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GROUNDWATER RECHARGE OF CONFINED AQUIFERS IN THE UPPER EWASO NG'IRO NORTH RIVER BASIN, KENYA

By

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Dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science in Hydrogeology and Groundwater Management.

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other institution of learning for academic award.

Signed.................................... Date 6/9/2010

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This thesis has been submitted for examination with my approval as the supervisor.

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Above all, I thank Almighty God for giving me strength, courage and wisdom to make it through to the end. May all the praise and glory be unto Him.

Amen!

DEDICATION

I dedicate this work to my family: My wife Eunia and my children

Eunice, Moses, Dennis, Davis and Judy

ABSTRACT

Groundwater has been, and will continue to be an important water supply for industrial, agricultural and residential use in Kenya. Rainfall is the main source of groundwater recharge. In order to estimate the groundwater recharge to confined aquifers of the upper Ewaso Ng'iro North River Basin, quantitative information on the response of groundwater levels to rainfall variability have been used. Recently a number of boreholes have dried up and some have dropped their water levels. Therefore, it became matter of concern to relate rainfall and fluctuations in water rest levels (WRL).

This work therefore is focused on the study area located in the Northwest of Mt. Kenya and to the North of Aberdare Ranges whose altitude varies between 1600 -5200 m above sea level. The area is composed of confined aquifers and extends from Ngusishi to Suguroi Rivers of the basin, the study was carried out between May to October 2009.

Objectives of the study were: i) Determination of groundwater flow directions in order to determine the recharge and discharge areas within the basin, ii), To determine the relationship between rainfall and groundwater level fluctuations; iii) Estimate groundwater recharge in six sub-regions of Upper Ewaso Ng'iro North River Basin.

Both primary and secondary data were utilized, rainfall data from 1983 to 2008 and monitored water rest levels from 2005 to 2009. Where data gaps existed, methods of spatial correlation and simple liner regression were used to fill the gaps.

Data from rainfall stations close to boreholes and those far of in the highlands were correlated and their correlation coefficient (r^2) was compared. Time lag and moving averages methods were used to mimics the graph correctly.

The results showed that rainfall is directly related to groundwater recharge; however fluctuations are steady due to confined aquifer conditions. Drillage time series showed that boreholes tapping from deeper aquifers have better yields than shallow ones. Groundwater Recharge occurs in the forest area while below the forest water discharge occurs in form of springs. The recharge that goes deeper gets into the aquifer and creates pressure that makes water to rise whenever a borehole is drilled. The water rise after drilling in the area confirms a confined aquifers characteristics.

The study, recommends longer groundwater monitoring period.

ACRONYMS

ASAL	-	Arid and Semi Arid Land
AWC	-	Available Water Capacity
BH No.	-	Borehole Number
CETRAD	-	Centre for Training and Integrated Research in ASAL Development
CRD	-	Cumulative Rainfall Departure
FAO	-	Food and Agriculture Organization
FC	-	Field Capacity
GPS	-	Global Positioning Systems
JJA	-	June – July – August
Lpm	-	liters per minute
MAM	-	March – April – May
MAP	-	Mean Annual Precipitation
NRM^3	-	Natural Resources, Monitoring, Modeling and Management
SON	-	September – October - November
UENNRB	-	Upper Ewaso Ng'iro North River Basin
WMO	-	World Meteorological Organization
WRL	-	Water Rest Level
WRMA	-	Water Resources Management Authority
WWC	-	World Water Council

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CHAPTER ONE

1.0 INTRODUCTION

Groundwater is an important source of water supply throughout the world whose use in irrigation, industries and drinking has increased (Okoo, 2007). The quantity and quality is equally importance (Todd, 1980). Kenya's semi arid and arid lands depend on groundwater more that surface water. Ewaso Ng'iro Basin has very unreliable rainfall and rainfall is the main source of groundwater recharge (Fetter, 1988). Rainfall events and amounts are not evenly distributed, the amount differ with zones and timing as well. Recharge from rainfall into an aquifer depends on the status of the aquifer system and ground surface conditions (Xu, *et al*, 2003).

The Central part of Kenya where the study is based has high potential in the highlands and low potential in the lowlands. Hence major economic activity in the area is both agriculture livestock and wildlife keeping. Has rainfall is unreliable; groundwater has became the source of dependence which is also becoming scarce.

According to the Ministry of Water and Irrigation (MWI), Code of Practice for the citing of Water Supply Boreholes (2006), over 17,000 boreholes have been drilled in the country and tens of thousands of shallow wells constructed. Groundwater is the main source of water for most rivers in Kenya run dry when there are no rains. Base flow that originates from ground water during dry periods is vital to the maintenance of Kenya's rich ecology and biodiversity. Considering the area of study which is arid and semi-arid, groundwater has been and will continue to be an important water supply that is heavily depended on for human, plant and animal survival. However, as it is invisible and often poorly understood, its value is often underestimated in terms of its quantity and quality Sahel Forum (1989). Due to this poor understanding in terms of limited information available on groundwater quantity coupled with its intensive exploitation, care must be taken to avoid permanent or long-term damage to aquifers.

Groundwater is sustainable if recharge exceeds discharge. Recharge is controlled by a number of factors such as the amount of rainfall, land topography, soil and rock types, lineament buffer, density and intersections.

1.1 Scope of the study

The study area, is bound by latitudes 00^0 20'N and $00^{0\ 17'S}$ and longitudes 36^0 30' E and 37^0 20' E, within the Upper Ewaso Ng'iro North Basin (UENNB) catchment; it covers two major rivers ; Ewaso Ng'iro and Nanyuki.

The study was aimed at determining groundwater recharge into the confined aquifers of the UENNB. This was arrived at by investigating the relationship between rainfall and groundwater fluctuations within the time period of 2005 and 2009. Further analysis involved estimation of groundwater recharge in six sub-regions of area.

