nepheline*. Chemically, they consist of the compounds listed in Table 1.6.

Table 1. 6: Geochemical Characteristics of the Phonolitic Nephelinites

Compound	Percentage (content)
$Si0_2$	51
Al_20_3	15
Fe_20_3	4
Fe0	2.7
Mg0	41.1
Ca0	4.4
Na_20	8
K_20	4.4
H_20^+	4.2
H_20^-	0.64
$C0_2$	0.27
$S0_3$	Nil
CL	0.01
F	0.05
Mn0	0.17

Source: Binge 1962

The geology of the catchment changes at the lowest parts from Kabianga towards the Yurith river-Kipsonoi river confluence. It consists mainly of banded ironstones and leucocratic granites (Figure 1.4).

1.7 Hydrogeology

Since, geologically, *phonolites* present good permeability, porosity (0.10-0.80) and water yields, the catchment has good ground water potential. However, this may not be the case due to catchment degradation which affects interception, infiltration and percolation rates into the ground water aquifers. Table 1.7 shows the groundwater recharge rates in the country.

Table1. 7: Estimated Groundwater Recharge per Drainage Basin in Kenya

Drainage Basin	Area (Km^2)	Average Rainfall		Annual Runoff (10^6 m^3/yr)	Ground water Recharge	
		Mm/yr	(10^6 m^3/yr)		(10^6 m^3/yr)	mm/yr
Lake Victoria	46,000	1340	61,640	13,800	394	9
Rift Valley	130,000	515	66,950	3,260	428	3
Athi River	67,000	690	46,230	1,310	296	4
Tana River	126,000	620	78,120	3,700	500	4
Ewaso Ngiro	210,000	360	75,600	340	484	2
Total	**579,770**		**328,540**	**22,410**	**2,103**	
Average		**567**				**4**
Percentage of rainfall				**6.8**	**0.64**	

Source: Ministry of water Resources (MWR, 1992)

It can be noted from this table that the national percentage of 0.64% groundwater recharge is well comparable to that of the Lake Victoria basin of 0.639% in which Itare catchment falls. This means that at least 0.639% of the rainfall can be safely abstracted for various water uses. The catchment has good groundwater potential as shown by the number of bore holes and shallow wells which are scattered all over the catchment, especially upstream areas. Groundwater exploitation can be used to indicate whether there have been changes in groundwater discharges over time due to changes in land use (Table 1.8).

Table1. 8: Borehole Depths and Water Yields in the Itare sub-catchment

Series No.	Date	Location	Total Depth (m)	Water Rest Levels m	Yield (m^3/hr)
272	1944	Keringet	71.6	12	2.27
273	1944	Keringet	123	85.3	9.27
332	1944	Keringet	154	70	2.7
333	1944	Molo	83	24	3.2
334	1945	Molo	124	61	11.6
344	1945	Keringet	138	82	9.5
455	1946	Kapkatet	131	120	1.81
831	1948	Ngoina estate	46	21	5
1285	1950	Kimari estate	183	72	3.63
1060	1950	Kimari estate	17.5	7.97	0.56
1302	1951	Sotik highland	238	25	7.15
2640	1956	Molo	229	164	5.9
3097	1960	Kericho	182	26	5.4
3341	1965	Sotik KTDA	192	112	2.27
8258	1989	Kericho	128	14.9	4.9

Source: Ministry of water and Irrigation (MWI, 2004)

Groundwater flows through aquifers from areas of recharge to areas of discharge and flow rates range from less than 1 metre per year to several hundreds of metres per year. From the chemical composition of the rock formations of the catchment, it can be concluded that under normal circumstances, the water flowing through these rocks will be soft water due to low calcium and magnesium concentrations of 1.0 and 0.8, respectively for the Kericho *phonolites* and 1.1 and 4.4, respectively, for the *phonolitic nephelines*. These values are far much below the critical value of 200ppm when they can cause hardness of water. The chloride concentration is equally low in the formations, 0.03% for the Kericho *phonolites* and 0.01 for the *phonolitic*. This suggests that the water from these rock formations will not be salty due to low concentration of chloride ions.

The most sensitive compound in terms of water quality is the fluoride concentration which normally exists in form of cryolite (sodium-aluminium fluoride) and apatite (calcium fluorophosphates). The concentration in the catchment rock formation is 0.03% and 0.05% for Kericho *phonolites* and *phonolitic nephelines*, respectively (Binge, 1962). This is low concentration considering the critical value of 1.5ppm when it causes dental florosis, hence in normal circumstances the waters from the catchment is safe from excessive fluoride concentration.

In terms of phosphorous occurring as phosphorous pentoxide in rocks (P_20_5), the concentrations are 0.6% and 0.27% for the Kericho *phonolites* and *phonolitic nephelines* (Binge, 1962), respectively. These are fairly low values but phosphorous can be enriched into the soil and water by sewerage or even pit-latrine in settlement and urban areas of the catchment, due to degradation.

1.8 Soil Characteristics

The soils are known to influence infiltration rates of water, soil water storage, soil water storage capacity and ground water recharge through percolation into the ground water aquifers and subsequently to the springs, streams and rivers. As a result, the chemical composition of the soil may affect the water quality as it is brought into the water through erosion and sedimentation. Soil plays an important role in determining runoff and the amount of actual evapotranspiration. When soil water storage is at full capacity, a portion of any subsequent rainfall becomes excess rainfall and percolates in to the ground water table to recharge ground water and the remainder becomes direct runoff (surface runoff). When the soil water content is less than soil storage capacity, any subsequent rainfall becomes direct runoff only. The direct runoff and base flow (subsurface flow), adds together to form the total flow (stream flow).The sediment may contain fertilisers and pesticide and other biocide residues from agricultural and other land uses and this certainly will change the quality of the receiving water body.

The soils of the Itare catchment vary from upper to lower parts of the catchment. In the upper and the middle parts of the catchment, the soils are well drained, extremely deep, dark - reddish - brown, friable clay with humic topsoil and with high fertility. In the valley sides, the soils are dark brown friable clay loam with humic topsoil. In the lower parts of the catchment, the soils are well drained, very deep, dark reddish brown, very friable and smeary, sandy loam to clay with thick humic topsoil. Along the valley sides, the soils are clay loam to clay type (Figure1.5). Well drained characteristics of the soils make them to be more susceptible to soil erosion and this together with the steep slope and gradient, coupled with changes in land uses, may lead to serious catchment degradation, whose effect includes reduced stream flow and poor water quality. The high soil fertility characteristic means that the soils have attracted settlements and farming and other land uses such as industrial development, especially the factories whose wastes will affect the water quality of the catchment. All these indicate need for a research to avoid a serious environmental catastrophe.

1.9 Hydro-Meteorological Characteristics

The climate of the (Itare) catchment can be described as being of highland sub-tropical with moderate temperatures, low evaporation rates and high rainfall. The catchment receives convectional and relief types of rainfall, influenced by its high altitude of 2860 m above sea level, and its proximity to the Lake Victoria.

The total annual rainfall ranges between 1400mm – 2700mm as shown in the table (1.8). The highest occurs in the middle parts of the catchment and reduces at the lower and upper most parts of the catchment.

Table 1. 9: Annual Rainfall

Station/year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Tea. Research	2263	1628.8	2268	2384	2410.8	2208.9	2074.8	2104	1686.8	2589.1
Sambret 9	1531.6	871.1	1600	1546	*	1241.3	904.7	1000.7	1235	1100.3
Sambret 15	1933.7	1617.3	2015.7	218.4	2311.2	1726	1731.8	1809.8	1400.9	1693.7
Sambret 18	1558.7	1348.2	*	*	*	1486.7	1440.4	1803.7	1245	11441
Sambret 10	1044.4	1401.7	1244.5	1584.3	1446.1	1284.5	1360.1	1448.1	1234.5	1160.3
Kericho town	1587.8	2029.4	2318	2065.6	1997.4	1705.3	1993.6	2074.2	*	*
Station/Year	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
T. Research	2074.5	2011.4	2154.8	2274.9	1881.8	1684.3	2286.7	2040.8	2121	
Sambret 18	1546.3	1337.4	1440.1	1466.1	1230	1235	1092.3	1246	*	
Sambret10	1334.4	1460.1	1238.1	1383.4	1493	1407	956.1	1200.1	*	
Sambret 9	1246	1300.1	1294.3	1200.1	1395.5	1125.9	1075.6	1401.5	*	

Source: Ministry of water Resources, 2004

* The gaps in some stations were due to lack of data because of vandalism of the equipment at specific periods in the time series.

The mean annual rainfall is 2008.52mm/year while mean annual evaporation is 1294.91mm/year. The monthly rainfall ranges between 140-170mm, while the average monthly temperature ranges between 16^0C and 20^0C. July is the coldest month while the hottest season is between December and February. Rainfall generally increases with elevation and prevailing winds are north-easterly. Two seasons exists: April-May-long rains and October-December-short rains, with a mid season centred around august and land use patterns follow the seasonality of rainfall see Table.1.9.

Table 1.10: Summary of Mean Annual Rainfall, Evaporation, Evapotranspiration and Excess Rainfall

Year	Total annual rainfall mm/yr	Total annual pan evaporation mm/yr	Total annual evapotranspiration mm/yr	Excess rainfall mm/yr	Excess moisture ratio EMR	Groundwater Recharge mm	% of excess
1955	1860.6	1376.4	1101.12	759.48	0.38	727.66	96
1960	2332	1699.5	1359.36	972.64	0.48	940.82	97
1965	1595.5	1667	1333.6	261.9	0.13	230.08	88
1970	2543	1327	1061.6	1481.4	0.74	1449.58	98
1975	2198.1	1525	1220	978.1	0.49	946.28	97
1980	1753.4	1197	957.6	901.7	0.45	869.88	96
1985	2263	1136	908	1355	0.68	1323.18	98
1986	1628.8	1156	924.8	705	0.35	673.18	95
1987	2268	1173	938.4	1329.6	0.66	1297.78	98
1988	2284	1060	848	1436	0.72	1404.18	98
1989	2410.8	1105	884	1526.8	0.76	1494.98	98
1990	2208.9	1165	932	1276.9	0.64	1245.08	98
1991	2074.8	1187	949.6	1125.2	0.56	1093.38	97
1992	2104	1105	884	1220	0.61	1188.18	97
1993	1686.9	1135	908	778.9	0.39	747.08	96
1994	2589.1	1113	890.4	1698.7	0.85	1666.88	94
1995	2074.5	1106	884.8	1189.7	0.59	1157.88	97
1996	2011.4	1063	850.4	1161	0.58	1129.18	97
1997	2154.8	1163	930.4	1224.4	0.61	1192.58	97
1998	2274.9	1173	938.4	1336.5	0.67	1304.68	98
1999	1881.8	1147	917.6	964.2	0.48	932.38	97
2000	1684.3	1340	1072	612.3	0.31	580.48	94
2001	2286.7	1102	881.6	1405.1	0.70	1373.28	98
2002	2040.8	1167	933.6	1107.2	0.55	1075.38	97
2003	2121	1686.95	1349.56	771.44	0.38	739.62	96

Source: Tea Research Foundation (2004), and Field Data 2004

Table 1.9 shows climatic data for Tea research foundation station, which is in the middle of the study area, note the high amount of rainfall and the corresponding excess rainfall; this means that there is a lot of rainwater available for infiltration to replenish ground water.

1.10 Land use Patterns

In terms of land use, the Itare catchment can be divided into three land use zones:

1.10.1 The Sheep/Dairy Zone

This area has a long cropping season and intermediate rains divisible into two cropping seasons. The major land uses include the growing of especially, peas, potatoes, cabbage, carrots and keeping of grade cattle and merino sheep, settlement infrastructural development especially roads, institutional development such as churches, schools and administrative posts, and urban development such as Kuresoi market centre and saw milling. This zone covers the upper most parts of the catchment areas like Githima, Kio, Matunda, Mafi-punda, Mola and Zinet.

1.10.2 The Forest Zone

This is very wet and steep area of the catchment and is covered by part of the south-western Mau Forest. The major land uses in this zone are forestry, wildlife conservation, lumbering, saw-milling, charcoal burning, fuel wood collection, hunting of wildlife animals, bark and honey harvesting. These land uses have led to depletion of the forest cover and hence degradation of the catchment, and could lead to reduced stream flow and water quality. This zone covers the middle parts of the catchment.

1.10.3 Tea/Urban/Industry/Dairy Zone

This zone is characterised by permanent cropping possibilities, divisible into two variable cropping seasons and has a very good yield potential .The major land uses include agricultural such as tea plantations, maize, kales and pasture for grade dairy cows, settlements, road network development, institutional development, construction works and urban development.

Industry is another land use in this zone, especially the tea factories for Brooke Bond and African Highland Tea companies, milking processing at Premier Dairy, *Jua kali* industries in Kericho town and Bread factories. All these land uses could have a negative effect on the hydrological regime and water quality of the catchment, through chemical fertilizers and biocides. This zone covers the lower parts of the catchment areas such as Chepsoi, Chemosit and Kabianga. Generally, the catchment has under gone enormous land use changes for the last fifty years (Table 1.11).

Table 1. 11: Land Use Changes from 1950 to 2004

Land use	1950	1980	2004
Agricultural& rural settlement	10 %	40 %	53 %
Urban settlement	5 %	15 %	20 %
Industry	1 %	3 %	5 %
Social amenities	7 %	15 %	20 %
Forest cover	77 %	27 %	2 %

Source: Researcher. 2004

From this table, the increase in agricultural and rural settlement from 10% of the total area of the catchment in 1950 to 40% in 1980 and 53% in 2004 can be noted. Much of this settlement has occurred in forested areas as evidenced by the decrease in forest cover from 77% of the total area of the catchment in 1950 to 27% in 1980 and a mere 2% in 2004. There is a general increase in urban settlement as more people have moved to work and do business in towns and small market centres such as Kericho and Litein Municipal Councils, which are hosting district headquarters with all government and non governmental departmental heads, and several medium and small centres such as Kuresoi, Chepsir, Koiwa in the upstream area.

1.11: Population Characteristics

The population density is estimated to be about 314 persons per square kilometre in the upper and lower parts of the catchment (Table 1.12).

Table 1.12: Population Density in the Catchment

Year	Population Density (persons/km^2)
1989	214
1997	277
1999	295
2001	314

Source: Kericho District Planning Unit, 2002

About 94% of the population in the catchment depend on agriculture and about 6% are urban dwellers, especially in Kericho Town and the small urban centres. Land acreage allocation is about 1.43ha/household of about 8 members and 0.43ha and 0.5ha/person occurs in the tea and dairy zone in the mid and lower parts of the catchment. All this is evidence of a lot of pressure on land by the population leading to catchment degradation due to cultivation of steep slopes and deforestation. The latter will affect hydrologic parameters such as interception, infiltration, surface runoff, soil erosion and sedimentation, whose consequences would affect stream flow and water quality. These may lead to water shortages and out breaks of water borne diseases such as typhoid, dysentery, etc. This will, definitely affect development as a poor health population will not be productive and also resources meant for development could be used to treat water and the sick.

1.12 Conceptual Framework of the Study

The effect of land use changes on stream flow in this study is conceptualized as consisting of the physical and human environment that interacts to form a given integrated environment which is affected by the land use changes, leading to environmental degradation. The degradation affects both surface and groundwater and therefore affecting the total flow and the water quality in the rivers (Figure1.13).

Mau complex have experienced serious deforestation effects (KFG,2003).The destruction has led to reduced interception, increased runoff, reduced infiltration, water shortages, floods, and soil erosion and sedimentation (ICRAF, 2000).

The Mau forest/catchment, apart from being a water catchment area for several rivers, is known for its biodiversity potential, hence an important natural resource for the local and national economy. Previous researchers in this area have not addressed the problem of variation in river flows due to changes in land use. An important feature of the Itare catchment is its resource potential for several land uses, which has attracted the various actors in development without due regard to their environmental implications.

Groundwater is recharged by rainfall and may vary widely depending on the total rainfall, evaporation, topography, soil types and land use types see table1.7 on the variation of estimated ground water recharge per drainage basin in Kenya. The Itare river catchment in the Sondu Miriu river basin within the lake Victoria drainage basin is within the heavily degraded Mau forest, (Plates 4a-e) , a catchment of an area of 705km^2 has, in the recent past been seriously affected by environmental degradation due to land use changes. The Mau forest is the major source of the rivers and comprises the Itare catchment, i.e., Timbilil, Kimugu, Saosa, Kiptiget, Marmar and Chemosit River and together with the river Kipsonoi catchment forms the large river Sondu basin. With a forest cover of about 90,000 ha initially, covering Nakuru, Kericho, Buret, and Bomet districts, it has been seriously reduced due to illegal excisions and encroachment. There is evidence of over exploitation of the Mau forest which has led to reduction of river discharges in some rivers. The opening of the forest for various land uses has compromised the quantity and quality of water in the catchment through increased surface runoff, soil erosion, and sedimentation. Because of the high rate of deforestation, soil/land has suffered both physical and chemical degradation. Vegetation influences precipitation and stream flow (discharge through roughness which holds moisture, as detention storage and depression storage, leading to increased amounts of ground water recharge. Soil types influence surface runoff and the water holding capacity, soil water storage, soil water storage capacity and other soil characteristics are affected by land use which finally affects river discharges. Even the movement of precipitation into the deep ground (percolation) forming ground water from where it reappears in swamps, springs, lakes, river and seas, depends on land use in their catchment areas. In the study area, destruction of forests for construction materials, fuel wood, charcoal burning, settlements, lumbering, farming and other land uses have modified runoff, interception and infiltration rates and ground water recharge and hence serious changes on the hydrological cycle. Clearing of vegetation changes; the hydraulic properties of top soil which increases surface runoff and reduces ground water recharge. River flow during the dry season is generally derived from delayed interflow and ground water which together makes base flows.

This study is therefore to investigate the extent of land use changes in the study area, and its corresponding hydrological consequences in terms of water quantity and quality. It emphasises on deforestation, settlements, agricultural practices, infrastructural constructions and other land use as they affect water quantity (discharges), quality, (turbidity), and sediment transport rates.