The study was conceptualized to answer to several questions such as: why a large number of boreholes are drying up in the area? And whether there is need to control groundwater abstraction? (Taking an assumption that abstraction is minimal and has no influence on groundwater level variations).

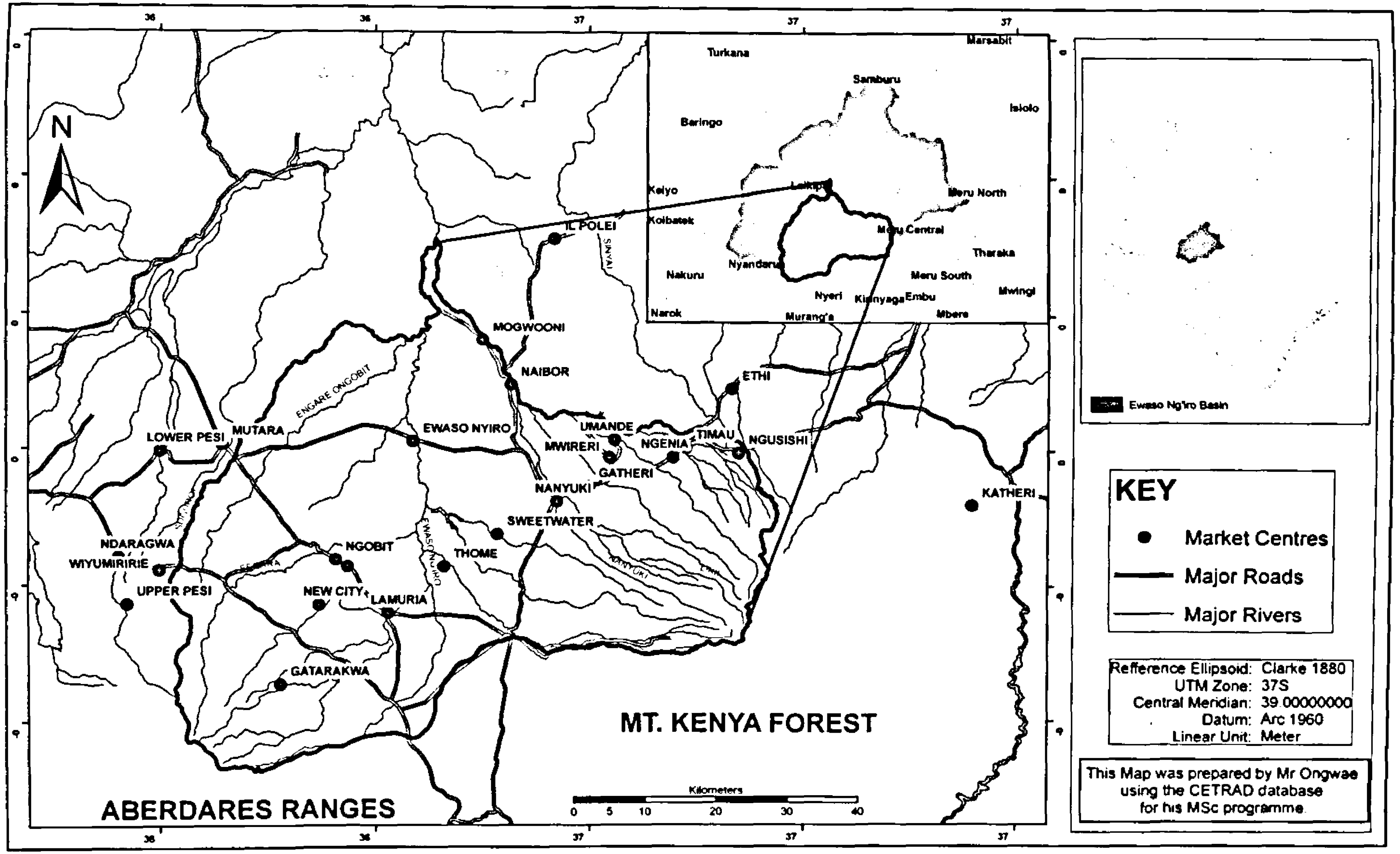


Figure1.1: Map of the Study Area

Source: CETRAD Data Base (2009)

1.2 Background Information

Water is an essential component to the livelihoods of people and other living organisms. It is a vital part of our socio - economic, religious and cultural values in the sense that it provides/ sustains life. Water is, however, becoming scarce in many areas and regions of the planet. The latest data from World Water Council's report on sustaining water shows clearly how alarming the situation is: "in 1950, only 12 countries with 20 million people faced water shortage; by 1990 it was 26 countries with 300 million people; by 2050 it is projected to be as many as 65 countries with 7 billion people, or about 60% of the world's population, mainly in the developing countries" (WWC, 1996).

Kenya is one of the countries with growing water shortages. Water scarcity in most parts of Kenya are expected to worsen owing to increasing population, uneven distribution of rainfall, underdevelopment of potential water resources, low water use efficiency and degradation of available water resources. Ewaso Ng'iro basin being one of the five basins in Kenya depends on both recharged groundwater and surface water. Groundwater recharge can be defined in a broad sense as an addition of water to a groundwater reservoir either naturally or artificially. Rainfall is a main source of groundwater recharge (Fetter, 1988).

Ewaso Ng'iro Basin's inhabitants depend heavily on groundwater rather than surface water during dry spells. Drought in the area has been known to occur more regularly than not at cycles of 2.4 years (Berger 1989) and they are known to occupy the better part of a year. Six to eight months may pass without any rain in the area.