1.14. Aims and Objectives of the Study

The overall aim of this study is to find out the causes and the extent of the land use changes in the Itare sub-catchment over time, its effects on the river flows and water quality and to propose possible interventions. Specific objectives of the study are:

(i) To examine the variability of stream flow and water quality parameters, including sediment load concentrations and turbidity for the Itare sub-catchment

(ii) To determine the space- time deforestation rates in the Itare sub-catchment

(iii) To establish the land use changes and stream flow relationships

(iv) To identify causes of catchment degradation in Itare and propose interventions for sustainable water management.

1.15 Hypotheses

Ho: is the null / research hypothesis

H1: is the alternative hypothesis

There were three research hypotheses:

1) Ho: There is no variation in the annual river flows in the Itare sub- catchment due to land use changes.

H_1: There is variation in annual flows in the catchment due to land use changes.

2) Ho: There is no significant relationship between land use changes and river flows in the Itare river sub- catchment.

H_1: There is a significant relationship between land use changes and river flows in the Itare sub-catchment.

3) Ho: There is no significant relationship between land use changes and water quality in the Itare sub- catchment.

H_1: There is a significant relationship between land use changes and water quality in the Itare sub- catchment.

1.16: Justification and significance of the Study

The Itare sub-catchment is within a high potential area with serious catchment encroachment, hence the need for a thorough hydrological study such as this.

The Sondu Miriu hydropower plant is located downstream of the study area within the river Sondu catchment and therefore, suspended sediment data from this study will be very useful in estimating the rate of siltation into the reservoir.

Lack of consistent and comprehensive data on catchment degradation in this country is in itself an enormous incentive to undertake this study to provide the necessary data for future use in water resource management programmes. The degradation of the Timbilil river sub-catchment on the Nakuru area, which caused water shortages in Kericho 1999-2000, is another incentive to undertake this study to be able to come up with the causes and interventions. The study on environmental degradation due to land use changes in the Itare sub-catchment is an original undertaking in Kenya. Literature review of related studies at global, continental and national levels indicates that there is no much information on this area of study.

Catchment studies in Kenya have tended to concentrate on soil erosion, soil characteristics, deforestation rates and soil and forest conservation without much coverage of the hydrological aspects, hence the need to undertake this unique study. The fact that catchment degradation will eventually lead to poor water quality, water shortages, water borne diseases, which in turn will lead to reduced life-expectancy, increased mortality rates, reduced fish and wildlife and unsustainable water resource management necessitates a thorough study.

Most hydrological research has tended to concentrate on general water balance studies, ignoring the effects of deforestation on runoff and soil management. This information is necessary for sustainable water resource management, hence the need for this study. This study is of paramount importance as it evaluates critical issues necessary for long-term catchment sustainability through interventions. The data which will result from this study will assist in the development of strategies and policies needed for rational use of water resources in the study area, Kenya, Africa and the tropical areas of the world.

Catchment degradation due to land use changes has become a great concern to governments, researchers, academicians, politicians, water engineers, hydrologists, administrators and the general public especially in developing countries because of its negative effect on economic development

This study, therefore, will be of paramount importance in that:-

(i) It will provide field based information on flow and water quality variability which can be used for future policy formulation on water catchment protection in the lake basin in Kenya and in the tropics;

(ii) It will underscore the rate and extent of catchment destruction and its hydrological implications in the Itare catchment in the Lake Victoria basin;

(iii) It will provide background hydrological and sedimentation data which will lead to the establishment of the discharging rating curves for the major rivers in the catchment; suspended load rating curves for river Sondu where the hydropower dam is located, Surface water induced soil erosion rating curves in the catchment, which is important for future soil conservation programmes in the catchment. Water quality data which give an insight of the water quality status in the catchment will enable the people concerned with water treatment to decide which water pollution control measures to adopt in order to avoid water-borne diseases outbreak. It will enhance the understanding of the land use change and river flow relationships. The study will provide an improved understanding of the causes of catchment degradation and the possible interventions which will lead to sustainable and effective water resources management in the Itare sub-catchment and the country.

1.17 The Scope of the Study

River catchment degradation due to land use changes has led to increased soil erosion, increased sediment load, in rivers and streams, and reduced interception. Surface runoff has increased, reduced infiltration, reduced ground water recharge. Flooding, water turbidity and nutrient concentration (water quality) have also increased. Other effects include agricultural effects such as reduced soil fertility, leading to reduced productivity by affecting various chemical and physical properties of the soil. General reduction of crop yields with corresponding financial losses, are some of the effects of catchment degradation.

The study started by looking at the general hydrology of the entire Upper Sondu river basin, which is made up of the Itare and Kipsonoi river sub-basins. But for the purpose of a detailed study, the study area was narrowed down to the Itare sub-catchment only.

This hydrological study focused only on the extent of water catchment degradation/land use changes in the Itare catchment and the corresponding downstream hydrological effects. The study highlights the physical characteristics, vegetation conditions, settlement patterns, land uses, agricultural farming methods infrastructural developments and their effect on soil erosion rates, sediment load, and variation in discharge and water turbidity (water quality). However, the study concentrated on the hydrological effects only.

The study concentrates on surface water induced soil erosion, e.g., rill erosion, gully erosion, and rain splash (sheet erosion) and overland flow erosion methods because the latter are the common forms of erosion in the study area.

CHAPTER TWO
LITERATURE REVIEW

2.0 Introduction

In this chapter a review of relevant past catchment based hydrologic studies in the world, Africa and in Kenya is presented in three sections. (i) Land degradation (Soil erosion and sediment transport), (ii) Forest/vegetation degradation, (iii) Stream chemistry in terms of turbidity. These are the major aspects affected by land use changes in the Itare catchment.

In general the aim of this review is to note and appreciate the work done by earlier researchers in terms of methods applied, key findings, identification of any gaps, similarities and differences with present study, and to try to bridge the gaps.

2.1: Land and Forest Degradation Studies in the World

Brune (1948), in his study in the USA, revealed that sediment yield per unit area decreased with catchment size for basins in the Mississippi Valley, while Langbein and Schum (1958) reported that increased rainfall increases surface runoff and hence increases soil erosion and sediment yield especially in un-vegetated areas of the catchment. Man's use of the landscape has tremendously increased soil erosion Douglas (1967), the author concurs with this observation and wants to use the same methodology to reveal the situation as it is in the Itare catchment. Wilson (1973) confirmed that sediment yield in a catchment is mainly influenced by land use. Howard (1975) is even more particular and identifies causes of soil erosion as being due to deforestation resulting from lumbering, and farming methods such as overgrazing, ploughing and harrowing up and down slope.

In a study done in India, Tejwani (1977) reports that siltation of reservoirs increased three times the expected rate due to deforestation of large areas within the catchments. This Wadsworth (1978) reported that, as a result of catchment degradation around the Panama Canal, ship channels were blocked by silt and water storage capacity of the Canal was tremendously reduced. Walling (1983) observed that since storage opportunities increases with catchment size, the sediment delivery ratio (a ratio between on site soil erosion and the amount carried by streams decrease with increase in basin size while Hamilton and King (1983) acknowledged that trawls, foot-paths, ridges, villages and mining points are important sources of runoff and sediment. They found a range of 0.16-0.27 ha/year sediment from settlements and road surfaces.

Dune (1984) advocated for a long-term observation of soil erosion and sedimentation processes so as to have more reliable data on which more reliable conclusions can be based. Hani and Pearce (1987) reported that, inadequate data collection and processing may lead to under- estimation of sediment loads.

Roessel (1950) in his detailed study on catchment degradation and their effects on stream flow has cautioned that, results from different catchments with contrasting land uses can not simply be compared because geological factors and topographical factors may override effect of vegetation. However, he did not give a method of apportioning the effects of each parameter on the overall stream flow variation and the present study will try to apportion the effects of various parameters. Hewlett and Hibert (1967), has observed that increase in storm flow is more after forest clearing for small and large rainfall events, and has attributed this to reduced infiltration.

Hydrological studies in Asia have emphasised the importance of forest cover in proper soil and water management In their study in Madagascar Bailly *et al.* (1974), using small basins, has compared amounts of flow emanating from under old secondary vegetation, dry land agriculture with soil conservation measures, temporary slash and burn agriculture, and he found out that runoff was highest in the last and lowest in the first. In his study in Haiti Kunkle (1976), has observed and correctly reported that price increases of kerosene and fuels have led to high pressure being exerted on forests, leading to their degradation. In his study, De Bruin (1977) has observed that, large spatial variations in corrective tropical rainfall may render estimates of a real precipitation relatively unreliable. FAO (1977) has identified that, overgrazing, poor cultivation methods, cultivation of marginal lands and firewood gathering are major sources of catchment degradation. Howard (1978) has attributed causes of soil erosion to deforestation by lumbering and poor farming practices, overgrazing and ploughing. They have concluded that forest destruction, soil erosion and scarcity of water are closely interrelated consequences of human interference in nature. Pritchet (1979) has pointed out that, the combination of forests, soils, roots, and litter acts as a sponge soaking up water during the rain season and releasing it evenly during the dry periods, as normal flow to the springs and rivers. Meyer (1980) has pointed clearly that, data on studies dealing with conversion of natural forests to annual cropping and their effect on stream flow is lacking. He continues to report that, most researchers have tended to concentrate on areas such as, infiltration capacity, surface runoff, and soil erosion.

Seiler and Crutzen (1980) have reported that, tropical forests are disappearing at a rate of 9-15million ha/year, while Meyer (1980) has put the rate at 24.5million ha/year. Whitmore (1990) has summed it up that; this rate is a major environmental problem to mankind. Degradation of forests and pasture land in river catchments contributes to disastrous floods and sediment yields Tejwani (1987). He concludes that, this poses a greater threat to the Indian economy. Lanley (1982) has reported that, shifting cultivation (slash and burn) agriculture is one of the important reasons for loss of tropical forests before 1980s. Bosch and Hewlett (1982) have reported that, the removal of natural forests cover may initially lead to considerable increase in water yield especially in high rainfall areas. However, he argues that depending on the rainfall patterns, there is a rather irregular decline in stream flow gain with specific new land cover. Richardson (1982) has gone further to report that total stream flows from catchment areas with contrasting land uses may lead to wrong conclusions due to catchments' water leakage.

Quian (1983) has reported that, the strong year to year variability of weather within the tropics, can lead to differences in stream flow, not necessarily associated with land use or land cover transformations. Bentrand (1983) has observed that, in developing countries, natural forests are being converted into plantations, and that this may lead to changes in hydrological regimes. This is the case in the study area where the natural south-western Mau forest is being replaced by tea and maize plantations. Mooley and Pathasarathy (1983) have observed no statistically significant trend or oscillations in the occurrence of floods in India between 1871 and 1980, due to vegetation cover changes. Boom (1985) reports that; forests represent an immense source of food, fibre, timber, medicines, fuel, etc. and emphasises the need to conserve them. Dyhr-Niel-son (1980), in his study in Thailand between ,1955-1990, concluded that, there was an increase in water yield due to replacing of tall trees by short trees, and there is no systematic trends in magnitudes of floods. He attributes any effects to be due to changes in climatic factors rather than due to changes in land use. On the same note, Ruined (1986) argues that, the commonly observed deterioration in river regimes following forest clearing is not so much to clearing itself, but rather reflects lack of good land husbandry. Erosion is being recognised as a hazard in temperate countries (Morgan, 1986), as it causes eutrophication of lakes and coastal waters.

Forest clearance affects rainfall through micro-climatic variations which increases evaporation rates, infiltration rates and soil erodability sequences, Lal (1987). Meher-Homji (1988), in his India based study, has observed a decrease in rainfall quantity with increased forest clearance. Richey (1989) reconstructed an 83-year record discharge of the Amazon river at Manua and discovered that there had been no statistically significant changes in discharge over the period of record (1903-85) which predates significant human interference in the river basin. Bruijnzeel (1990) has reported that, water yield after maturation of the new vegetation may remain above the original total stream flow. Gladwell and Bonell (1990) have predicted that, from 1980-2000, the world population was expected to increase by 50% to a total of 6.5 billion. They have gone further to report that, as a consequence of this, demands on water and land resources were to rise often at the expense of the remaining natural vegetation.

In his study in South Africa Calder (1998) has found natural forests to be less evapotranspirators than commercial forests. Forests generally influence local hydrology through high transpiration and good infiltration due to rich litter and humus layer. The Interception loss for tea is lower than indigenous forest cover because tea has a smoother canopy, Commercial forests with their smooth single layered canopy have also lower interception rates (Blackie, 1979a). Wet tropical forests have been found to intercept about 38-40% of rainfall while eucalyptus intercepted only 20-25% and acacia intercepted 30-35% (Chinnamani, 1985). The overall impact that various land uses have on hydrology of an area depends on the combined effect of the differences in interception, transpiration and infiltration capacities (Blackie, 1979b), he concludes that the balance between interception and transpiration processes depended on spatial and temporal rainfall distribution.

Bosch and Hewlet (1982) have reported a relationship between the removal of forest and increased stream flow in both temperate and tropical environments. Wilk and Anderson (2001), in their study in northern Thailand, have found no significant changes in water balance after the decline in forest cover from 80% to 27%. They have attributed this to spatial and temporal variability which could mask many of the cause and effect links between land use and hydrology.

2.2. Land and Forest Degradation Studies in Africa

Fournier (1960) related an index of seasonality of sediment load to sediment yields and Lal (1966), in his study in western Nigeria, observed that runoff loss is governed by soil hydrological characteristics and not slope. Douglas (1967) reported that man's use of the landscape has increased the rates of soil erosion in that they far exceed those rates before man became an active geological agent. Temple and Sundbury (1972) in their study in Rufiji catchment in Tanzania, observed sediment transport of about 1 million tonnes of suspended sediment load daily. Rapp *et al.* (1972), in his study within the Morogoro catchment, discovered that most sediment came from areas cleared for farming and settlements. The researcher borrowed methodology used.

Temple (1972), in his Zimbabwe and Uganda based studies, emphasised the importance of vegetation cover in controlling water and soil losses. Temple and Murray-Rust (1972), in their study based on the Uluguru Mountains in Tanzania, found out that cultivation practices were destructive and recommended soil conservation measures to be adopted in mountainous areas. Rapp (1975), in his study in Lesotho and Tanzania, observed that there is no quantitative assessment of rates of forest destruction in Africa. Rapp (1977), in his Botswana -based study, further emphasised the importance of continuous monitoring of water and sediment yield in studying soil erosion rates and their consequences in reservoir or any water works.

After a detailed study on sediment transport in South Africa, Roseboom (1993) points out that eight years of continuous monitoring are necessary for obtaining reasonable estimates of suspended export from a single catchment. Nyssen and Mitiku 2004) in their study in the Ethiopian highlands have reported that sediment yield data are important ingradients in effective land management, Mitiku, Karl and Stillhardt (2006), in their study of the Tigray highlands in Ethiopian have recommended an improvement of the indigenous soil and water conservation practices land management.

Pereira (1962), in the East African based study, has observed increased stream flow from cleared forested catchment unlike from forested catchments. Hibbert (1967) has noted that, the increase in stream flow is proportional to reduction in forest cover. Kenworthy (1969) has emphasised the role of vegetation cover on proper soil and water management. Edwards (1979) has presented a long term comparison of stream flow from these small and presumably water light basins in Upland Tanzania with evergreen forest, and one with traditional agriculture. He found a consistent difference of about 400mm/year of stream flow. Lal (1980) has reported that large scale deforestation for agriculture leads to ecological imbalances which affect the hydrological cycle through soil compaction, water runoff and accelerated soil erosion. Lal (1983) has observed increased runoff coefficients in a Nigerian catchment from secondary forest, nil, manual clearing, 1%, conventional tillage, 5%, and from mechanical tillage was 6.5%. Odemerhu (1984 a&b) has observed significant changes in streams geometry such river channel widening in headwater basin in south-western Nigeria following a shift in land use from slash and burn agriculture through one with short fallows to permanent cultivation. Dunne (1979), Manan (1980) and Hurdson (1987) have argued that, improper agricultural practices are responsible for the deterioration of the stream flow regime.

. In their studies in South Africa, Andrews and Bullock (1994) have attempted to quantify the effects of land use changes on the availability of water downstream, but they concentrated on estimating the mean annual runoff. Kleeberge (1991) found a positive relationship between land use changes and hydrology and other components of the environment.

2.3 Land and Forest Degradation Studies in Kenya

Dunne (1975 (a & b) constructed suspended sediment rating curves for 97 Regular Gauging Stations (RGS) using regression analysis methods based on 1948-65 sediment load and flow data, but he cautioned that, due to poor quality and quantity of data used, not all of the curves will be useful. He went further to say that the total amount of sediment carried by a stream may vary from year to year, due to changes in land use in the catchment. The Kenya Soil Survey (1975) identified that shifting cultivation increases soil erosion in Kindaruma area and may lead to sedimentation of Kindaruma reservoir. Dunne and Ongwenyi (1976) in their study on the Thiba, Tana and their main tributaries like Chania, Thika, Maragua, Mathioya and Sagana, concluded that, most of the earlier reports on soil erosion and sedimentation were underestimated and instead they came up with a sediment yield of 573,237 tonnes/year; while Dune (1977), in his Kajiado District based study found, 0.3-1.2cm/year soil loss, an equivalent of 300-1200 tonnes/year. Dunne *et al*., (1977), using a Geomorphological relationship to calculate soil erosion, found an average of 24 tonnes/km^2/year.

Moore (1978) reported that man increased soil erosion by two-fold and he further reports that soil erosion rates at most of Kenya's catchments range between 18-24 tonnes/ km^2/year from undisturbed forested land,50-140 tonnes/ km^2/year from slightly grazed Arid and Semi-Arid land, and 10,000 or more tonnes/ km^2/year from heavily grazed land and intensively farmed land.

In his very elaborate study on the Upper Tana, Ongwenyi (1978), identified overgrazing in forested areas and cultivated zones as major sources of sediment, however he did not specify they the quantity from each source. Ongwenyi (1978) went further to point out that there is very little scientific work on soil erosion and sedimentation in Africa, and particularly Kenya. Wenner (1980) observed that, soil formation is a slow process for example, it takes about 300 years to increase the topsoil by 25mm and Wenner (1980) continues to stress that the present topographic and soil distribution in the world is the result of erosion and sedimentation processes over millions of years. He attributes this to man's activities which have damaged the natural forests and grasslands. Wamicha and Mungai (1985) developed a soil erosion hazard map using slope-angle, vegetation cover, soil depth, soil texture, clay mineral type characteristics, organic carbon content and soil salinity. Schneider (1990), in a study of sediment solutes into the Masinga Dam, identified densely populated areas and intensively cultivated areas, foothills, cattle tracks as major sources of sediment into the dam and so reducing its lifespan. Kitheka (1991), in his study Nguu-Tatu catchment found soil erosion rates of 0.7cms per year, equivalent to sediment yields of 10,500tonnes per kilometre square per year. It is important to the present study as it is based on a small tropical sub-humid catchment as compared to the majority of other studies. Wamicha, *et al*. (1992), in their study on soil degradation in the Upper Migori river catchment, concluded that soil erosion was due to clearing of vegetation for cultivation, mining and road construction.

Denga and Ongwenyi (2000) in their analysis of soil erosion and sedimentation problems in Kenya, traced the problem back to 1930s and recommended both qualitative and quantitative assessment of soil erosion and sedimentation in Kenya, so as to enhance the development of Kenya's water resources. This review dealing with soil erosion and sediment transport in the world, Africa and Kenya, led the researcher to understand the general processes that underplay catchment degradation in tropical catchments such as the Itare sub-catchment.

Pereira (1962), (1973), has provided important information of the water balance equation while Kiangi and Obasi (1976), have emphasised the situation in Kenya. However, it was a generalised study on the water balance but not focused on catchment degradation and its effect on the quantity and quality of water.

Wamicha, Mungai and Maingi (1992), in their study of soil degradation on the upper Migori river catchment, observed that, soil erosion was due to clearing of vegetation for cultivation. Njeru and Mungai (1992), in their study in Naro-Moru catchments, has reported rightly that, forests are important for stream flow and ground water recharge. Mackenzie (1992) in his study on the impacts of land use practices on natural forests and watersheds in Lake Nakuru catchment, has established that deforestation, clearing of vegetation for crop-production, livestock pasturage, heavy losses of soil, have caused serious degradation in most catchments in Kenya. He continues to point out that watershed sediment transport rates of major rivers have adversely been affected leading to siltation and fluctuation of water levels in major lakes and dams in Kenya. The researcher agrees with the foregoing observation; however the study omitted the effects of land use on water quality which our study wishes to address.

Murimi (1992) has identified forest encroachment as an indirect cause to fluctuations of the lake-level in Kenya. Njeru and Mungai,(1988), have identified vegetation (forest) as important for recharging the ground water table, thus ensuring a continuous base flow during dry periods and soil and ground water recharge.

ICRAF (2000), in a study in the Nyando basin, has reported a considerable evidence of strong relationship between land use, runoff, and sediment. It has have continued to argue that sediment loses from undisturbed forested areas was about 20-30 tonnes/km^2/year. They further identified the dense networks of roads and footpaths which make about 1% of the basin area affecting infiltration and could be contributing between 25-50% of the basin sediment yield. All these studies at global, continental and national levels, point to the fact that vegetation as part of the catchment has a big role to play for both quality and quantity of surface and ground water resources.

CHAPTER THREE

METHODOLOGY

Various methods were used to collect and analyse the various types of data which were relevant so as to achieve the objectives of the study. Secondary data were extracted directly from previous records, while primary data were collected from the field using various scientific methods from well-chosen representative sites of the catchment, the details are discussed.

3. 1: Data Collection

A variety of relevant data were collected and analysed so as to achieve the objectives of the study and this was done as follows:

3.1.1 Secondary Data

This category of data involved existing data which were relevant to the study and were collected from previous study reports, articles and professional papers, river monitoring records, annual hydrological and agricultural reports, and journals. The main sources for these data were libraries of National Universities, Ministry of Environment and Natural Resources, Ministry of Agriculture, Lake Basin Development Authority, Permanent Presidential Commission and Water Conservation reports, Lake Victoria Environmental Management reports, National Environmental Management Authority and from consulting firms dealing with water in Kenya.

The secondary data provided the necessary historical data which are very important in hydrological studies such as this. Secondary data collected included monthly rainfall, evaporation, stage/water levels, discharge, land use such as forest cover, population data such as settlements, crop cover, grazing land, ground water levels and yields, topographic characteristics of the catchment, soil characteristics, water quality characteristics, water strike depth, ground water yields, sediment concentrations and geological characteristics.

3.1.2 Primary Data

Given the very short record of high spatial-temporal hydrological observations in the Itare catchment, three years of intense measuring helped to considerably increase knowledge about the spatial-temporal variability of stream flow and water quality in the catchment. This category of data was collected directly from the field through visual observations, face to face interviews with relevant people, actual field measurements, laboratory analysis of water samples, photography and field reconnaissance. This was to identify the general hydrological situation of the catchment. The data included vegetation conditions, soil characteristics, erosion rates, conservation measures, topography, slope (gradient) slope lengths, valley types, altitude, catchment areas cross-sectional and profiles of streams. The other data was on rivers, rock patterns, population density and distribution, land use types, discharges, drainage characteristics and climatic characteristics. The methods used to collect various primary data are discussed in detail:

3.2 Flow Data Collection

Stream flow data was obtained by using two gauging methods as follows:

3.2.1 The rod-float method

This method is cheap and fairly accurate as float can be made locally. This technique is simple so that it was used correctly by briefed gauge observers in the field in the absence of the researcher or qualified personnel. This was possible because the researcher could not be at all gauging stations at the same time, while the gauge observers stayed next to the station. Discharge measurements were done at specific and representative sites of the catchment where flow was well mixed and this was done as follows: A 100-200 metres long straight rod-float reach was carefully selected. Both the upper and lower rod-float timing reaches were marked by physical features such as a stone, a stump or a tree. The mid channel straight distance from the upper rod-float reach was accurately measured and this value was to be used at all times of rod-float measurements.

A throwing position was determined carefully upstream of the upper rod-float reach to ensure that the rod-float enters the water and got into buoyant position before it enters the timing reach. The rod-float immersion should be more than a quarter depth of the water. Using a stop watch, the travel time of the rod-float from the upper rod-float timing reach to the lower one was accurately recorded in a booking sheet. The procedure was being repeated three times for each measuring time, this was to get an average value of the velocities of the stream. The station number, date, gauge height and time of the day were recorded in the booking sheet for subsequent data analysis. When using the rod-float method the following precautions were taken, any rod-float which did not take up position in the central third of the river width was not recorded and also any rod-float which snagged in the river bed or on an obstruction below the water was not recorded. The rod-float was being keenly observed as it passed from the upper to the lower timing reaches to ensure accuracy of the data.

Rod-float velocity measurements provided an estimate of the upper half meter velocity along the middle of the river over the length of the rod-float reach and not estimate of the average velocity through the gauging station cross-section. The former was converted to the latter by multiplying the same by a correction factor of 0.85.

3.2.2 Wading method

This method uses a current meter revolution counter, base knob and a three meter long wading cable together with wading rods which are graduated in centimetres and each rod is 0.75 metres long. This method was used only for shallow waters in the catchment at well chosen points where the flows was well mixed and appoint where there was a straight stretch of about 100m long. Gauging commenced by taking the depth of a vertical from either side of the river banks using the wading rod which was dipped into the water until it touched the bed. The depth was taken and recorded, then that same depth value was multiplied by a factor of 0.6 to give the position of the current meter from the surface of the water or by a factor of 0.4 to give the same position from the river bed, this position is known to represent the average velocity of the water see (figure3.1).

The position is meant to give the average velocity of the river and the number of revolutions and time taken were read off from the revolution counter, from which mean velocity of each vertical was calculated using a conversion table of the Braystocke model current meter.

The cross-sectional area (A) was calculated from the depth and a chain age (width) reading by multiplying the depth and the width (see figure 3.1) and the formula given in equation 3.1 was used to calculate water discharge follows:

$$
\begin{aligned}
&Q = AV \\
&where \\
&Q = disch\arg e\ in\ m^3/\sec \\
&A = cros\sec tinal\ \ area\ \ in\ m^2 \\
&V = average\ \ velocity\ \ in\ m/\sec
\end{aligned}
\qquad 3.1
$$

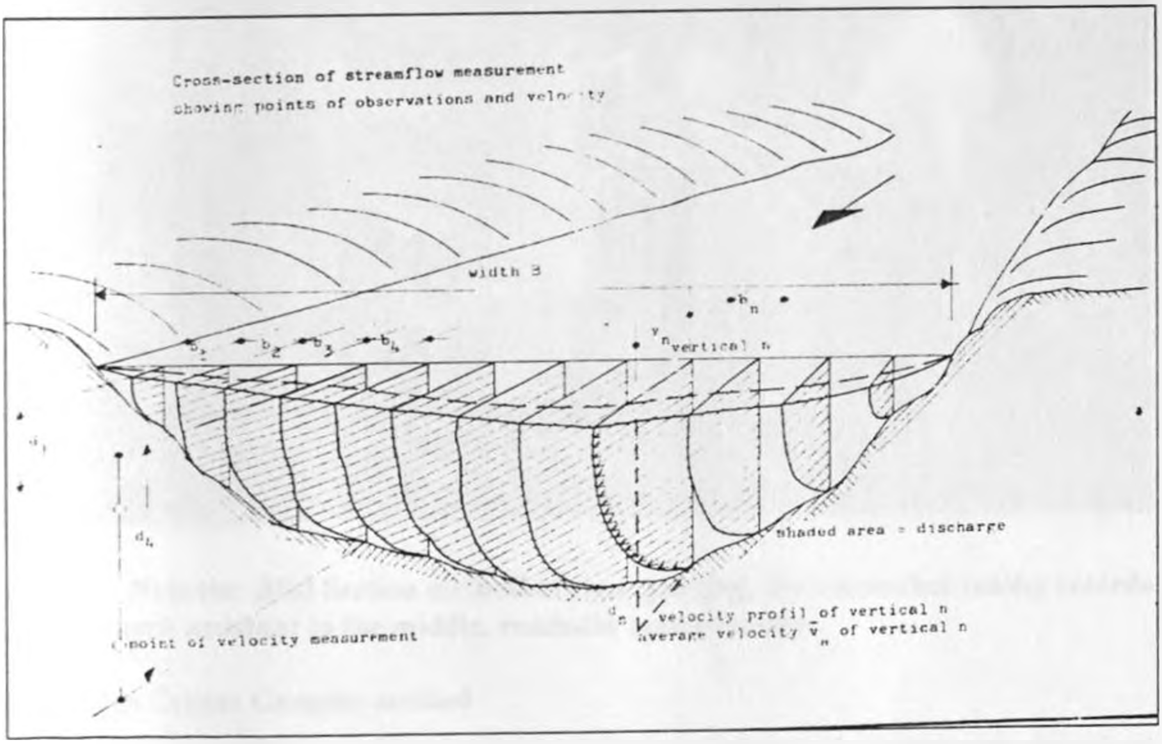


Figure 3.1: Mid section (wadding) Gauging Method used during the study

Source: Shaw E. (1988)

This method is advantageous over the others because it is highly sensitive, has little interference with flow and it is least affected by upstream flow disturbances. Since it gives reliable information it was preferred, plate 3.1 show how the method was used.

Plate 3. 1: Note the Mid Section method of river gauging, the researcher taking records as the research assistant in the middle. reads the meter counter.

3.2.3 Bridge Crane: Gauging method

After identifying a suitable gauging site, an area with a straight stretch of about 100m long and where river flow is well mixed, approximately uniform river bed, bushes and branches on the riverbank were cleared to ensure that the bridge conveyed floodwater satisfactorily without blocking flow. The current meter was mounted on to a bridge crane by a gauging reel and suspension bar. An appropriate size of sinker depending on the turbulence of flow at that time was attached to the current meter to stabilise it in the water so as to provide stream-lined flow. Gauging begun from a fixed painted reference point at the end of the bridge deck which had permanently painted markings at chainage positions which were used during gauging.

The current meter was lowered using a gauging reel fitted with a brake to control the lowering of the meter and sinker weights at specified marked chainage positions along the bridge deck. The velocity of water was measured at 0.6m from the water surface or 0.4m from the channel bed at every single vertical. The velocity values were read off from a conversion table using the number of revolutions and time taken from the revolution counter (n). The depth, chainage, the number of revolutions, time, and gauge heights at the starting and finishing time of gauging period were recorded in a special booking sheet. The depth and chainage (width) readings were used to calculate the river cross-sectional area (A) as already discussed above, while average velocity was determined from a calibrated table for the Braystoke meter model used and equation 3.1 above was used. This method was used for deep waters such as at rivers Ainabkoi, Chemosit, Yurith, and Itare especially during high flows. Its advantages over the other methods include, being less risky during high flows and it is good for deep waters.

3.2.4 Measurement of stage

This was done in two ways:

3.2.4.1 Staff gauges.

These are graduated set put in water with zero level at the river bed so that the level of water surface can easily be observed at all stages. They ranged from 1 for small streams to a series of three or more vertical gauges for large rivers to ensure that at least one plate was in contact with water at any one time (plate 3.2), each standard gauge plate is graduated for a range of 0.5m.

They were installed firmly on river banks, bridge walls or at the river beds ensuring that they were not swept away by flood water. This was done at well selected and representative points of the catchment. A gauge observer was hired and briefed on what to do and was stationed at each station to take readings twice daily at 9.00 a.m. and 5.00 p.m. on the river level fluctuations.

Plate3.2: Note a single staff gauge in the river and the measurement fo gauge height and river discharge simultaneously to generate a rating curve for the station IJC 19 – Kimugu - Kitenges

Current meter gauging were simultaneously taken at this staff gauging station to allow subsequent generation of a discharge rating curve for each station by plotting discharge (Q) in the X axis against gauge height in the Y axis and statistically fitting in the line of best of fit using the regression analysis equation shown in equation 3.2.

$$Y = mx + b \qquad 3.2$$

Where:

m is the gradient or slope of the line

b: is the Y intercept when x = 0

The advantage of the staff gauge method includes the fact that it can be handled by semi-skilled personnel, it is easy, cheap and is durable.

When the data are plotted on a logarithmic paper the equation for the rating curve is as follows:

$$Q = aH^b \qquad 3.3$$

Where:

Q = *discharge, in* m^3/s

H = *stage, m*

a *and* b *are constants (coefficients) obtained from data.*

$$\log Q = \log a + b \times \log H$$

3.2.4.2: Water Level Recorder

This is automatic water level recording equipment normally installed on calm water surface on which a float of the recorder rests. The float is attached to the pen and responds immediately to significant changes in water levels in the river.

The pen is driven by a clock work at a constant speed across the chart and it is connected to the river by a four inch inlet GI pipe. this was installed at 1JC19. This method is advantageous because it is accurate. collects continuous data and operates on its own and can be checked after one or three months depending on the chart size used. The following formulae were used to determine the range of change in water levels in automatic water level charts:

$$R = n * c \qquad 3.4$$

$$S = L / R$$

Where:

R = *the range in water level in m*

n = *the maximum number of rotations of the float wheel required to move the pen from one end of useable drum length to the other.*

c = *the circumference of the float wheel in m.*

s = *is the scale or reduction ratio*

L = *the usable drum length in m*

(ii) Hand - Grab - Method of sampling

This method involved hand-grabbing of 1 litre full of water using sampling bottles at specified well selected and representative points in the catchment. The samples were then labelled as mentioned earlier and taken to the laboratory. This method was used intensively during the study. Its advantages include the fact that, it can be used by unskilled personnel like gauge observers, it is cheap and easy to use, can be used when samplers are not available, and can be used when velocities in the river water are too high.

(iii) Laboratory Analysis of Samples

This was done using standard methods as given by the US Health Organisation manual only physical was carried out. Chemical and Biological analyses were not done because they were was not relevant to the study.

3.4: Sample Size and Sampling Points

The sample size (record length n) of the annual runoff and annual rainfall time series used in the study ranges from 3-54 years for seventeen rainfalls and five regular river gauging and several miscellaneous gauging stations. Water sampling points were selected to cover only surface water and samples were taken once a month during both high and low flows.

3.5 Soil Erosion Rates

Modelling was used to estimate soil erosion. The Modified Universal Soil Erosion Equation (MUSLE), in the IAHS (2000), was used as follows.

$$E = ARKLSCP \qquad 3.5$$

Where:

A = the area in acres

E = Annual Soil loss in tonnes per km² /year

R =Rainfall Erosivity index (MJ mm/ha/hr) (rainfall energy /erosion force), it depends on geographical location; the value (480) rainfall erosivity index was taken from Moore (1978).

K = Soil erodability index 0.15 was picked from Moore (1978) for the soils of the catchment

LS = Slope length and slope angle index [dimensionless] which reflects the effect of slope length and steepness on soil erosion in the catchment was taken to be 0.25.

C = Crop/cover management practice index [dimensionless} (April value of = 28) was picked for the catchment and was found to vary from season to season due to varying maturity levels of crops or vegetation.

P = Conservation/ supporting practice index [dimensionless] was taken to be 0.12 for the catchment.

3.6: Drainage characteristics of the catchment

To give a picture of the hydrological characteristics of the Itare sub-catchment, the following parameters were analysed, Drainage density, stream density, bifurcation ratio and all other attributes of the catchment were determined from actual counting of all streams, measuring their lengths, drainage area from topographic sheets of the catchment as follows:

Drainage density $= Dd) = Ls / A$

Where:

Dd = drainage density

Ls = total length of stream segments (channels) in km

A = basin area in km^2

Stream density $= Ns / A$

Where:

Ns = total number of stream channels

A = basin area km^2

Basin form = *basin area / (basin length)*^{2}

Basin shape = *(basin length)*^{2} */ basin area*

Stream orders were determined using Strauhlers (1952)'s method and bifurcation ratios were estimated for each sub catchment as follows:

$$Rbn = nu / n+1$$

Where:

nu = Number of first order streams,

Nu +1 = is next order number of streams,

$$WRB = Rbn1 + Rbn2 + Rbn3 / N.$$

Where:

WRB = weighted or mean bifurcation ratio,

Rbn 1 to 3 = bifurcation of three catchments,

N = total number of catchments.

All these parameters affect hydrological characteristics of the catchment in one way or the other and therefore they are important in understanding the hydrological behaviour of the catchment.