Rain is experienced in phases, where long rains concentrate in MAM, continental rains of JJA and short rains in SON. Mount Kenya forms a resource of all rains received in the area, hence acting as a "rich island" in the savanna dominated environment (Liniger, *et al* 1998). Mt. Kenya and adjacent Upper Ewaso Ng'iro Basin forms a highland-lowland system in which improved management of mountain water resources and mitigation of water-related conflicts deserves the highest priority Kiteme *et al,* (2002) The characteristics of these highland-lowland systems and their dynamics and complexity are compared to and illustrative of many regions in Eastern and Southern Africa and other parts of the world Liniger, 1995; Ojany and Wiesmann, 1998).

1.3 Statement of the Research Problem

Water scarcity is a phenomenon that many communities are now experiencing, not only in the Upper Ewaso Ng'iro Basin but in the whole country and the continent of Africa at large. The variability in groundwater level fluctuations in the study area in some cases leading to drying up of boreholes is a problem to inhabitants; human beings as well as animals. Changes in water quality and quantity can not be overlooked (Todd, 1980), thus the drive of finding out the recharge behavior in response to rainfall for boreholes found in the region which is mainly a confined aquifer.

Therefore, this project was undertaken to provide accurate and reliable hydro-geoscientific information groundwater recharge for the purpose of future exploitation of groundwater.

1.4 Literature Review

1.4.1 Groundwater recharge and balance in volcanic formation

Mountains of the world are water towers for the 21st century, which is a contribution to global freshwater management (Liniger *et al.* 1998). It is further reported that mountains play very crucial role in supply of fresh water to humankind, both in the mountains and the downstream lowlands. The montane forests are an important part of water-flow regulation, flood mitigation, water storage, groundwater recharge, water purification, micro-climate regulation, reduced soil erosion and siltation. The forests also provide other major environmental services, including nutrient cycling and soil formation. This is the case in the study area which is influenced by the forests in the two highlands, Mount Kenya and Aberdare Ranges.

In many volcanic areas of the world, soils are very thin and permeable and vegetations are shallow rooted. Consequently, in wet seasons a large part of rainfall becomes recharge. Values greater than 50% of the local rainfall are possible (Custodio *et al*, 1997), but in arid climates, even in sparsely vegetated areas, most of the rainfall returns to the atmosphere, partly by direct soil evaporation.

Recent volcanic formations have low permeability and are devoid of significant vegetation, but where they are porous and with irregular land surface they tend to transform most of the trapped rainfall into recharge. In the case of canary Island, (Custodio, 1992) found out that deep aquifers were being recharged through connected porosity that showed open fissures.

1.4.2 Soil Water Movements

Soil water movement is the flow of water from one point of high saturation to another of low saturation within the soil. This is infiltration process that is controlled by the rate of redistribution and the supply of water and soil properties such as hydraulic conductivity and water- retention characteristics. The same factors enables the soil water to flow faster in saturated than unsaturated conditions (Marshall and Homes, 1988, Kironchi, 1998). In such conditions water distribution tend to take place from an upper to lower soil horizon or layer because the water content exceeds the field capacity.

1.4.3 Aquifer Water Movement

Recharge water into an aquifer originates as soil moisture and tends to move vertically downwards towards the water level. The actual detailed movement depends on the combination of layers, blocks and fissures (Custodio, 1978). During infiltration process, recharge water enters an aquifer and moves within it under influence of gradient difference. To maintain the equilibrium some points of weak pressure are created as points of discharge that form springs (Kulkarini *et al.*, 2000). Some of these springs end up in forming large and permanent streams that flows to balance recharge and storage.

Figure 1.2 below illustrates the relationship of confined and unconfined aquifer conditions. After rainfall, recharge or replenishment of an unconfined aquifer occurs at the ground surface directly above the aquifer. In contrast, recharge to a confined aquifer may occur many kilometers away, typically at a higher elevation where the aquifer is no longer confined; i.e. where the overlying materials are permeable and allow percolating rainfall to reach the confined aquifer.

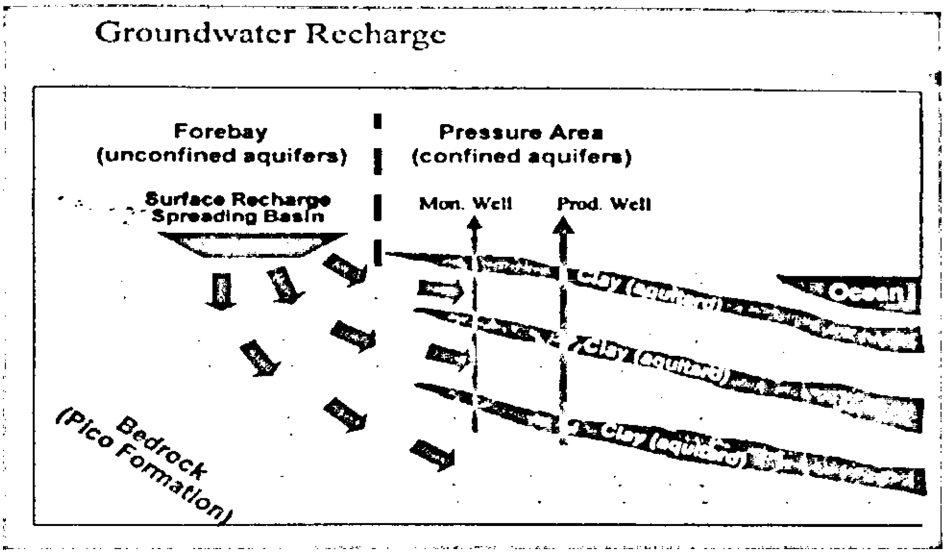


Figure 1.2 : Relationship between unconfined and confined recharge conditions

Source: *http://www.wrd.org/water_quality/recycled-water-groundwater -recharge.php*

Water in basalt formations move through vertical fissures and horizontal interflow layers, and is stored in blocks and storage is in the blocks and interflow layers (Kulkarni *et al.*, 2000). When the equilibrium is exceeded, water flows between the layers producing springs as the formation cover thins out. This kind of flow is described successfully at regional scale of anisotropic condition by continuous media equations such as Darcy's Law and by means of pumping tests (Fetter, 1988).