3.7 Meteorological Data

Various climatic parameters were determined by different methods for example:

(i) The primary data on rainfall were collected from records of seventeen manual rain gauges installed all over the catchment and one full meteorological station with long term data as indicated in figure1.3 on page 9, and Plates (3.3a &3.3b.) below.

Plate 3 .3 a: Note newly installed rainfall station at Githima Primary school (upstream) with Professor Hoshino inspecting the station.

Plate 3.3b: Note the researcher collecting rainfall data from a rain gauge at Sitotwet Secondary School (midstream of the catchment).

(ii) Using a graduated measuring cylinder in mm, the volume of rain water was taken every morning of a rainy day and recorded in a booking sheet. Rainfall data were also obtained from one automatic rainfall recorder. These data were important in that, rainfall is directly related to ground water recharge, stage and discharge variation.

3.8: Evaporation

Evaporation in the study area was estimated from one screened class (A) evaporation pan installed within the catchment before the study commenced. From daily observations evaporation was determined using the formula:

$$E = R + (0.5 * c)\, mm \qquad 3.6$$

Where:

E = *Evaporation in mm*

R = *rainfall in mm*

C = *numbers of standard cups added (+) or taken out (-) from the pan.*

3. 9: Hydrograph Separation

Hydrograph separation into total flow, base flow, and direct flow were done using a semi automatic separation technique in the computer programme (HYDATA) which is a hydrological database and analysis system. designed to handle the types of data most often encountered in hydrological studies. Total flow (TF), direct flow (DF), base flow, (BF) and the base flow index (BFI) were calculated for each hydrological year.

The base flow index was calculated by dividing the volume of water under the base flow hydrograph (Qb) by the volume of water under the total flow hydrograph over the same period (Qt), thus:

$$BFI = Qb / Qt \qquad 3.7$$

Where:

BFI = *base flow index*

Qb = *the volume of water under base flow hydrograph*

Qt = *the volume of water under the total flow hydrograph*

Years with high base flows have high values of BFI than those with low base flows.

The base flow index ranges between zero (0) meaning no base flow, to one (1) meaning all base flow. This index was important because it helped in assessing the groundwater within the catchment and in understanding the water balance of the catchment.

Direct flow (surface runoff) was calculated from total flow and actual recharge as:

$$DF = Total\ flow - Base\ flow \qquad 3.8$$

Where:

DF = *direct flow,*

Base flow *is the actual recharge.*

Therefore total flow which consists of base flow (subsurface flow) and direct flow was calculated as:

$$TF = BF + DF \qquad 3.9$$

Where:

TF = *total flow,*

BF = *base flow, and*

DF = *direct flow.*

3. 10: Storm Flow /Runoff Coefficient (Kmax)

This was calculated using the following equation:

$$R = kP. \qquad 3.10$$

Where:

R = *Direct runoff (DF), in mm,*

k = *the runoff / storm flow coefficient,*

P = *Precipitation (rainfall) in mm.*

This coefficient depends on the physiographic characteristics of the catchment in the following relationship:

$$k\ max = a\ function(f) = S * Dd * Gc * Ds * URB * IMP * AGR..$$

Where:

S = *Basin area (km²),*

Dd = *Drainage density (km /km²),*

Gc = *Basin form,*

Ds = *Specific slope,*

IMP = *% impermeable substratum (pavements, tarmac roads etc),*

URB = *% of urban area,*

AGR = *% of agricultural land.*

It should be noted that the first four are natural variables, while the last three are forms of land use, which have varied with time in the catchment.

The variation of this coefficient throughout the period reveals the changes in the basin response to individual rainfall events through surface flow. The coefficient shows the degree of saturation of the basin; its values are high when the basin is saturated, while the total flow/storm flow is low.

3.11 Surface Runoff

It was estimated empirically using the Horton (1945) overland flow model, which has also been used successfully by Kirkby (1952) and it depends on climate, geology, Physiographic, soil characteristics, vegetation and land use. Dunne (1979) has also applied it in his Machakos study. For this study surface runoff was estimated using the following formula:

$$LO = 1/2Dd$$

where:

LO = *average length of overhead flow,*

Dd = drainage density.

3.12: Geological Data

Geological data, such as rock-types, aquifer characteristics, discharge rate (water yields), porosity, and permeability and water rest levels were obtained from secondary data from the records of the Ministry of Water Resources. Water rest levels were sometimes determined directly from boreholes and shallow wells using dippers.

3.13 Demographic Data

Demographic data such total populations and population densities were obtained from secondary data from population statistics offices within the catchment and interview with local administrations mainly Chiefs and assistant Chiefs, who gave formation on population trends over time and density in the Itare sub-catchment. The chiefs were interviewed because they know the history of the area especially settlement patterns, they keep population statistics for their sub-locations and therefore they were the right people to be interviewed.

3.14: Land use /Land Cover Analysis

Land use data were extracted from secondary data, field observations and interviews with the District forester, the Agriculture Officer, the District Environment Officer, the area residents, the District Development Officer and the District water Officer within the catchments.

To determine the patterns of land use change in the catchment over the last fifty years, land satellite imageries for 1986 and 2000 for the Mau forest catchment were as follows: False colour composite (bands, 2 –green, 3- red and 4 – infra-red) land satellite images of the study area were processed for the years 1986 and 2000 and mosaiced. The study area was then clipped from the mosaic giving the images of the study area figure (4.1a & 4.1b). The forested areas of the study area were extracted from1986 and 2000 forest maps by subtracting the 2000 forest image from the 1986 forest image and the difference gave the changes in forest cover for the period.

3.15: Data Analysis

Both statistical and non statistical techniques were used to assess the temporal variability of land use and stream flow, the methods were:

3.15.1 Qualitative Analysis

This involved the use of maps to show the various aspects of the catchment such as its location, drainage characteristics, geology, use of tables to summarize data in various aspects of the study. Graphs were also used to present base flow, rainfall, total flow, direct flow (surface runoff) low against water turbidity , turbidity against time and rainfall against time. Descriptive Analysis involved the use of percentages, pie-charts and proportions for comparison purposes. It was used to draw comparative conclusions from data, especially between rainfall and total runoff, base flow, and direct flow, land use changes over time, changes of total runoff, base flow and direct flow over time.

3.15.2 Quantitative analysis

Quantitative analysis methods used in the study were mainly statistical moments or descriptors especially the mean and median, regression analysis, s, hypothesis testing, trend analysis, Mann Whitney U- test and the split sample test were used to identify a shift in the mean stream flow time series. This was so because hydrological data are known to be skewed and non-normal, hence direct use of parametric tests such as t-test needed normalization of the data first, but the non–parametric tests are better in this type of data. Some of the statistical methods used in the analysis are as follows:

3.16 Hypothesis Testing

Hypothesis testing was carried out as a means to draw conclusions based on the data analysis. Three null and alternative hypotheses were formulated in relation to the various objectives for testing. The significance level was specified α, the risk of rejecting a true HO. The statistics were computed and the calculated values were compared with the critical values from appropriate statistical tables.

3.17: Trend Analysis in Stream Flow Time Series

A simple linear trend model for annual river flows was used to identify whether the time series had a declining, an increasing or no trend at all *(Maidment, 1998)*, as a result of changes in land uses. This was represented as follows:

$$yi = yo + \beta ui + \epsilon_i \qquad 3.11$$

Where:

yi = annual flow,

$i = 1 ------ n$,

n = number of years of record,

yo = the y- intercept,

u = the year,

β = is the parameter representing the slope of the trend model,

ϵi = independent variables with mean zero (error term).

The hypothesis which was to be tested was $\beta = 0$, meaning no linear trend.

The first step was to estimate β and its variance s_β^2 as follows:

$$\beta = \Sigma(yi - \bar{y})(ui - \bar{u}) / \Sigma(ui - \bar{u})^2 \qquad 3.12$$

$$s^2 = \epsilon i^2 / (n-2) / \Sigma(ui - \bar{u})^2 \qquad 3.13$$

s_β - is the standard deviation

Where:

$\bar{y}$, $\bar{u}$, are the mean values of yi =1953-1978 and ui =1979-2004 series respectively,

ϵi^2 is the sum of squared errors, which is equal to ,

$$\epsilon i^2 = \Sigma(yi - \bar{y})^2 - \beta^2 \Sigma(ui - \bar{u})^2 \qquad 3.14$$

The t –statistics is calculated as:

$$t = \beta / s_\beta \qquad 3.15$$

this was tested by using the **t** –test distribution table.

The null hypothesis would be rejected at a given significance level α if the calculated t was greater than the critical value of t-from the t- distribution tables with $n-2$ degrees of freedom.

When ordinary trend analysis of data did not show any trend, and the researcher felt that practically there ought to be some trend related to changes in land use, the moving average smoothing (M.A) was used. This was meant to remove seasonality from the data and make it stationary. The general formula for differencing is given as

$yt - yt - 1$,

Where:

yt Had a trend and $yt-1$ had a trend but, their difference has no trend.

3.18: Split Sample Test for a mean shift in segments of annual river flows

Since the data used in the study ranged from 1950s to date and to be able to evaluate the effect of land use changes from 1953-2004. the annual flows time series was divided into two segments with anticipated different means (statistically different from each other) which was to be attributed to variations in land uses. This was done using the automatic time series segmentation method. The time series for two regular gauging stations was divided into two segments. 1953 to1978. and 1979 to 2004. This was done with an assumption that much of the catchment degradation has been experienced between 1979 to date when land use patterns have changed tremendously.

The classical t-statistic for a shift in the mean between two segments y_1 and y_2 of n records of annual discharges was given by the following formula;

$$t = \underline{\bar{y}_1 - \bar{y}_2} \sqrt{\quad N1 + N2 / N1N2} \qquad 3.16$$

where:

$N1$ and $N2$ are the lengths of years in each segment,

$N1 + N2$ -2 is degrees of freedom,

$\underline{\bar{y}}$ is the mean observation.

At a given significance level α, the null hypothesis that the shift in the mean annual flow is insignificant, can be rejected if the sample t statistic calculated is greater than the critical value of t –from the distribution table with n – 2 degrees of freedom. This enabled the researcher to be able to statistically point out whether the change in land use has changed the stream flows negatively or positively.

For comparison purpose, since t test statistic is a parametric, a nonparametric test Mann Whitney –U test was used to test for a shift in the mean annual flows in the flow time series. This is the most powerful distribution free tests with about 95% efficiency.

The data for the two segments of 1JC 13 regular gauging station time series Y_1 =1958 -1978 and Y_2 =1979 -2004 were ranked but their identity retained.

U is the statistic required and is obtained by inspecting Y_2 in turn and counting the number of Y_1 which precedes it. Using the U-value from the data, and sample sizes n_1 and n_2. the associated probabilities are obtained from the Mann Whitney table, and at rejection level α = 0.05, and if the probability obtained is less than the significant level, we can reject Ho and accept H_1

In the case of time series of 1JC13, U value was found to be = 20 and n_1 was =20 (1958 - 1978) and n_2 (1979-1995) was = 16 and using two tailed test at α = 0.05 then critical U from the table was found to be $U_{critical}$ = 98. It is true that U critical (98) is greater than U calculated (20) hence U is significant and therefore we accept the HO: hypothesis that there is no significant shift in mean annual river flows in the catchment during the period of 1958-1995.

3.19 Regression Analysis

Linear regression analysis was applied for purposes of establishing the relationships between flow variability, rainfall and land uses. In general simple linear regression equation is as:

$$Y = a + bx + \epsilon i. \qquad 3.17$$

where:

Y = *the dependent variable,*

X = *the independent variable,*

ϵi *is the error term.*

a And b are constants derived from the data, a is the intercept value of Y when $X=0$

b Is the gradient of the line of best fit and they are computed as follows:

$$b = (n\sum XY - \sum X \sum Y / n \sum X^2 - (\sum X^2)) \quad 3.18$$

$$a = (\sum Y - b\sum X / n) \quad 3.19$$

n, is sample size (length of record)

This method was used to develop rating curves for the gauging stations 1JA02 and 1JC13 in the catchment.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

In this chapter a discussion on the results and key findings of the study are presented, and an attempt is made to integrate stream flow, rainfall, turbidity, sediment transport and land use variations. The causes of land use change, their extent and effects are examined in relation to the objectives of the study.

4.1 Land use changes

Land use changes has been taking place for many years; however, the pace of change has been increasing rapidly especially after independence. Initially the activities of man and the natural environment were in some kind of balance fluctuating slightly but stable. Man has affected this balance by clearing forests, grazing, cultivation and all these are due to the rapid population increase which increased demand for various services.

Table 4. 13: Land Use Changes from 1950 to 2004

Land use	1950	1980	2004
Agricultural & rural settlement	10 %	40 %	53 %
Urban settlement	5 %	15 %	20 %
Industry	1 %	3 %	5 %
Social amenities	7 %	15 %	20 %
Forest cover	77 %	27 %	2 %

Source: Researcher, 2004

From table 4.1, the increase in agricultural and rural settlement from 10% of the total area of the catchment in 1950 to 40% in 1980 and 53% in 2004 can be noted. Much of this settlement has occurred in forested areas as evidenced by the decrease in forest cover from 77% of the total area of the catchment in 1950 to 27% in 1980 and a mere 2% in 2004. There is a general increase in urban settlement as more people have moved to work and do business in towns and small market centres such as Kericho and Litein Municipal Councils, which are hosting district headquarters with all government and non governmental departmental heads, and several medium and small centres such as Kuresoi, Chepsir, Koiwa in the upstream area.

The history of land use changes in the Itare catchment can be generalized into three periods according to the results of an interview with the local residents, the period before 1960, the catchment was much more covered by natural forest, few settlements and artificial forests started to appear and soil and water conservation methods were practiced, during the period 1960-70, the catchment experienced increased settlements, reduced natural forest cover, increased tea and other agricultural cropland and other land uses. At the same time soil and water conservation cultivation methods were abandoned in favour of conventional cultivation methods especially on slopes. In the period 1970–90 natural forests reduced drastically, there was increased settlement, urbanization, industrial development and the development of infrastructure, increased commercial forests and increased land under agriculture especially tea plantations and small scale farms.

The main changes in land use in the catchment are:

i. Increase in the area of land used for agricultural purposes by clearing of forests and replacing it with various crops table 4.1.

ii Increase in the proportion of steep land and valley bottom land under crops increasing soil erosion and high flows in rivers figure 4.5a and b.

iii. Changes in crop patterns due to the emphasis on cash crops especially tea which is grown in large scale plantations and small scale farms. This has affected the processes of interception and infiltration table 4.3.

iv. Increased urbanization and industrialization which has affected runoff characteristics and therefore water yields table 4.1

v. Increased infra- structural facilities such as schools, Hospitals, Churches, and Road network all of which have negatively affected the processes of infiltration and percolation. This has affected the ground water table and therefore groundwater discharge especially during dry season. This explains the observed reduction of dry spell flows and increased surface runoff and high flows table 4.1.

vi. Reduced swampy areas as a result of draining to reclaim land for agriculture especially for horticultural farming.

vii. Change in crop production methods due to increased use of inputs such as improved crop varieties, chemical fertilisers, biocides and mechanisation.

viii. Increasing pressure on forests in terms of settlement, cultivation, charcoal burning, timber harvesting .

ix. Change from grazing of low grade cattle to high grade ones and zero grazing.

x. Change of land tenure from communal to individual ownership.

xi. Reduced forest cover and those in the shamba system of farming have changed from taking care of tree seedlings into destroying them deliberately.

xii. Reduced land holding size due to subdivision of former large farms which has led to fragmentation and intensive tillage and soil degradation.

xiii. Small holding settlement on former forest land/ water catchment areas.

xiv. Replacement of natural forest with exotic varieties such as Eucalyptus, Pine, and Cypress which utilize much more water.

All these changes have implications on water resources of the catchment and therefore proper water conservation strategies are of urgent need.