Darcy's Law (or Darcy velocity) is expressed as

$$q = -K\frac{dh}{dl} \qquad (1)$$

q = specific discharge or volume flow/unit area,

In more general terms as;

$$Q = -KA\frac{dh}{dl} \qquad (2)$$

Where Q = volume rate of flow, K is constant and A = unit area.

Where $\frac{dh}{dl}$ is known as hydraulic gradient, l is length, h is hydraulic head between the ends and it is inversely proportional to the flow length, l. At macroscopic scale of flow in volcanic formation, Darcy's Law has been found to be very valid as it takes all parameters of flow into account (Fetter, 1988). The same principle can be applied in water quality to find velocity of solutes traveling in groundwater. If equation (1) is divided by effective porosity, an average linear flow velocity is obtained.

$$v_x = \frac{Q}{n_e A} - \frac{K}{n_e}\frac{dh}{dl}$$

(n_e) is the effective porosity

v_x is the average linear velocity

1.4.4 Hydraulic Conductivity

This is a coefficient of proportionality describing the rate at which water can move through a permeable medium. It's measured as the ability of soil or rock to transmit water and depends upon both the properties of the material and the fluid (Klute and Dirksen, 1996). Total porosity, pore size distribution and pore continuities are the important characteristics of a material affecting the hydraulic conductivity. On the other hand, fluid properties that affect hydraulic conductivity are viscosity and density (Kironchi, 1998).

1.4.5 Groundwater level monitoring in volcanic formations

According to studies (Custodio, 1978) groundwater monitoring in volcanic formations covers three aspects:

- Water levels fluctuations
- Water physio-chemical and quality characteristics
- Water abstraction

Although often poorly permeable, volcanic formations conserve connected porosity. Some permeability and open fissures go down to greater depths. Therefore deep drainage occur through regionalized systems that exist in the large active thickness of the formation; in the process, any hydraulic disturbance is followed by a long transient period which is measured in terms of

$$\frac{L^2S}{T}=\frac{L^2S_Y}{K} \Longrightarrow K=\frac{Q}{A}\left(\frac{dh}{dl}\right)$$

In which:

K - Permeability; which is a function of the properties of both the porous medium and the fluid passing through it.

In which;

L = Linear dimension of the system

S = Storage coefficient

S_y = Specific storage coefficient

1.4.5.1 Transmissivity (T)

According to Fetter (1988), Transmissivity is a measure of amount of water that can be transmitted horizontally by the full saturated thickness of an aquifer under a hydraulic gradient of 1. The transmissivity is the product of the hydraulic conductivity and the saturated thickness of the aquifer; b and can be expressed as: T = bK

K - Permeability

b - Thickness

Hence, for a multilayer aquifer, the total transmissivity is then the sum of the transmissivity of each layer and expressed as:

$$T=\sum_{i=1}^{n} T_i$$

In accordance to the Ministry of Water Development study on Water Resources Assessment Programme WRAP, 1987) carried at Lamuria area, Laikipia, four boreholes were test pumped; results are shown in table 1.1. Transmissivity was found to vary from 2.6 m^2 to 30.7 m^2/day when applying the formula below (Kruseman, *et al.*, 1970);

$T = 0.183Q/\Delta S$

Q - Discharge (m^3/hg)

ΔS - Change of Bh Water Rest Level with Q

T - Transmissivity m^2/day

Table 1.1: Discharge and Transmissivity of selected boreholes

BH No.	Region	ΔS =10 meters	Specific capacity Q/S= m^2/day	Discharge(Q))m^3/hour at a drawdown, S=10metres	Transmissivity (T) m^2/day
C555	Lamuria	10	0.3	0.13	5.4
C957	Lamuria	10	3.8	1.59	13.4
C887	Lamuria	10	4.7	1.59	21.3
C2858	Lamuria	10	4.6	1.93	30.7

Source: WRAP 1987

This is obtained by calculating S of drawdown and recovery phases with change of water heights, ΔS being 10 meters when test pumping the boreholes.

Specific capacity = $Q/h_o-h = Q/s$; obtained by dividing pump rate, Q by drawdown in the pumping well, S.

Transmissivity can be estimated following (Driscoll, 1986) using a constant K of 1500 or 2000 for unconfined and confined aquifers respectfully e.g.

T=K*Q/s (unconfined)

T=K*Q/s (confined)

Units used (T=m2/day Q= M3/hr; s= meters)

1.4.5.2 Water levels fluctuations

Groundwater level fluctuations are monitored through piezometers of boreholes. The ideal situation is when there exists a separate observation boreholes, in cases where the borehole is used for domestic or/and other uses, a recovery period of 24 hours is needed before any reading is done (Custodio, 1978).

1.4.6 Hydrogeological Properties of Volcanic Formations

Total porosity of volcanic formations is generally high due to voids created by exsolved gases and to the frequent scoriaceous and brecciated parts, as well as to their often clastic nature. Compact lavas and dykes have less than 5% total porosity. Specific yield (drainable porosity) is small for fine pyroclastic formations, ashes and weathered rock whose porosity values range between 1 and 8% (Custodio, 1989) as shown in table 1.2, derived from a wide literature review and experience in the Canary Islands. It was also noted during that study that porosity decreases with age.