The results of temporal Land sat image analysis for the Mau forest in 1986 and 2000 indicate a big variation in land cover changes, (see figure 4.1a and 4.1b) showing the land cover map of the larger Mau forest catchments. The extent of the Mau forest cover in 1986 was 435,071.8 Ha or (4,350.718 km^2), and the extent of the Mau forest by the year 2000, was 352,603.5 Ha or (3,516.035km^2).The total area of deforested land was 58,906km^2 and the rate of deforestation was 8,890.6 Ha /year. The extent of changes at the year 2000 was as follows:

Forest cover = 292,192.4 Ha (2921.92 KM^2),

Deforested area = 142,879.4Ha (1,428.794 km^2),

Reforested area = 60,411.0 Ha (604.11km^2)

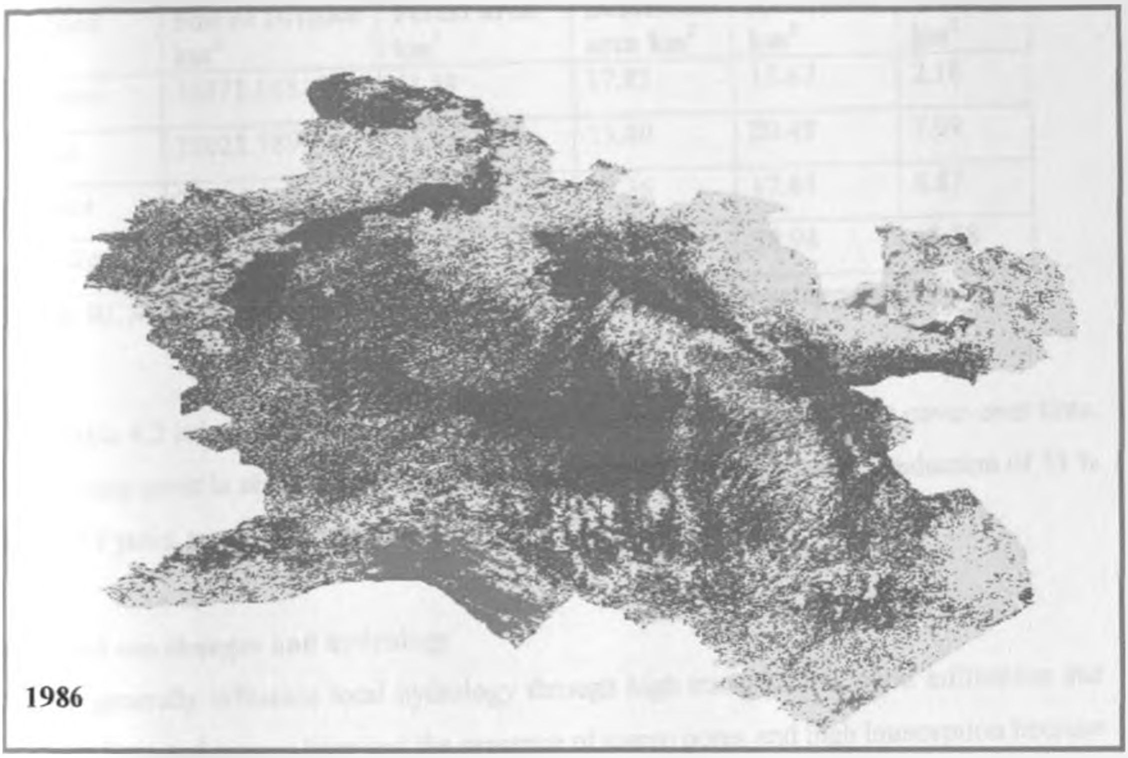
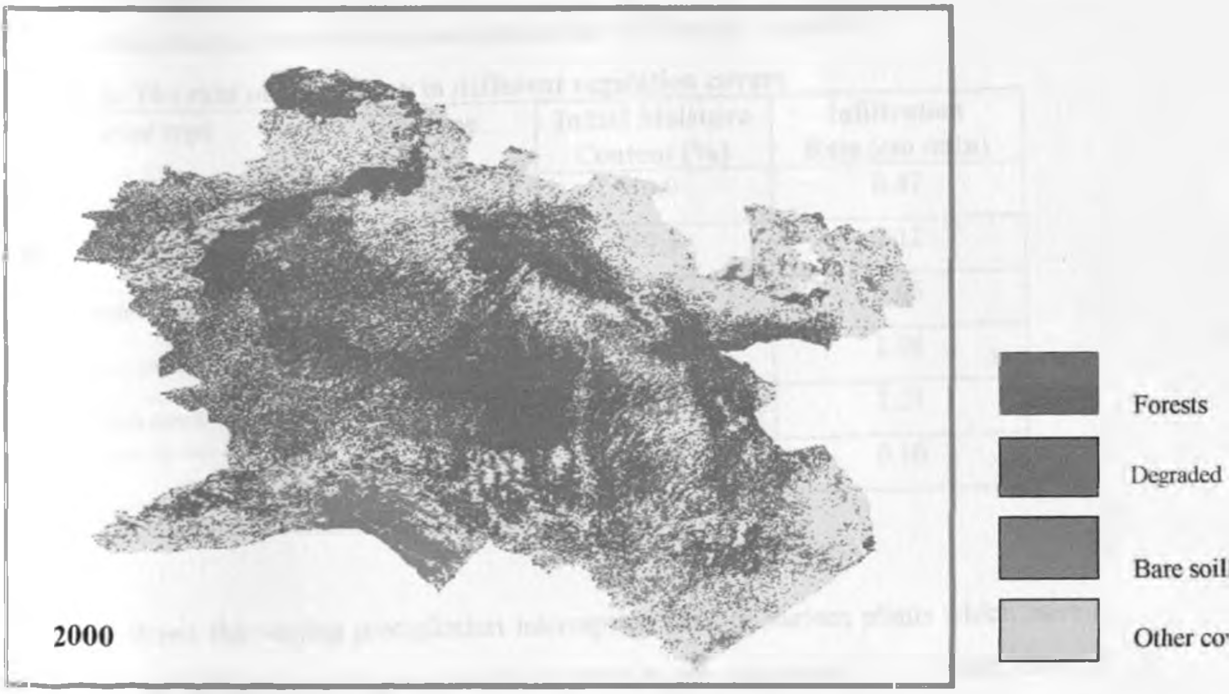


Figure: 4.1a and 4.1b: 1986



4.1b: 2000 imagery of the larger Mau catchment

Note from the key the increased portion of degraded forest in the 2000 imagery Compared to the 1986 one (reduced acreage under forest cover).

Table 4. 2: Forest cover changes between 1986 and 2000 in the study area

Division	Size of Division km^2	Forest area km^2	Deforested area km^2	Reforested km^2	Change km^2
Ainamoi	30371.668	41.19	17.83	15.67	2.16
Belgut	28621.789	35.93	13.40	20.49	7.09
Kuresoi	29094.034	74.38	29.36	17.85	8.87
Kimolot	3074.853	94.27	20.36	38.94	18.58

Source: RCMRD (Regional Centre for Mapping and Resource Development 2000).

From table 4.2 it is evident that there have been enormous changes in forest cover over time. The present cover is about 67 % from what it was in 1986. This indicates a reduction of 33 % within 14 years, translating to a reduction rate of 2.4% per annum.

4.2 Land use changes and hydrology

Forests generally influence local hydrology through high transpiration, good infiltration due to a rich litter and humus layer and the presence of macro pores and high interception because of their high canopy coverage.

The overall impact that various types of land use have on hydrology depends on the combined effect of differences in interception, transpiration and infiltration capacities.

Table 4. 3: The rate of infiltration in different vegetation covers

Cover type	Soil type	Initial Moisture Content (%)	Infiltration Rate (cm /min)
Bare cultivated area	Clay	50.9	0.47
Grass covered area	Clay	59.5	0.12
Natural forest cover	Clay	57.3	2.06
Young tea cover	Clay	56.7	1.06
Mulched tea cover	Clay	53.7	1.21
Roads	Murram		0.10

Source: Tea Research Foundation Kericho. 2005

Table 4.3 shows the varying precipitation interception rates of various plants which have a bearing in the infiltration and groundwater recharge in any catchment. It is noted that the results in table 4.4 are from other areas outside the study area but they are only for comparison purposes.

Table 4. 4: Interception by different plants

Tree sp.	% of rain water interception
Natural forest	10 – 30 %
Exotic acacia	30 -35 %
Eucalyptus	20 -25 %
Grasses	30 -60 %
Corn /maize	15 %
Soybeans	15 %

Source: Gregory and Walling 1973

Natural forests have been found to be less efficient evaporators than commercial forests. This is because of the layering which allows a better retention of moisture in the canopy. Interception loss by tea is lower than from indigenous forest cover because tea has an aerodynamically smoother canopy, Blackie (1979a).

Commercial forests such as eucalyptus with a root depth of about 8.0 m and other deep rooted trees can extract water from deep layers even when the top soil is dry. Therefore, the replacement of forests with crops such as tea whose root depth is 2.5 m has reduced water losses by evapotranspiration. Studies by Blackie (1979b) in the same area indicate that tea is a low water user compared to forests.

The total interception by individual plant is directly related to the amount of foliage and its character and orientation (leaf –area to ground –area ratios)

From the analysed data base flow seem to increase over time and this means increase in ground water recharge from about 59mm in1954 to 65mm in 1995 an increase of about 10%. This means increased total flow which has increased from 65mm in 1960 to 69mm in 1995 as indicated in the table 4.4. Natural forests have been replaced by exotic forests such as Pine (Pinus patiula), Cypress from Europe, Grevillea Robusta and Eucalyptus from Australia and agricultural crops. This obviously will affect the stream flow regimes see plates 4a -4d showing natural forest, artificial plantations of Eucalyptus, Pine and Cypress.

Plate 4a: Take note of encroachment of the forest by large scale tea plantations and note the natural forest in the foreground ground. The plate taken in April 2002 is from upstream parts of the study area, around Kapkorech area. (Photo: Researcher)

4b: See Eucalyptus plantation which has replaced natural forest (an exotic species which uses a lot of water). This can exploit ground water reserves at relatively greater depth. Plate taken in 2002, in the midstream parts of the catchment (photo: Researcher)

Plate 4c: See Cypress plantation which has replaced natural forest in the catchment. plate taken in 2002 in the midstream of the Itare catchment. (Photo: Researcher)

Plate 4 d: Degraded forest land upstream of Kimugu sub-catchment, note the drying natural forest due to human interference. (Photo: Researcher)

Plate 4 e: Tea plantation which has replaced natural forest but being a low water user, it enhances interception and infiltration which increases ground water recharge and total flow. (Photo: Researcher)

4.3: Hydrological Changes Over time

The result from data analysis indicates that, there is an enormous change in the hydrological regime of the Itare catchment and this is discussed as follows.

4.3.1 Stream Flow

Stream flow has been positively affected by the changes in land use systems for example results from trend analysis indicate that there is an increasing trend over time in total stream flow in the catchment. It has increased from 65mm 1960 to 69mm in 1994 at 1JC13 (Timbilil) gauging station, an increase of 6.2% (see figure 4.2a) and from 3.1m^3/sec 1960 to 5.0m^3/sec1994, an increase of about 61% for 1JA02 Kiptiget gauging station (see figure 4.2b).

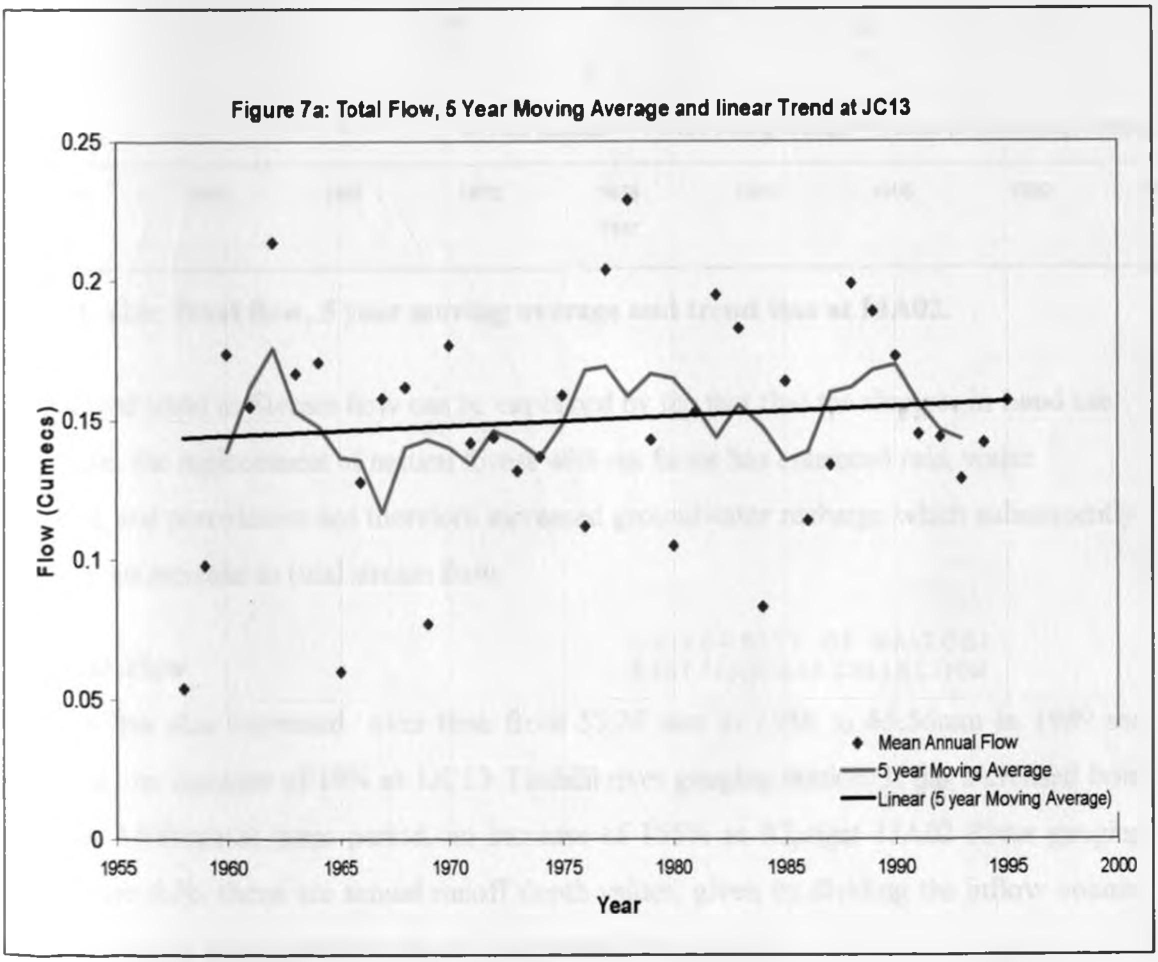


Figure (4.2a); Total Flow, 5Year Moving Averages and trend Lines at 1 JC 13.

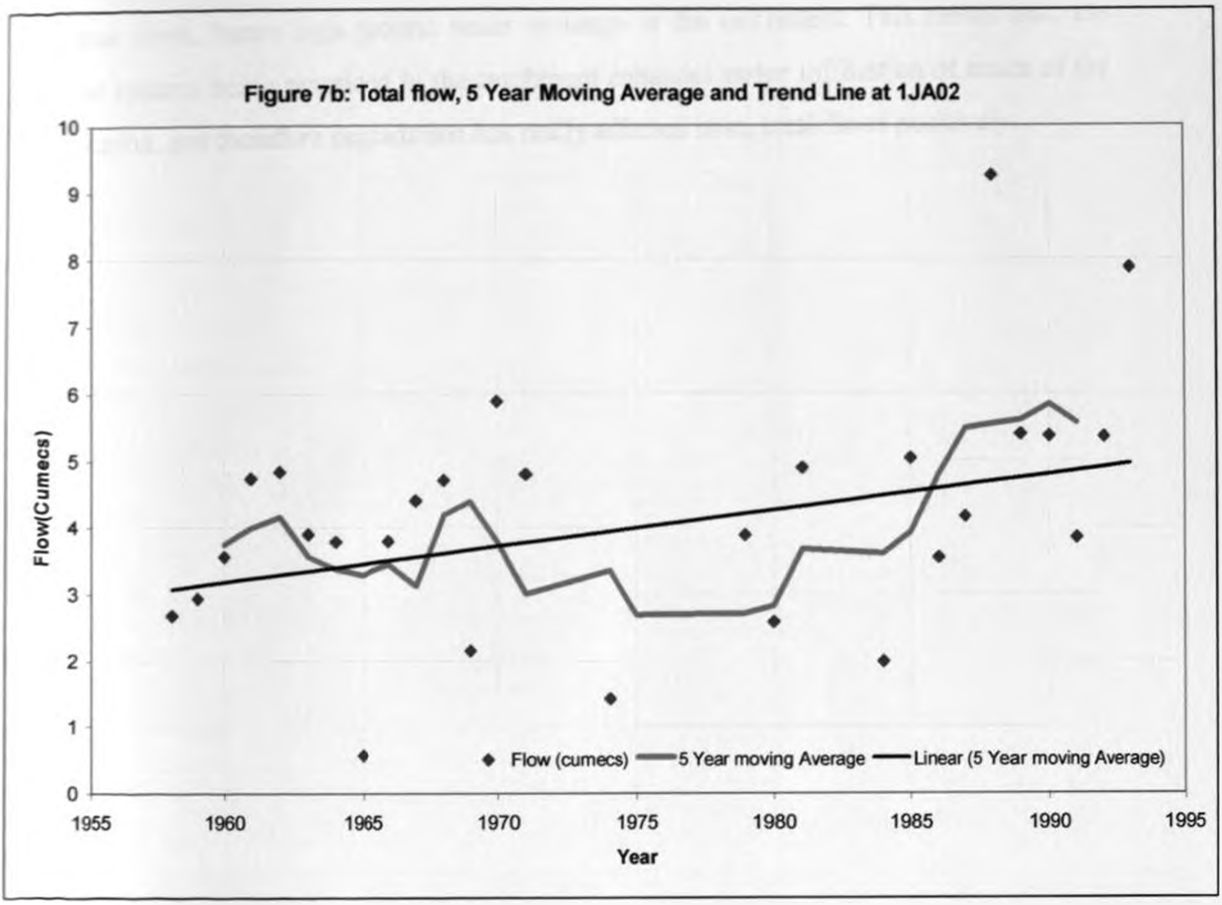


Figure (4. 2b): Total flow, 5 year moving average and trend line at 1JA02.

The observed trend in Stream flow can be explained by the fact that the changes in Land use for example, the replacement of natural forest with tea farms has enhanced rain, water infiltration, and percolation and therefore increased groundwater recharge which subsequently has lead to an increase in total stream flow.

4.3.2: Base Flow

Base flow has also increased over time from 55.20 mm in 1958 to 65.56mm in 1989 see figure 4.3a, an increase of 19% at 1JC13 Timbilil river gauging station. It has increased from 550mm to 1400mm at same period, an increase of 155% at Kiptiget 1JA02 River gauging station figure 4.3b, these are annual runoff depth values, given by dividing the inflow volume by the inflow area, and therefore they are not annual river flows.

The base flow index (BFI) which is ratio of base flow to total flow range between 0.86 and 0.95 at the catchment are represented by Timbilil 1JC13 gauging station, and 0.55 and 1.00 in the catchment represented by Kiptiget 1JAO2 gauging station. These high BFI values indicate high base flows, hence high ground water recharge in the catchment. This means that, the land use systems being practiced in the catchment enhances water infiltration of much of the precipitation, and therefore degradation has really affected base, total flows positively.