Table 1.2: Total porosity and drainable porosity of volcanic rocks

Material	Total Porosity (%)	Drainable porosity (%)	Comments
Basaltic formation	5-40	2-8	Increases with contacts of Scoria and pyroclastics
Conglomerates	2-25	1-4	Mostly basaltic
Phonolites	2-4	1-6	Dense flow
Pumice	50-85	<0.1-1	Non connected pores, unfractured
Rhyolites	0.1-30	0.5-5	Dense to vacuolar
Volcanic soils	40-60	<1-5	Variable

Source: Custodio (1989)

Table 1.3: Permeability and Transmissivity of volcanic rocks

Material	Permeability M/day	Reported transmissivity values M^2/ day	Comments
Basaltic formation	0.01 – 20	2-100	Several flows with pyrocastics
Recent basaltic formation	$1\text{-}10^3$	$100\text{-}10^5$	Unaltered
Conglomerates	0.01-0.5	3-50	Mostly basalts
Loose pyroclastics	0.1-50	10-500	Young
Phonolites	0.1-20	20-1500	Effect of major fissures
Rhyolites	0.01-0.1	0.1-10	
Alluvium and terraces	1-10	2-200	Poorly sorted derived from volcanics.

Source: Custodio (1989)

Tables 1.2 and 1.3 contain values that compare different formations' porosity, permeability and transmissivity for water at normal temperature (10 - 25°C).

Permeability decreases with age and degree of thermal alteration; older volcanics are less permeable than young ones, this is known as 'age effect'. Although old volcanics are generally poorly pervious, after exhumation, they develop fractures. Reported transmissivity values may not represent the whole formation but the part penetrated by the well (Custodio, 1989).

1.4.7 Rainfall

Recharge from rainfall into an aquifer depends on the status of the aquifer system and ground surface conditions (Xu, *et al*, 2003). In arid and semi arid conditions rainfall events and amounts are not evenly distributed, the amounts of rainfall differ with zones and timing as well. In the case of the study area, the long rains are expected in March - May, continental rains are in July-August, and short rains in November – December (Berger, 1989). The cumulative rainfall departure method, based on the water-balance principle, is often used for mimicking of water level fluctuations; this method has been applied widely for estimating either effective recharge or aquifer storativity (Xu, *et al*, 2003).

1.4.7.1 Perspectives on Groundwater Recharge Estimation from Rainfall

According to Xu *et al.* (2003), recharge is governed by the intricate balance between several components of the hydrologic cycle, each of which is a function of several controlling factors that include:

- Rainfall; it is a function of intensity, frequency, variability and spatial distribution.
- Evapotranspirative losses; it is a function of temperature, wind, humidity and phreatophytes.
- Discharge losses; it is a function of interflow, springs, base flow, lateral flow and artificial discharge.
- Catchment; it is a function of soil type, thickness, spatial distribution, topographical feature and vegetation.
- Geology; it is a function of rock types, characteristics of fracture networks and occurrence of dykes.

Using these parameters, complex hydrological models have been developed to accommodate all interrelationships between groundwater, surface water and pollution. The complexity of the models often limits their practical value as does a lack of real data, which often have to be approximated by regional parameters or estimates by experts. Studies in the Republic of South Africa have shown that a simple approach can reveal much about groundwater recharge, and that sparse data should not necessarily be a constraint (Xu, *et al*, 2002).

The need to simulate the high variability of recharge over short intervals of time is not as critical as is generally perceived, because annual values of recharge can be converted into monthly values by applying annual average recharge coefficients to monthly rainfall (Xu *et al.*, 2003). This is a valid approach because groundwater behaves in a similar fashion to a surface water reservoir in smoothing the variability of monthly run-off. The averaging period producing a linear response is characteristic of the catchment, regardless of whether or not it yields surface flow or groundwater recharge. Studies of the response of springs to rainfall have revealed much about the recharge characteristics of aquifers and have been demonstrated in the case of the Dinokana spring (Xu *et al.*, 2003). The flows of the dolomitic springs in a specific month corresponded remarkably well to the average antecedent rainfall over several months. Similarly, monthly groundwater levels conform to the average rainfall over a number of preceding months.

1.4.7.2 Infiltration

Natural factors affecting infiltration include precipitation, seasons and moisture which vary with time and space and interact with other factors in their effect on infiltration (Kironchi, 1998). A clay layer impedes flow owing to its low saturated conductivity while a sand layer retards the wetting front owing to the lower unsaturated conductivity of the sand at equal matrix suction (Hillel, 1980).

Table 1.4: Rock formations and Rainfall Infiltration

Formation	**Rainfall Infiltration (%)**
Sandy alluvial area	12 – 18
Valley fills	10 – 14
Silty / Clayey alluvial area	5 – 12
Granites	2 – 4
Basalts	1 - 3
Laterite	2 – 4
Weathered phyllites, shales, schist and associated rocks	1 – 3
Sandstone	1 – 8
Limestone	3
Highly classified limestone	7

The water flow into a dry sand layer can take place only after the pressure head has built up sufficiently for water to move into and fill the large pores of sand.

1.4.7.3 Runoff

When the rate of water supply by rainfall into the soil exceeds infiltration rate, water starts to accumulate over the soil surface. The volume of water collected before runoff starts depends upon the surface roughness and ground slopes (Branson *et al.*, 1981). Runoff results when the rate of rainfall exceeds the potential rate of infiltration (Hillel, 1980).

1.4.7.4 Evaporation Water from Soil Surface

The amount of water that evaporates from soil surface depends on soil properties and environmental conditions. In the absence of vegetation, evaporation from bare soil surfaces can be a major cause of water loss (Hillel, 1977). Liniger (1991) reported that evaporation from the soil surface in the semi arid areas of Upper Ewaso Ng'iro Basin under conventional tillage was between 40% and 60% of the rainfall.