Table 4.5: Total. Base. and Direct flows at 1JC13 Timbilil gauging station

	Total flow mm	Direct flow mm	Base flow	Base flow index BFI
1959	42.988	4.502	38.486	0.8953
1960	3.852	8.697	65.155	0.8822
1961	70.03	8.665	61.365	0.8763
1962	96.368	4.817	91.551	0.95
1963	75.516	10.907	64.609	0.8556
1964	75.702	5.689	70.013	0.9249
1965	27.125	4.953	22.172	0.8174
1966	57.678	6.384	51.294	0.8893
1967	71.281	3.77	67.511	0.9471
1968	73.125	5.208	67.917	0.9288
1969	34.437	3.367	31.07	0.9022
1970	72.074	7.891	64.183	0.8905
1971	64.138	3.249	60.889	0.9493
1972	64.911	6.033	58.878	0.907
1973	59.19	8.111	51.079	0.863
1974	53.895	5.465	48.43	0.8986
1975	64.754	4.703	60.051	0.9274
1976	50.729	4.141	46.588	0.9184
1977	91.885	5.738	86.147	0.9376
1978	102.872	7.303	95.569	0.929
1979	64.583	6.378	58.205	0.9013
1980	46.087	6.788	39.299	0.8527
1981	69.187	8.266	60.921	0.8805
1982	88.09	6.563	81.527	0.9255
1983	88.11	5.293	76.817	0.9355
1984	37.595	3.455	34.14	0.9081
1985	73.965	4.687	69.278	0.9366
1986	51.157	4.482	46.675	0.9124
1987	60.666	8.282	52.384	0.8635
1988	89.954	4.483	85.471	0.9502
1989	85.057	5.457	79.6	0.9358
1990	78.001	5.511	72.49	0.9294
1991	65.186	4.306	60.88	0.9339
1992	65.006	4.417	60.589	0.9321
1993	58.004	3.745	54.259	0.9354
1994	64.222	8.671	55.551	0.865
1995	61.813	3.7	58.113	0.9401

Source: Researcher 2005

From the third objective of the study, and from table 4.5, the land use changes in the Itare catchment have positively affected base flows.

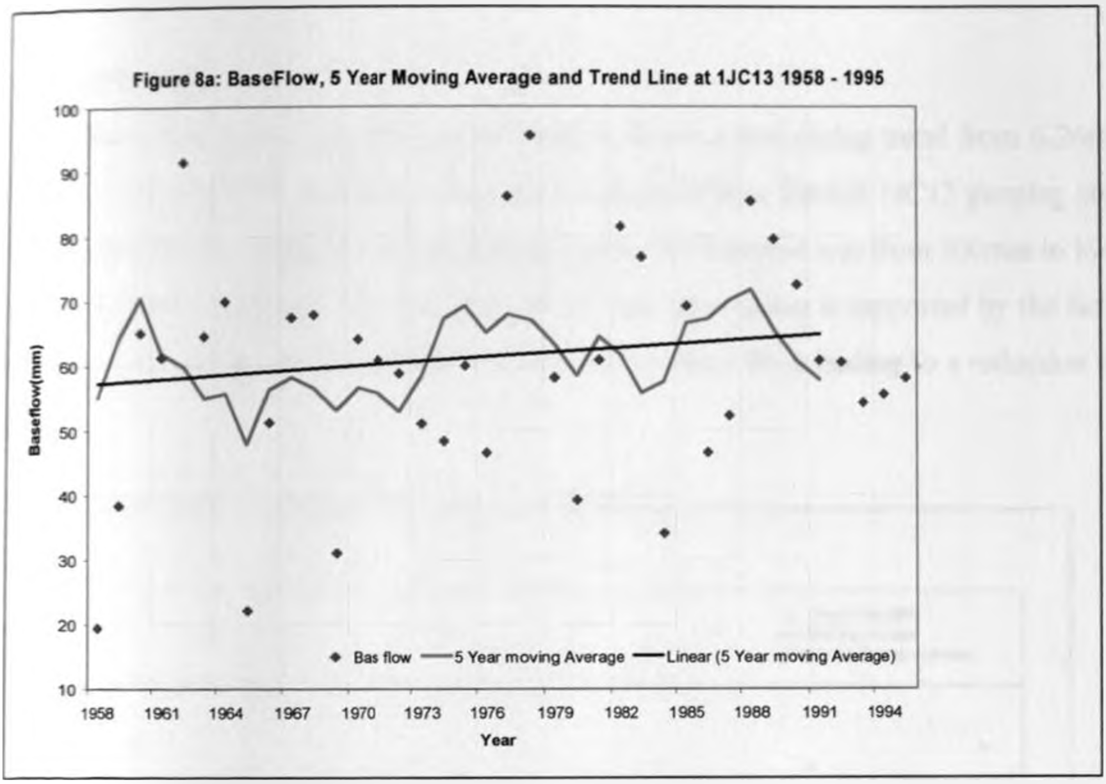


Figure (4.3a): Base flow, 5 year moving average and trend line at 1JC 13.

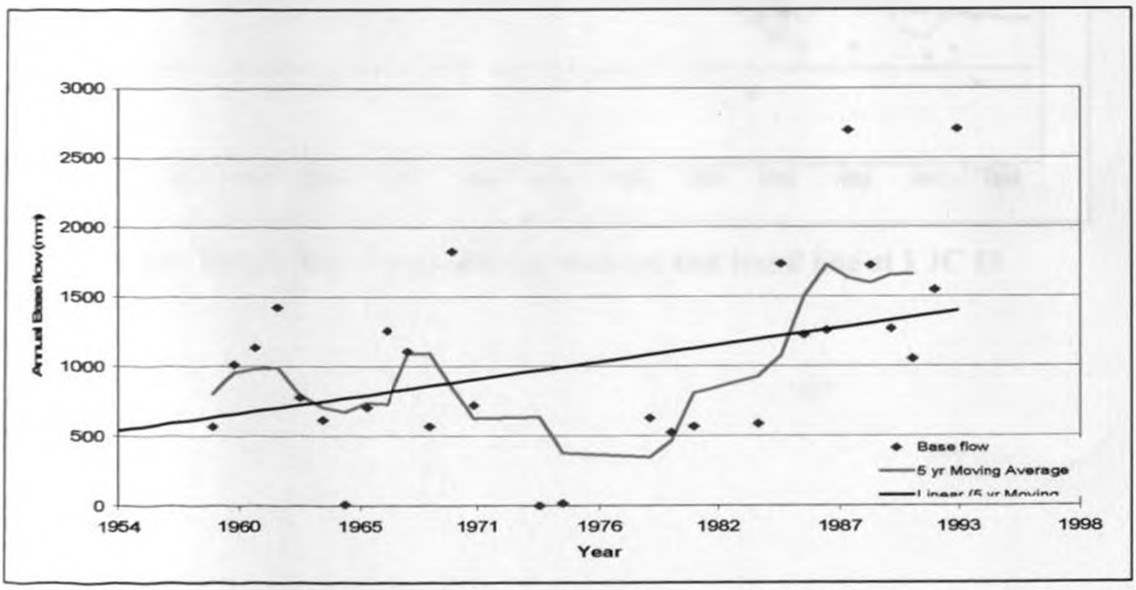


Figure (4.3b): Base Flow, 5Year Moving Averages and trend Lines at 1JA02

4.3.3: Direct Flow

When direct flow data is plotted against time, it shows a decreasing trend from 6.26mm in 1960 to 4.5mm in 1994, which is a decrease of about 28% at Timbili 1JC13 gauging station. see figures 4.4a. For Kiptiget 1JA02 gauging station the decrease was from 300mm in 1960 to 250mm in 1994, which is 17%. See figure 4.4b. This observation is supported by the fact that base flows are increasing hence little water is left for direct flow leading to a reduction in the latter.

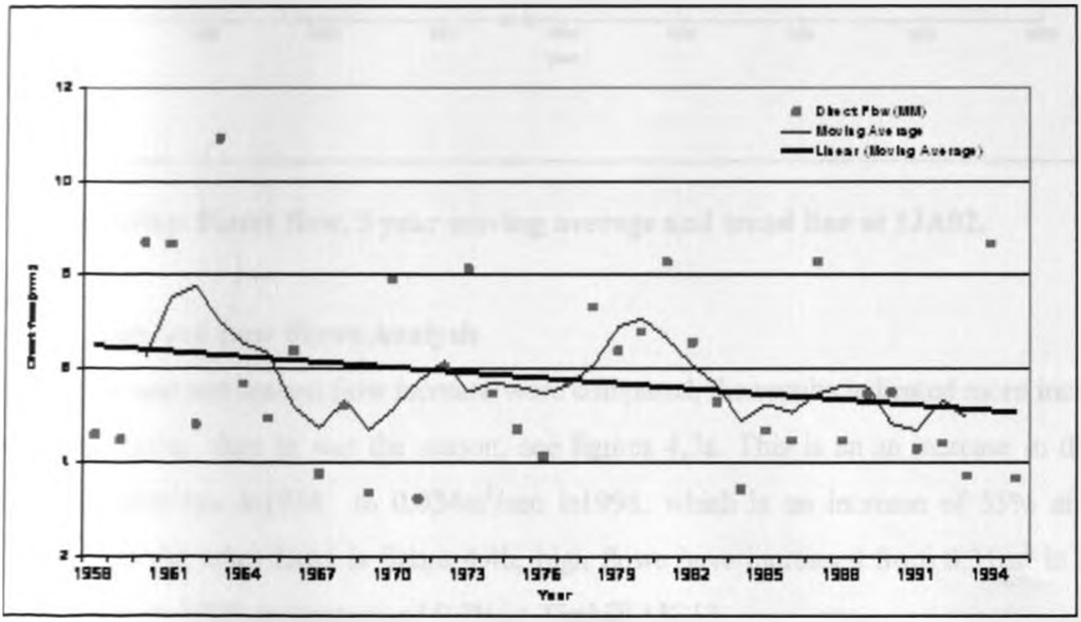


Figure (4.4a): Direct flow, 5 year moving average and trend line at 1 JC 13

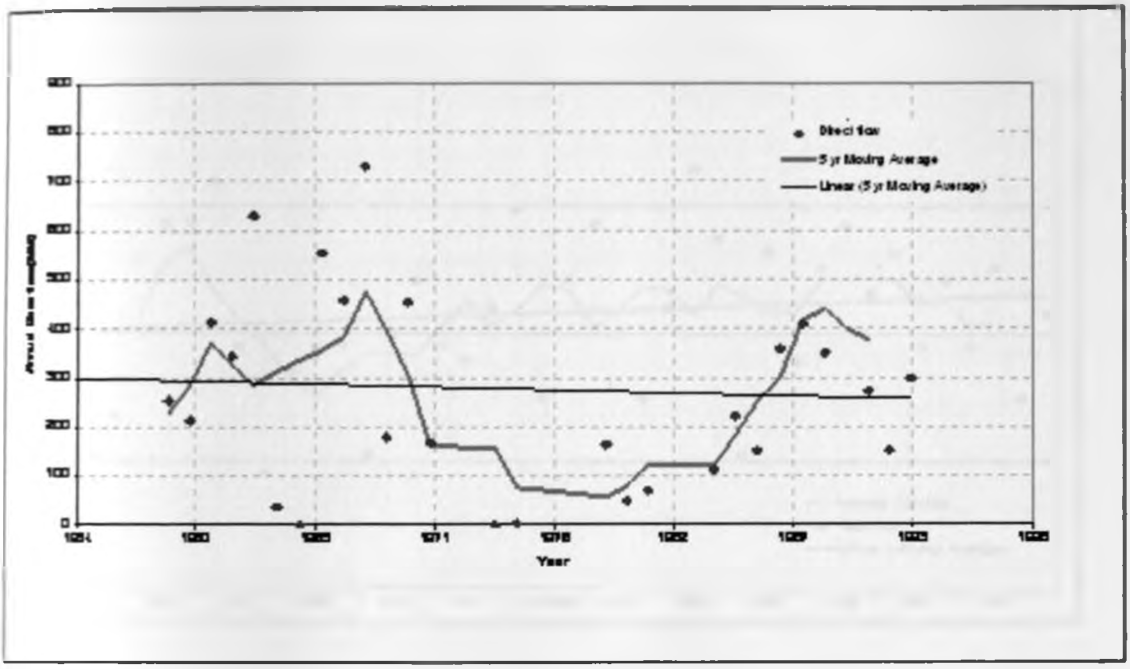


Figure (4.4b): Direct flow, 5 year moving average and trend line at 1JA02.

4.3.4: High and Low Flows Analysis

When dry and wet season flow increase were compared, the results indicated more increase in the dry season than in wet the season. see figures 4.3a. This is an an increase in discharge from 0.028m^3/sec in1958 to 0.034m^3/sec in1998, which is an increase of 55% at Timbili 1JC13. On the other hand in figure 4.4b, high flows have increased from 0.31m^3 in 1958 to 0.34m^3/sec in 1996, an increase of 9.7% at Timbilil 1JC13.

Testing for in the trend was done at $\alpha = 0.05$ and degrees of freedom 20 -2, the $t_{critical} = 2.5$ and calculated $t_{calculated} = 8$. This results indicates that $t_{critical} = 2.5$ is less than the calculated $t_{calculated} = 8$, hence at significant level $\alpha = 0.05$ there is a significant trend.

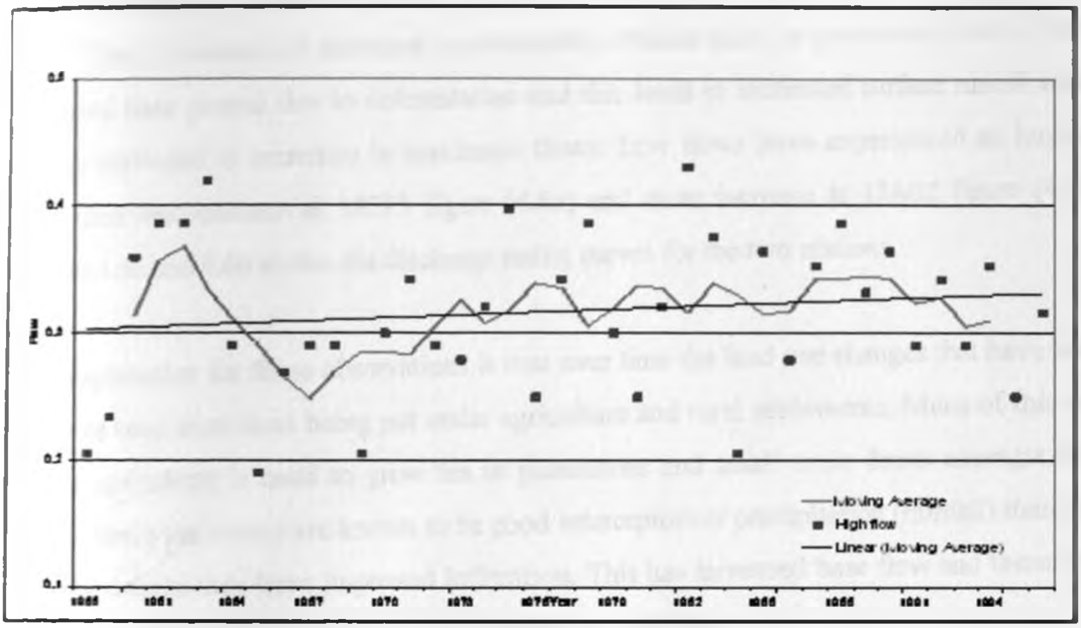


Figure 4.5 a. High flow, 5 year moving averages and trend line at 1JC13.

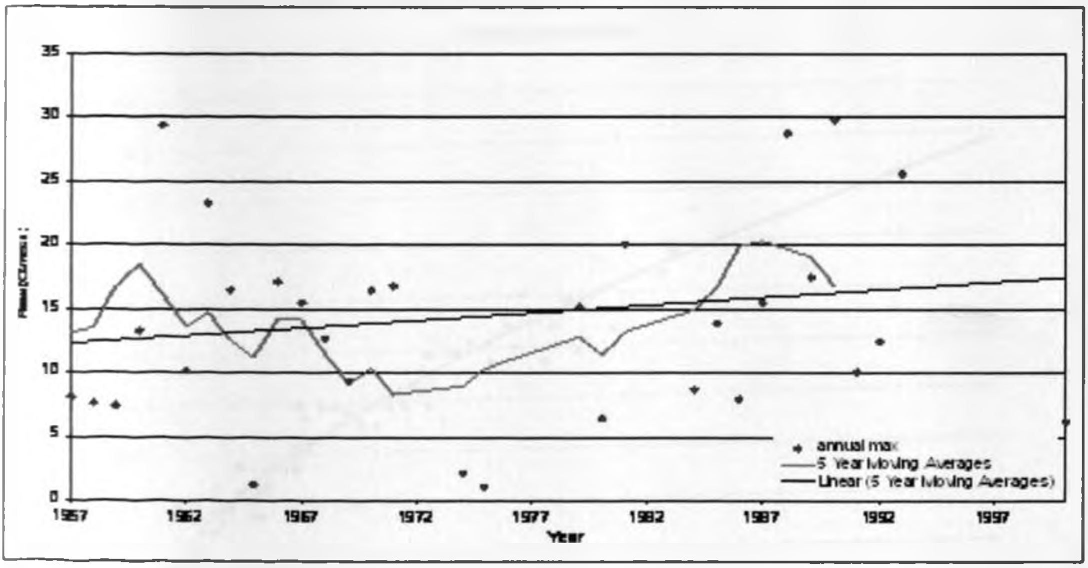


Figure 4.5b: High flow, 5 year moving average and trend line at 1JA02.

Close evaluation of maximum flows indicates an increase from $0.21m^3$ in 1954 to $0.30m^3$ in 1995. This is because of increased impermeable surfaces such as pavements, roofs, roads, increased bare ground due to deforestation and this leads to increased surface runoff which can be attributed to increases in maximum flows. Low flows have experienced an increase over time less increase at 1JC13 figure (4.6a) and more increase at 1JA02 figure (4.6b), figures 4.6a and 4.6b shows the discharge rating curves for the two stations.

The explanation for these observations is that over time the land use changes that have taken place as seen more land being put under agriculture and rural settlements. Much of this land under agriculture is used to grow tea in plantations and small scale farms amongst other crops. Since tea bushes are known to be good interceptors of precipitation (rainfall) than even natural forests, they have improved infiltration. This has increased base flow and therefore a decrease in direct flow and subsequent increase in total flow.