1.4.8 Impact of land use and management on soil water balance

The type of land use and/or management system modify soil surface conditions that play a key role in partitioning rainfall into infiltration and runoff and influence evapotranspiration within a given environment. Various land uses in Upper Ewaso Ng'iro Basin are mainly attributed to differences in ecological conditions (Jaetzold and Schmidt, 1993). In this study, land use refers anthropogenic influence through agricultural practices such as crop cultivation and livestock grazing or rangeland reserved for wildlife. Major land use and management systems in the Upper Ewaso Ng'iro Basin are grouped into:

(a) Forest land with characteristics such as
   - i) Natural forest
   - ii) Plantation forest

(b) Crop land

(c) Grazing land

Activities which disturb the soil surface or vegetative composition and cover have the potential of reducing soil water intake, thereby reducing infiltration and recharge (Gaither and Buckhouse, 1983).

1.4.8.1 Land Cover and Recharge

The term land cover here refers to natural vegetation cover. Forests cover is less than 2% of Kenya's land, under protected status as a natural resource (Mugo, 2005). In a country like Kenya which is severely hit by drought, forests are critical for water conservation. According to (Matiru and Waweru, 2005), at least 10% of the land needs tree cover by forest to ensure a reliable water supply. The neighboring country Tanzania for example has 36% forest cover while Kenya has only 1.7% (Matiru and Waweru, 2005). The destruction of Mt. Kenya and Aberdares forest which serves as critical water catchment in the entire Ewaso Ng'iro basin will experience serious water shortage and alter water quality and reduce water levels in river Ewaso Ng'iro (Njeru, 1995). This will go further to reduce groundwater hence affect the livelihood of most households who depend on the water in the locality (Kinuthia, 2005). Therefore removal of forest cover results in immediate and drastic degradative changes in soil properties (Ghuman *et al.*, 1991). Vegetative cover protects the soil from raindrop impact while the leaf litter and root mass reduce the velocity of the surface runoff. Infiltration rates are controlled by vegetative, edaphic, climatic and topographic influences. Of these, vegetation can be easily manipulated by management (Wood and Blackburn 1981). This is through cultivation or livestock foraging to increase soil water intake.

Due to high organic matter content, increased microbial and worm activity and reduced disturbance, forest surface soils' porosity consists of high proportion of macropores. Macroporosity comprising of large non capillary pores, voids in soil, fauna holes, decayed root channels, and structural cracks, that are open at the soil surface, capture the free water available at its surface during rainfall or runoff and conduct it downwards very quickly bypassing most of soil matrix (Lal and Cummings, 1979; Alegre *et al.*, 1986).

Result of runoff studies carried out by (Lundgren, 1980) in the humid mountain slopes of Usambara, Tanzania, indicated that runoff increased with removal of natural forest for small scale cultivation. Infiltration and soil water storage were also reported to decrease after forest clearing for crop production in South Western Nigeria (Hullgalle *et al*, 1984, Ghuman *et al.*, 1991). However, Alegre *at al.*, (1986) reported that tillage and soil management practices adopted after land clearing may be more important than the vegetation removal *per se* with respect to altering of soil properties important to water infiltration and storage. Alegre *at al.*, (1986) concluded that in areas where natural cover has been cleared for crop production and soil and water conservation techniques are used to manage the soil, water retention and food production can be optimized.

1.4.8.2 Crop Land

Generally, infiltration rate of tropical soils under natural vegetation cover is high. However, removal of the natural cover and cultivation for crop growth results in disturbance and exposure of soil to rain drops which causes a rapid decline in the infiltration rate (Kironchi, *et al*, 1992). Due to reduced infiltration, less water will be available for storage in the soil to further reach the aquifer.

The ever increasing demand for food has kept pushing crop production to areas otherwise unsuitable for arable agriculture. This is mainly in the semi arid tropics and subtropics. In recent years, research has been intensified in these areas to alleviate the constraints and optimize production. (Ulsaker and Kilewe, 1985) strongly suggest that the risk to crop production and soil degradation can be reduced through the application of techniques which enhance water storage during fallow: by killing weeds, modifying soil structure and using mulches to maximize infiltration and minimize soil evaporation.

1.4.8.3 Grazing Land

Grazing land refers to patches of land within small scale crop production areas that are used for grazing. These types of land use are common features in East Africa especially in high potential areas. A similar trend of mixed farming has been adopted in the newly settled semi arid areas like Laikipia Plateau after land subdivision (Flury, 1987; Kohler, 1987). Even though most land in the semi arid areas is being put under crop production, investigations of the soil water balance (Ondieki, 1994) showed that these relatively small parcels of land should not be overlook, as they are key source areas of catchment runoff.

1.4.8.4 Range Land

These are semi-arid to arid areas not used for crop production but for extensive livestock grazing and wildlife management (Stoddart *et al.*, 1975). In East Africa, range lands have diverse vegetation cover (Pratt and Gwynne, 1977) ranging from grasslands to bush lands.

The ecology of ASAL is rather delicate and should vegetation be destroyed, there can be considerable effects on rainfall-runoff response (Strange, 1980). Livestock grazing alters the natural infiltration-runoff relationships by reducing the protection afforded by vegetation cover, by reducing and scattering litter, and compacting the soil through trampling (Stoddart *et al.*, 1975). The magnitude of these changes is determined by the intensity of grazing land as well as the soil type, climate, topography, livestock management and vegetation type (Branson *et al.*, 1981). Most studies have been conducted to evaluate the impact of grazing in range lands on the hydrologic properties of soils have mainly concentrated on measurements of infiltration rates (McGinty *et al.*, 1979., Wood and Blackburn, 1981; Mbakaya, 1985). Consistently low infiltration rates are reported from over grazed plots and at times, livestock enclosures have similar infiltration rates as some of the controlled grazing systems (Kironchi, 1998).

1.5 Objectives and Rationale of the Study

The overall objective of the study is to investigate the relationship between groundwater recharge and rainfall of confined aquifer of the Upper Ewaso Ng'iro Basin.

To achieve the above, specific objectives are:

1. To determine groundwater flow directions in the Upper Ewaso Ng'iro basin in order to determine the recharge and discharge areas within the basin.
2. To determine the relationship between rainfall and groundwater fluctuations (year 2005 to 2009 rainfall series)
3. To estimate groundwater recharge in six sub-regions of upper Ewaso Ng'iro North River basin

The study was conceptualized based on the need to generate answers to several questions such as:

a. What is the direction of groundwater flow?

b. Is rainfall related to the water rest level fluctuations?

c. What amount of rainfall gets into the aquifer?

1.6 Justification and significance of the study

Several studies have been done in other areas of the world: India (Chaturvedi R. S., 1973), South Africa (Xu, *et al*, 2002), and (Bredenkamp, *et al*, 1995) among others, but little information is available in Kenya and Upper Ewaso Ng'iro Basin for that matter. This research therefore intended to establish the relationship between water rest levels and rainfall of the area and further resolve on applicable statistical method of estimating ground water recharge. On the same direction provide necessary accurate and timely information for the management of water resources efficiently so as to satisfy human needs,

CHAPTER TWO

2.0 THE AREA OF STUDY

2.1 Introduction

The study was carried out in the upper Ewaso Ng'iro River Basin from Suguroi River to Timau-Ngusishi River covering about 4600 Km^2. It lies within latitudes 00^0 20'N and 00^0 17'S and longitudes 36^0 30' E and 37^0 20' E. It traverses four districts namely Nyandarua, Nyeri, Laikipia and Meru in which the following divisions: Ndaragwa, Kieni East, Lamuria, Central Laikipia, and Timau are found. It is located in the North West of Mt. Kenya and to the North East of Aberdare Ranges. The area whose altitude varies between 1600 -5200 meters above sea level (figure 1.1).

2.2 Climate

2.2.1 Rainfall

The project area covers the Highland – Lowland system of Upper Ewaso Ng'iro North catchment, which experiences varied annual rainfall ranging between 400 mm/yr to 600 mm/yr in the lowlands and 900 mm/yr to 1500 mm/yr on the highlands (Berger, 1989). Figure 2.1 shows trend of rainfall distribution. The central plateau extending from Narumoru through Lamuria to Nanyuki receive an average rainfall, of about 600 - 800 mm per year (Berger, 1989).

2.2.2 Temperature

There is a wide range of temperature in the area; it falls by an average of 5°C per 1000 vertical meters from the base of the mountain. Temperatures are low in the highland and increase with decrease of altitude. In the lower alpine zone, temperatures usually do not go below 12°C. Since cold air can hold less moisture, as the mountain air cools, it will lose its moisture as rain. Consequently, as the prevailing winds from the Indian Ocean, the eastern and south eastern slopes of the mountain tend to be the wettest; elevations above 4000 m are characteristically dry; and the summit of Batian at approximately 5200 m is icy.

2.2.3 Evaporation

Mean annual evaporation rates are a function of altitude of an area. The low lying northern regions of the study area experience high annual evaporation rates of 2000 mm/year, (6 - 10 mm/day) while the highland lose about 1000 mm/year through evaporation (Kirochi, 1998). This worsens during hot days where humidity goes below 60%, and is witnessed with high wind velocities (Kihara, 1997).

2.2.4 Vegetation

The study area has several distinctive vegetation zones which vary with altitude, rainfall and soil types and fauna and flora. The lowlands; below 1,740 meters, is used for grazing of livestock and wildlife. The major vegetation cover is *Acacia bush land*: *A. etbica, mellifere* and *tortilis* species are dominant.

Plate 2.1: Bush Land

On the lower regions of the mountain, between 2,000 - 2,500 meters, the slopes are covered with montane forest; *Juniperous, Podocarpus* and *Olea* species. Many species of plants and animals live in this warm moist environment, although the species differ around the mountain with the varying rainfall.

Plate 2.2: Forest plantation

In other areas natural forest have been replaced with plantations of Eucalyptus saligna (Sydney Blue Gum)