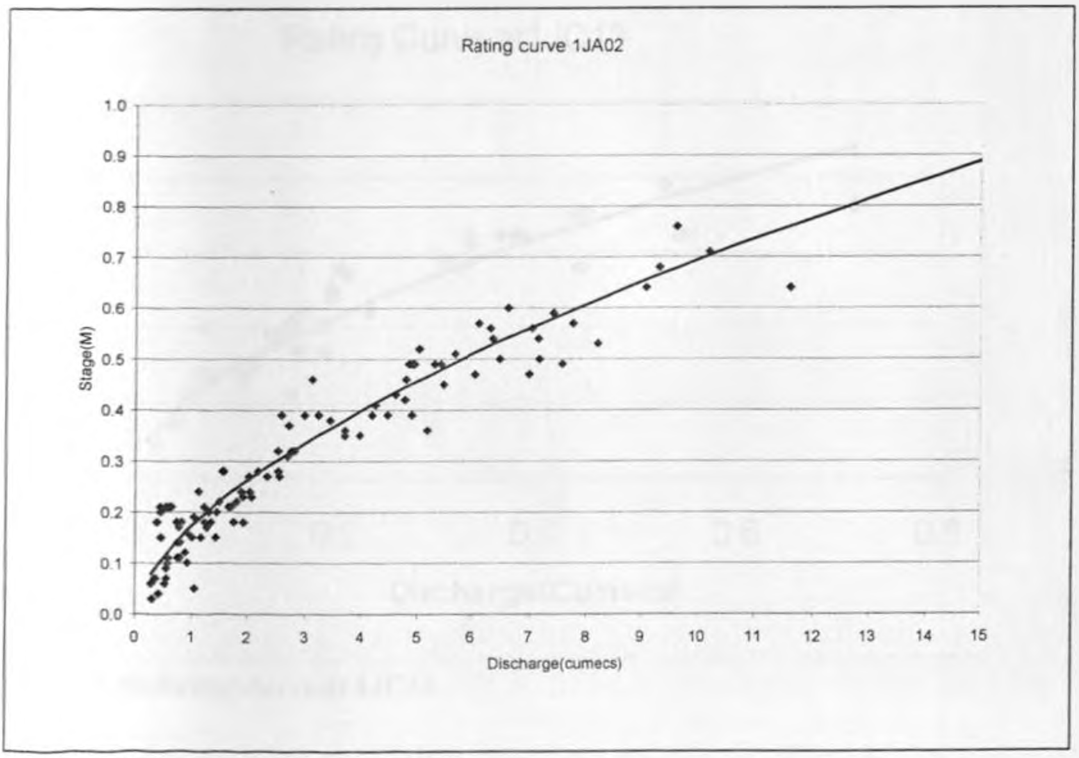


Fig. 4.6a Rating Curve of IJA02

In the sixth objective of the study, the results were as follows: the anthropogenic forces that have caused land use changes/catchment degradation are: population change, technological change, economic growth, political and economic structure, attitudes and values. The dominant driving force for land use change is basically the growth of consumer demand for agricultural and forestry products, space for industry, urban and other social facilities. Demand is closely linked to population size and level of income, hence demand for food, fibre, wood fuel, timber, space for settlement and other uses. Therefore, the major causes of land use changes degradation in the Itare catchment were found to be, unsound forestry practices such as the shamba system (non resident cultivation) (N.R.C.), where local farmers are given portions of the cleared parts of the forest to cultivate and grow various crops with an undertaking that they will take care of the tree seedlings during the initial stages of tree establishment (Plates 5a and 5b.)

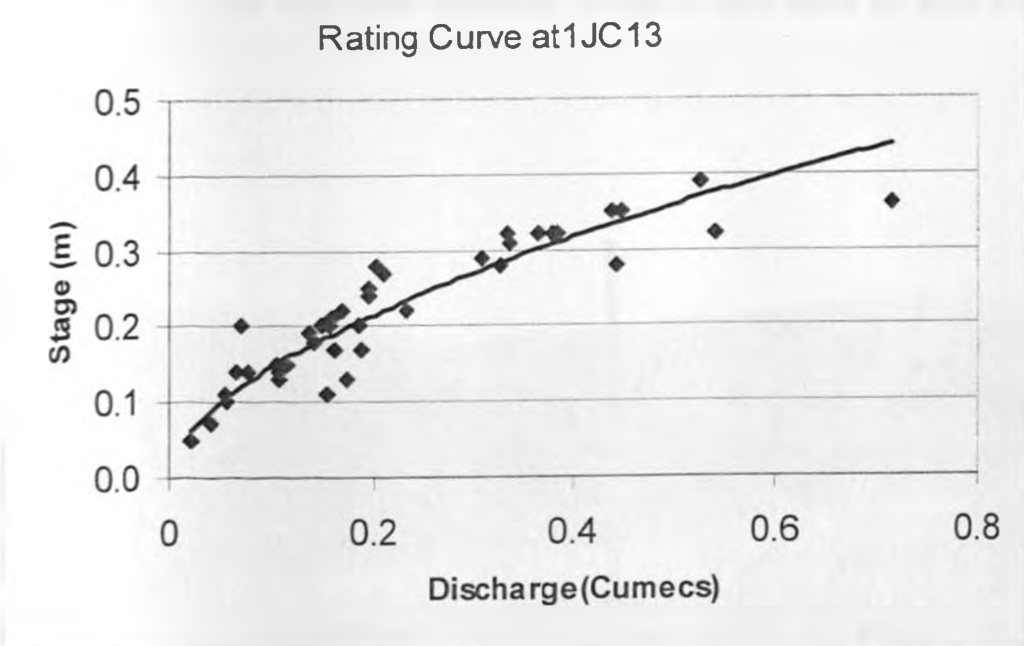


Figure 4.6b Rating curve at 1JC13

Plate 4f: The Shamba system where maize has been intercropped with cypress trees. some of which have been excessively pruned to give room for farm crops. (photo: Researcher)

Plate 4g: The densely settled area which was formerly part of the natural forest (photo: Researcher)

The non resident cultivation (NRC) has its roots in the colonial period when the British government undertook the first massive deforestation in Kenya as it cleared forested land and bush for commercial agriculture and for the establishment of plantations of exotic trees especially, cypress from Europe, and eucalyptus and grevillea robusta from Australia. To achieve this at no cost at all, the colonial authorities invited the local communities, especially the landless and the poor living near forests to provide unskilled labour for planting and nurturing the seedling. In exchange to the labour, they were permitted to access forestry products and to inter plant the exotic tree seedlings with crops such as potatoes, beans, maize, peas, and vegetables, hence the introduction of the shamba system.

Once the tree shade became intolerable, they were moved to new cleared sites to establish new shambas. The crops provided food for the households and were sold to generate income. This system worked well initially but latter the system become corrupted and exploitative leading to environmental degradation. The foresters became poachers, landlords of forest land and illegal loggers. The farmers on the other hand never wanted to take care of the tree seedlings any more but encroached the forest even more to increase land acreage under their control and planting of trees ceased and others settled in the forests leading to degradation of the forest/catchment.

The other causes of catchment destruction as revealed from the field survey are, illegal excision of gazetted forests, illegal logging of timber, fuel wood, bark, poles, and allocation of forest land to other purposes other than forest.
According to the third objective of the study, when rainfall was plotted against time rainfall indicated a decrease from about 2150 mm in 1958 to abut 2050 mm in the year 2001, a decrease of 4.7 % in 44 years which translates to 0.11 mm reduction/ year (see figure (4.7a).

This observation indicates that there were climatic changes over time where rainfall decreased, and this helps the researcher to argue with confidence that the hydrological changes observed (increases in total flow, base flow, high flows, low flows,) are not due to climatic change. This is so because rainfall is decreasing and we could have expected a decrease in the flows, but the flows are increasing hence the increase is due to changes in land us in the catchment (Figure 4.7b). The variation of base flow and rainfall over time and the negative relationship is very clear, when base flow is increasing; on the other hand rainfall is decreasing.

To point out further the effect of land use changes on the hydrology of the catchment, rainfall was plotted together with mean monthly stream flow figure (4.4c) for 1958,and figure (4.4d). the year 2004, from these the figures it is evident that the amount of rainfall is lowest in January–February and increases to a maximum in April–May, and starts to decrease in June–July before it increases slightly in August–September–October and then it decreases in November-December–January.

Monthly stream flow on the other hand seems to follow the same trend but at different magnitudes depending on the season, it increased very much between April–September 1958. High flow was 0.161m^3/sec in September 1958, 0.283m^3/sec in September 1992, a big increase, despite the decrease in the amount of rainfall from 288.09mm in April 1958 to about, 260mm April 1992.

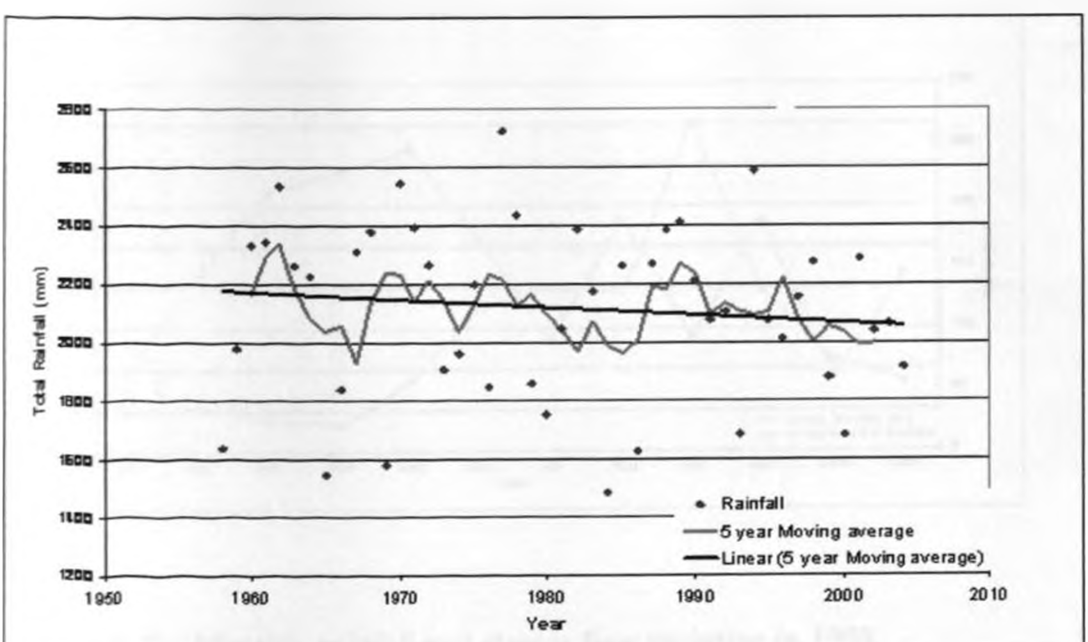


Figure: 4. 7a: Rainfall Variation over Time at Tea Research

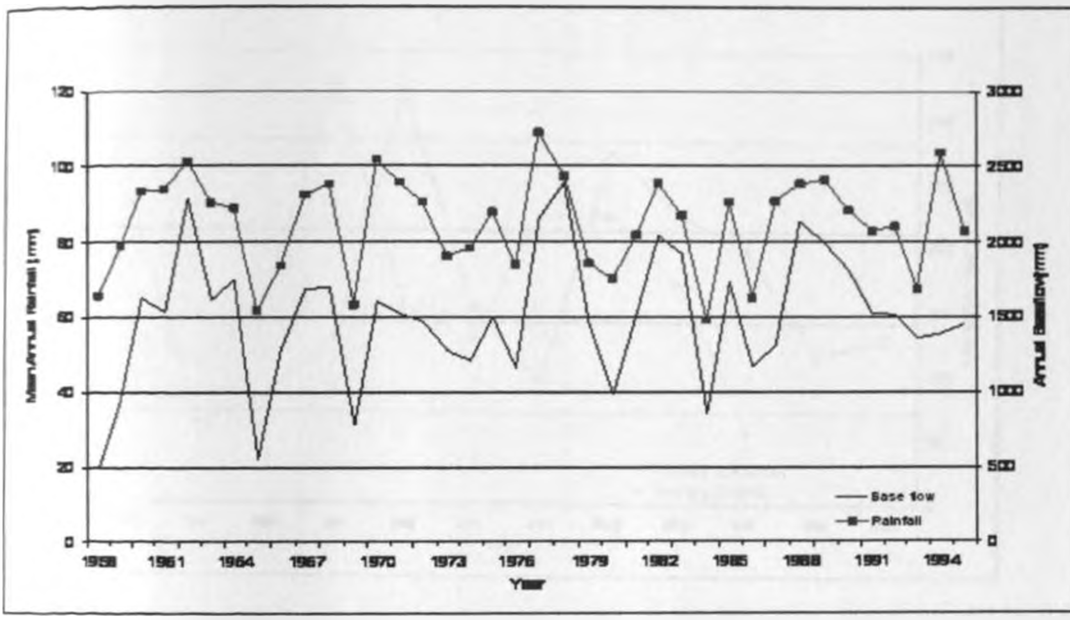


Figure 4.7b: Base flow and Rainfall variation over time

There is a relationship between base flow and rainfall as evidenced from figure 4.7b, where base flow varies with rainfall proportionately.

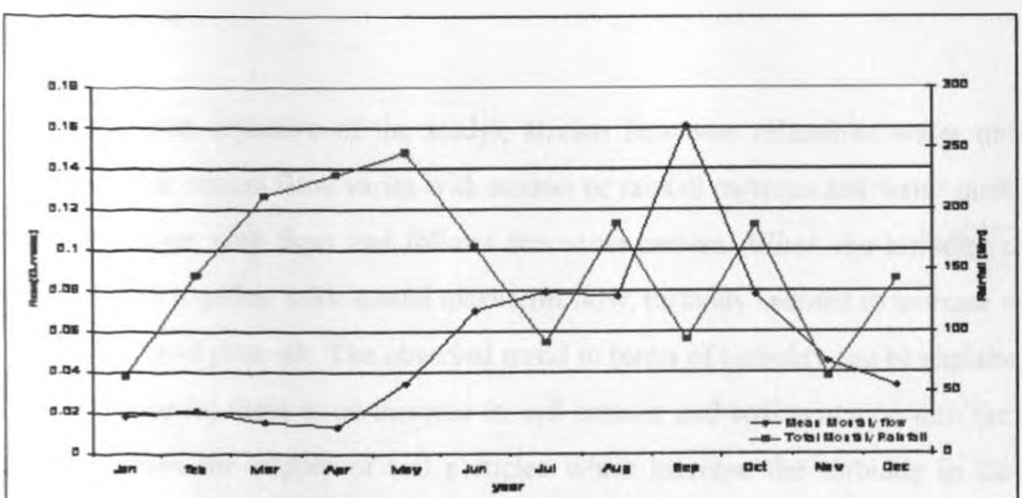


Figure: 4. 7c: Monthly rainfall and stream flow variation in 1958

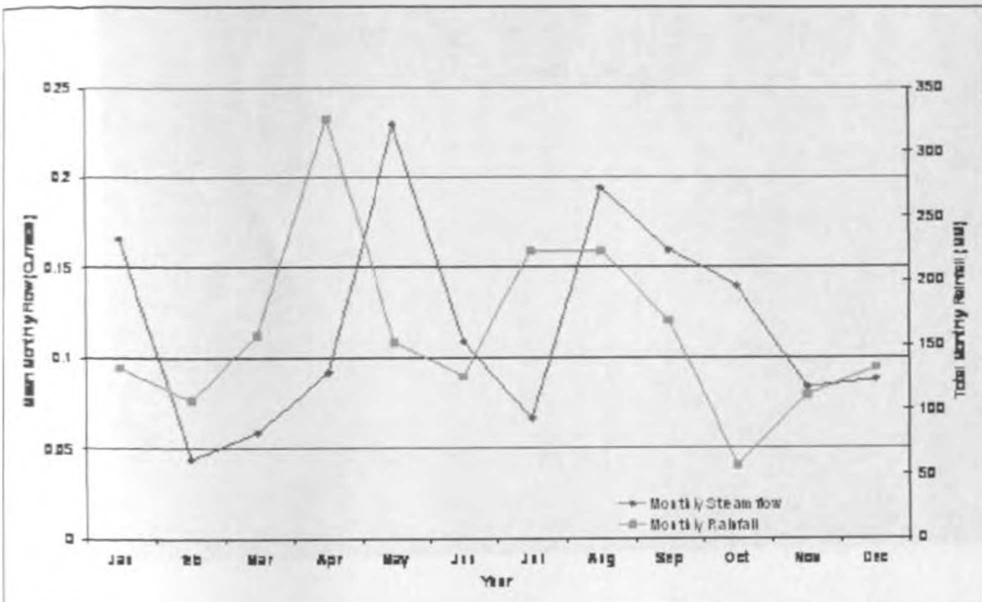


Figure 4.7d Monthly Rainfall and Stream flow variation in 2004

Figures 4.7c and 4.7d indicates the temporal variation of the relationship between monthly rainfall and stream flow, in 1958 when landuse was minimal and the year 2004 after enormous changes in land use in the Itare catchment. Note particularly the peaks in April–May in 2004 unlike in 1958.

For the fourth objective of the study), stream flow was related to water turbidity. It was observed that stream flow varies with season or rainfall patterns and water quality in terms of turbidity varies with flow and follows the same pattern. When the turbidity concentrations were plotted together with annual maximum flow, turbidity seemed to increase with flow. See figure (4.8) and plate 4h. The observed trend in terms of turbidity can be explained that during the rainy season, there is an increase in soil erosion and sedimentation into the river system. This increases the supply of soil particles which increase the turbidity in the water to 34 N.T.U in April, while it is less during the dry season January-February. Sediment concentrations also seem to increase with flow table (4.4).

Plate 4 (h): Notice highly turbid water (due to high sediment concentration) at 1JD4 Ainabkoi River and washing of vehicles which is a source of water pollution(photo: Researcher)

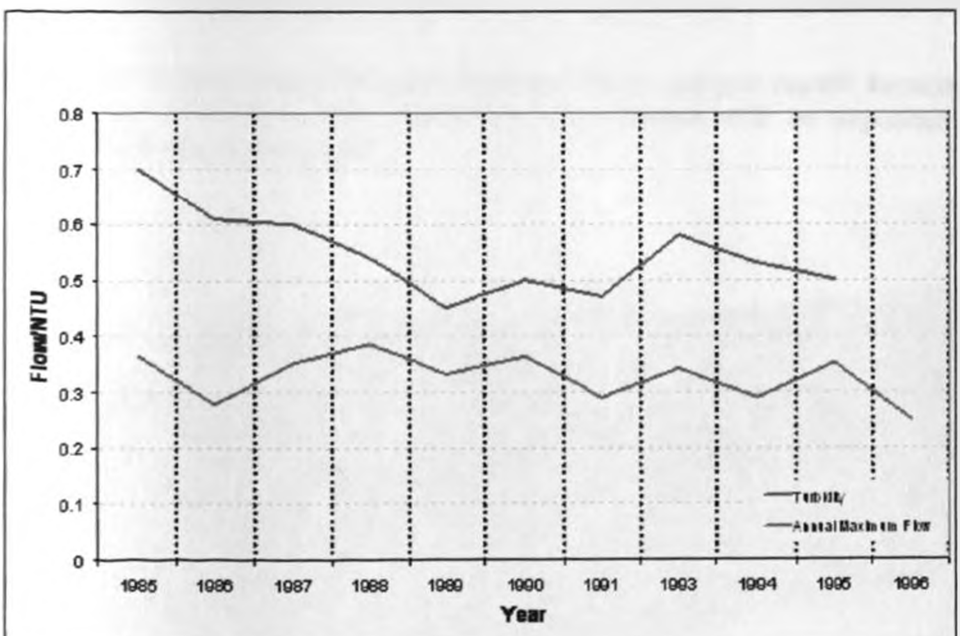


Figure: 4.8 High flow and turbidity at 1JC13 Timbilil.

4.4: Soil Erosion Rates and Sedimentation

Sheet and rill soil erosion methods are the most dominant in the study area with little evidence of gully erosion, especially from farmlands and road sides as shown in(plate 4 (i)a and b

Plate 4i : Note erosion from road sides and farms. surface runoff forming small gullies along the road sides, and much of this sediment will be deposited in the river systems(photo: Researcher)

Plate 4ib: An eroded road at Githima – Kio area. a source of sediment into the river systems at the uppermost part of the catchment(photo: Researcher)

The amount of soil erosion in the study area was found to be equal to 42,638.4tonnes/km^2/year. This has a direct influence on the rate of sedimentation and turbidity in the rivers of the catchment.

4.4.1 Suspended Sediment and Turbidity Discharge

Sediment discharge and turbidity variation in the catchment were mainly monitored from the R.G.S. 1JD3 which was the station at the outlet of the catchment, just before the waters of the Chemosit river and Ainabkoi river join the Kipsonoi river to form the Sondu–Miriu river and other gauging stations on the Kimugu and Kiptiget rivers. Concentrations of suspended sediment varied from season to season and it varied with discharge see table 4.5. The highest sediment discharge was recorded August 2001,when it was 65.1 tonnes/day, and the least was recorded in 4.2 tonnes/day in January 2003 at 1JD3.The relationship between river discharge(Q) and total suspended concentrations (TSSC) was found to be and positive and significant with a coefficient of determine (r^2) = 0.71.

This means that river discharge accounts for about 71% of the variations in suspended sediment concentrations in the catchment. The other factors could be land uses. it should be noted that land use in the catchment changes with season, meaning that at different times of the year, there are different land uses which exposes different percentages of land to erosion and sedimentation, hence a variation in TSSC with season. Generally there an increasing trend in terms of suspended sediment.

Some land uses increases direct flows especially during the rain season which subsequently increase discharge in rivers and therefore increased sediment concentrations. This is due to the fact that, high river flows have high velocities and therefore causing increase in the transport capability of water to carry more sediment.

The TSSC changes in the Itare catchments can be predicted using the following:-

Regression equation: $Y = 110.805 + 45.25X$. (Y is the total suspended solids, X is the river discharge).

Table 4.6: Sediment and Turbidity Discharge

Station No.	Name	Date	Gauge height (m)	Discharge (m3 /sec.)	Mean sedim. Conc.	Sediment discharge/day (ton/day)	Turbidity conc. (N.T.U).
1JD03	Yurith	31/8/2001	1.37	33.583	29.3	65.1	150
1JD03	Yurith	23 /3/2002	0.84	5.093	46.2	16.3	125
1JD03	Yurith	23/7/2003	1.8	56.990	36.3	17.10	165
1JD03	Yurith	30/11/2003	1.04	24.220	2.0	4.2	110
1JD03	Yurith	4/6/2004	1.2	34..859	2.3	4.7	148
1JA02	Kiptiget	2/2/2003	3.15	13.25	13.3	1.6	65
1JA02	Kiptiget	6/9/2004	3.39	5.477	1.0	0.5	34
1JC19	Kimugu	9/9/2004	0.66	13.99	13.0	2.0	50

Source: Field data

Sediment is known to affect water turbidity, when turbidity was statistically related to sediment yield. it was found that the two had a weak positive relationship with $r^2 = 0.004$. and a predictive equation of $Y = 74 + 0.61X$ .When turbidity was statistically related to river discharge it was found that the two have a strong positive relationship with the coefficient of determination $r^2 = 0.66$. meaning that river discharge explains 66% of the variations in turbidity in the catchment while34% can be explained by other variables. The predictive equation of the relationship between the variables is $Y = 61.768 + 30.78X$.

When the research hypotheses were tested. the results were as follows:
Testing for in the trend in the first research hypothesis at $\alpha = 0.05$ and degrees of freedom 20 -2, the $t_{critical} = 2.5$ and calculated $t_{calculated} = 8$. This results indicates that $t_{critical} = 2.5$ is less than the calculated $t_{calculated} = 8$, hence at significant level $\alpha = 0.05$ there is a significant trend. Therefore the null hypothesis that there is no trend in the mean stream flow over time due to land use changes in the Itare catchment is rejected and instead the alternative hypothesis that there was trend in the mean stream flow in the catchment is adopted.

In the second HO, (null) Hypothesis, and from the observations and land sat imagery analysis there is evidence of land use changes over time figure(4.1a and b), and there is evidence of positive changes in stream flow, but there is negative changes in terms of mean annual rainfall (reducing over time) as shown in fig. (4.7a). This means that we can authoritatively argue that, there is a positive relationship between land use changes and stream flow, this is because the positive change (increase) in stream flow cannot be due changes in rainfall which is decreasing, otherwise stream flow could be reducing as well. Hence the HO: hypothesis that there is no significant relationship between changes in land use and stream flow is rejected in favour of the alternative hypothesis that: that there is a significant relationship between land use changes and river flow variation in the Itare catchment.

The third null hypothesis, the researcher had an assumption that much of the changes in land use have taken place between 1970 onwards. To prove this, the stream flow time series was spilt into two time series, 1958-1978, and 1979-1995. This was to check whether there has been significant shift in the mean flows during the two periods. Using a non parametric test Mann-Whitiney U- test, at $\alpha = 0.05$, and $n_1 = 20$, $n_2 = 16$, U-calculated = 20.0 and U-critical = 98. When these two values of U are compared, U–cal < U – critical (U calculated is less than U critical) meaning that U is significant, and therefore the HO: hypothesis that there is no shift in the mean flows in the catchment is accepted, despite the evidence of changes in land use over time. This means that the alternative hypothesis that there is a significant shift in the mean flows is rejected. There is no significant change in flow patterns in the study area between the two periods. The mean of 0.145 in the 1958-78 period is slightly low compared to 0.151 of the between 1979 -2004, the observed difference of 0.6 could be explained by the changes in land use which were more pronounced in the latter period.

CHAPTER FIVE

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

5.1 Summery

There have been enormous land use changes in the Itare sub-catchment as it is in the larger Mau catchment. This has changed the ecological balance which has affected the hydrological system in the catchment. According to the results of an interview with the area residents, the Itare catchment was covered fully by natural forest before 1960. Between1960-1970 settlements started and between1970-2004 the forest cover was drastically reduced due to increased settlements, urbanization, and increased land under tea and road networks. According to research results, the forest cover is reducing at a rate of about 2.4% per annum this is a quite a high rate which is bound to raise concerns amongst the various environmental and water experts.

Much of the natural forest in the Itare catchment has been replaced by exotic/artificial forests, such as Eucalyptus, Cypress and Pine plantations and small scale holdings. Natural forests are known to be less efficient evaporators compared to exotic species; therefore the changes could increase water losses through evaporation. Most of the former forest land has been put under tea and tea is known to be low water users than natural forests. This means that the tea bushes which have replaced natural forests saves soil water resulting to an increase in ground water recharge and stream flow despite the reduction of natural forest. This explains the observed increases in base flow, total flow, high base flow index and reduced direct flow.

The total interception of an individual plant is known to depend on leaf area to ground area ratios and, in this case tea has bigger ratios than natural forest. Therefore tea intercepts more water but uses less causing an increase in base flow and total flow in the catchment. Base flow has increased from 59mm in 1960 to 69mm in 1995, 10% increase, while total flow has increased from 65mm in 1960 to 69mm in 1995 during the same period of time. This means that the land use changes that have taken place in the Itare catchment have actually increased stream flow rather than reducing it. At RGS 1JC 13 Timbilil on the Timbilil river stream flow has increased by 6.2%, while at RGS 1JA02 on the Kiptiget River which covers a larger area than Timbilil, stream flow has increased by 61%. This enormous increase in the Kiptiget sub-catchment is due to the fact that much of it has been put under tea and the explanation already given above applies.

The base flow index (BFI) for 1JC13 Timbili ranges between 0.85-0.95 while that of Kiptiget 1JA02 ranges from 0.55-1.0. These high values of base flow index imply high base flow and therefore high ground water recharge in the catchment. Direct flow on the other hand, has decreased from 6.26mm in 1960 for 1JC 13 to 4.5mm in 1995, a decrease of 28% and from 300mm in 1960 to 250mm in 1995, an increase of 17% for 1JA02. The dry season flows (low flows) have increased more than high flows over time and this can be attributed to improved interception and infiltration, increased percolation due to the replacement of natural forest and finally high ground water recharge. This is because low flows depend on ground water discharge into the river systems.

The small increase in high flows can be said to be due to the increased impervious surfaces and increased bare ground due to deforestation and therefore increased surface runoff into rivers. The dominant driving force for land use changes is basically population increase which has increased consumer demand for agricultural and forest products together with services. The major causes of forest reduction in the Itare catchment are: the non resident cultivation (NRC) also known as shamba system, settlements, forest encroachment in various ways.

Rainfall has shown a decreasing trend over time, from 2150mm in 1958 to 2050mm in 2001 which represents 4.7% and this translates to about 0.11mm/year. This is evidence of change in climate which in normal circumstances should reduce flows. This therefore means that the increase in stream flows in the Itare catchment is due to the changes in land use and not due to climatic change.

The most common types of soil erosion in the Itare catchment are rill and sheet with little evidence of gully erosion, and it was estimated to be 42,638 tonnes/km^2/year as per the year 2004 and this is bound to increase in future. This means that there is a lot of sediment is entering the rivers of the catchment. This was supported by suspended load data from RGS 1JD3 Yurith, that had the highest value of 4.7 tonnes /day, at 1JA02 Kiptiget 1.6 tonnes/day and at Kimugu 1JC19 2.0tonnes/day during the same period. Sediment concentrations have a bearing on the water quality of the catchment especially turbidity, which was found to be 148 N.T.U at 1JD3, the downstream station and the out let of the catchment. A strong positive relationship exists between the river discharges and the amount of suspended load in the catchment, and the river discharge explains the variation of suspended sediment in the Itare catchment.

Some of the gaps identified after the literature review were that: Most of the previous researchers concentrated on the estimation of annual mean runoff (MAR) at the expense of the actual seasonal and annual flow variation. Studies on land use changes by Blackie (1979 a&b) in the study area only related the land use changes to the water balance equation but not to the water quality aspects. Most researchers have concentrated on such areas as infiltration capacity, surface runoff, soil erosion and sedimentation aspects, most studies have generally been on land use changes and how they affect sediment yield but not stream flow variation and water quality.

5.2 Conclusions

The overall conclusion drawn from the study results is that the land use changes that have taken place in the Itare catchment have increased total stream flow and base flow, but have reduced direct flow. The dynamics of land use changes in the catchment are complex and have evolved over time, since the colonial periods and the independent Kenya. Land use changes have been mainly attributed to demand for various services and products, which are in turn dependent on population pressure.

The Itare catchment has experienced enormous land use changes in the recent years, where there have been increased settlements, which, apart from settling in the forest have developed schools, hospitals, churches urban centres, roads, all of which have changed the hydrology of the catchment. These changes however, have had positive effects on stream flow characteristics of the catchment.

There is no statistically significant shift in mean annual river flows in the catchment over the years and there is evidence of a positive trend in stream flow variation. There is a statistically significant relationship between land use changes and river stream flow variation.

Clearing of natural forest and replacing it with exotic forests and annual crops has led to increased base flow and total flow, but has negatively affected the direct flow. Increased sedimentation due to sheet and rill erosion is one of the major effects of land use changes and this could affect the quality of water. The increasing trend shown by the suspended load concentrations over time means that the water quality parameters especially turbidity has been increasing over time and therefore continued deterioration of the quality of water. The increasing trend of suspended load means that siltation of water works and dams, especially the Sondu-Miriu hydro–power, which is situated downstream of the Itare catchment is going to be a problem in future. Forest cover/catchment is reducing at a rate of 2.4% per year although much of this land is being put under tea.

Changes in land use have increased stream flow. However, this should be checked because it could be a short term change which latter can to be negative and we may have a reduction of stream flow .The increasing of base flow and total flow despite the reduction in natural forest is due to the fact that tea which has increased in acreage is a low water user and naturally it is known to increases infiltration and therefore increased groundwater recharge. Increase in base flow by 10% means an increase of 0.24% per year.

The base flow index differences between Timbilil and Kiptiget are due to the fact that Kiptiget sub - catchment is larger in area than the Timbilil, and high base flow index means high ground water recharge. The decrease of direct flow by 28% for Timbilil 1JC 13 and 17% for Kiptiget 1 JA02, respectively means that the land use changes that have taken place have increased rainfall interception, infiltration and ground water recharge more in the Timbilil than in the Kiptiget sub catchments. This can be attributed to the fact that there are more tea plantations within the Timbilil sub-catchment than in the Kiptiget. This explains the increase in low flows more than high flows.

There is evidence of climatic change in the catchment over time and this is shown by the decrease by 0.11% per year in the amount of precipitation. However, this change has not affected stream flows negatively as stream flow has been increasing over time.

5.3 Recommendations

In this section recommendations based on the research findings are given and are divided into two: i.e. to Future researchers and water policy makers

5 3.1 Recommendations for further Research

Based on the research findings of the study, the following recommendations are made to future researchers:

That the resource potential for the Itare has attracted many development actors without regard to environmental implications is indeed critical, there is a need for an integrated water development plan.

- Kenya, being an agricultural country meaning that land use changes are inevitable, there is urgent need for further focused research on the various hydrological aspects, especially within the five major water catchment areas namely: The Mau forest complex, Cherangani Hills, Aberdare ranges, Mount Kenya, and Mount Elgon.
- The effect of wetland draining on both surface and ground water resources, as it was discovered that most wetlands in the Itare catchment have been drained.
- Ground water quality changes in the realization of the dangers from several pit latrines scattered all over the catchments due to increased settlement in the catchment.
- The Itare catchment drains into the Sondu Miriu River along which the Sondu- Miriu hydro- electric power station is situated. Therefore, monitoring of soil erosion and sedimentation rates should be investigated for purposes of maintaining water quality and protecting the dam from siltation as a result of large quantities of soil loss in the Itare catchment

- The effect of decreasing trend exhibited by precipitation (rainfall) on water resources in the catchment should be investigated and accounted for and appropriate interventions put in place.

- The high water demand by exotic forests such as Eucalyptus, Cypress and Pine varieties should be investigated against their economic productivity, so as to accurately assess their effect on water resources of the catchment. In the Itare catchment, indigenous forests have been replaced with exotic trees.
- The government through universities and other research institutions should increase research funding for both small and large scale research, especially in water resources, and there is need for improved co-ordination of water resources research and communication among scientists and agencies to minimize duplications and enhance the sharing of experiences.
- Research should be directed towards deeper understanding of the physical, chemical, and biological processes in the Itare river sub-basin and the development of predictive models on how land use change affects various aspects of water resources.
- Research on sound forest management practices so as to conserve the forests which are also catchment areas as in the Itare catchment.
- 10. The effect of converting areas covered by natural forests into tea plantations and small scale tea farms should be investigated further despite the fact that this study indicates an increase in water flow

5 .3.2: To Water Policy Makers

Based on the research findings, the following are the recommendations to water policy makers and water managers.

- The falling of the water supply per capita index for the country from the present $647m^3$ to the projected $235m^3$ by the year 2025, compared to the international standard of $1700m^3$ should be a matter of concerned to water managers and policy makers and therefore proper intervention measures should be put in place.
- The difference between the water demand and the dependable supply available should provoke concern from all stake holders and appropriate measures put in place to avoid possible conflicts amongst the various water users.

- The increasing recognition of the role of water in national development should result into an expansion in water resources activities in all sectors of life.

- The expanded water resources activities should create considerable demand for water resources professionals and a change in perspective within the profession. Working in water resources sector should be made an occupation with high public visibility and water resources professionals should become consultants in a host of environmental and conservation issues as opposed to the largely developmental issues they have been doing. For example, university programmes in water resources should be expanded in size and number and. Kenya should strive to be recognized as one of the leaders in water resources management in the African region and even in the world.
- Rational decisions must be taken in catchment protection and conservation if the country is to achieve its water supply objectives by the year 2020, this is so because the results from this study indicate a high rate of deforestation in catchment areas.
- Legislation should be enacted to strengthen substantially the contributions by the universities and university scientists as individuals and organizations in the evolution of effective national water policies.
- There is need for harmonization of the management of water catchment areas. The forest department which manages the forest/vegetation cover, wildlife department which manages the animals in the forest/catchment, water department which manages the water, land adjudication and surveying that allocates and demarcates catchment areas and agriculture which encourages increased food production even within catchment areas should be harmonized.
- There is an urgent need for a land use policy to regulate land use changes to avoid possible destruction of catchment areas which could affect water discharges and quality.
- Both the public and the private sector should recognize the need for enlarged water resources research and educational efforts and substantial financial allocation to the water sector especially on water resource evaluation.
- There is need to strengthen support of graduate training and research by developing university research centres or groups in different parts of the country, to carryout research in water resources through a multidiscipline organizations and staff skilled in various fields.

- This country should have a national water resources research and education policy to be able to conduct applied long range research.
- Research teams at universities, institutes, companies and government units should be allowed to play an important role to make Kenya's water sector a science based up to-date functioning system and this can be done through financial facilitation.
- The IWRM (integrated water resource management) should be enhanced and made fully operational in this country and the public should be made aware of this new strategy.

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