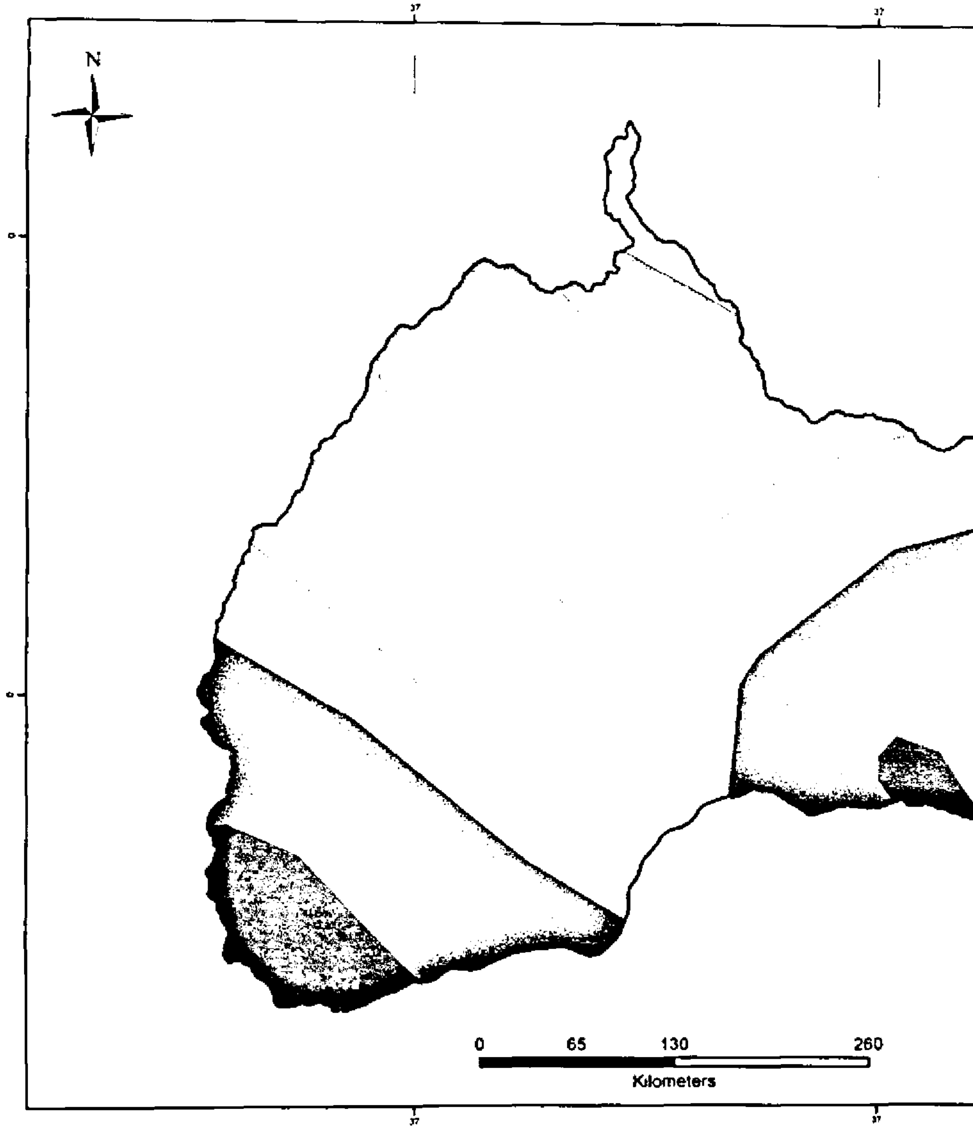
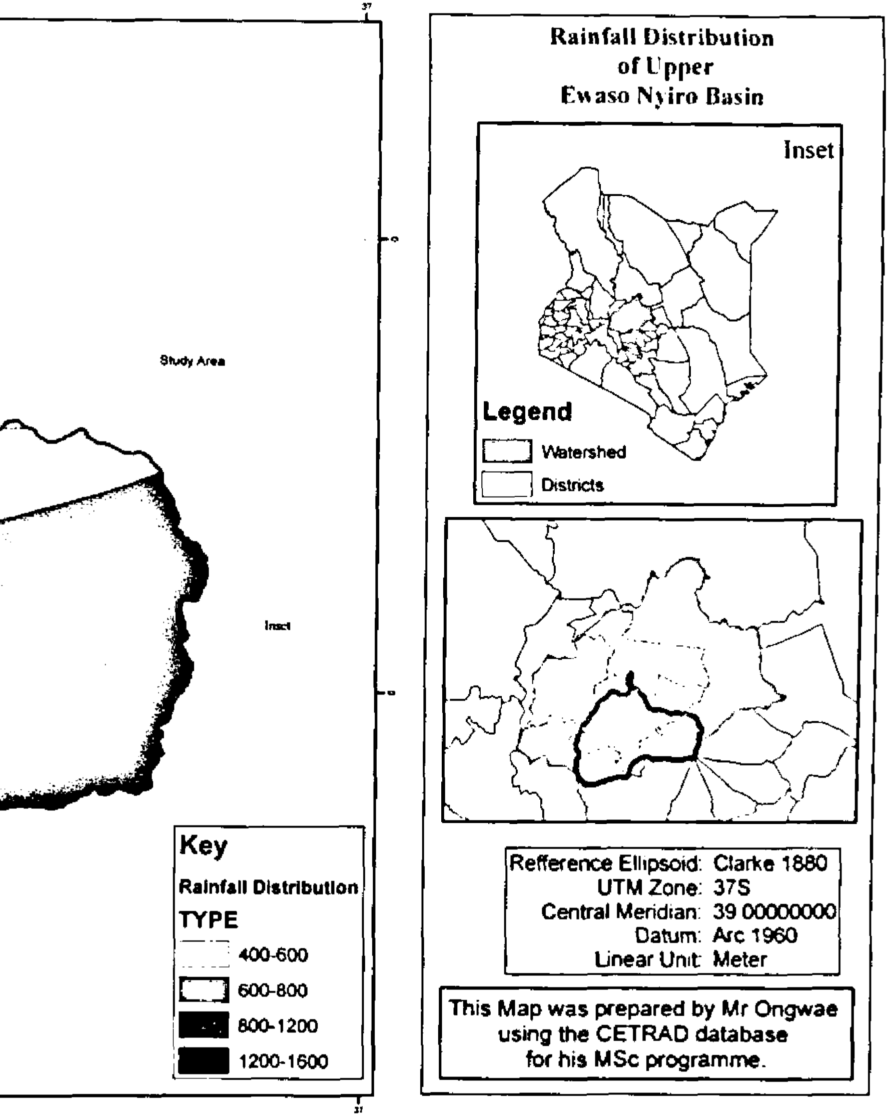


Figure 2.1: Map showing Annual Rainfall Distribution in the Area

Source: CETRAD Data base (2009)


Rainfall Distribution
of Upper
Ewaso Nyiro Basin
Study Area
Inset
Key
Rainfall Distribution
TYPE
400-600
600-800
800-1200
1200-1600
Inset
Legend
Watershed
Districts
Refference Ellipsoid: Clarke 1880
UTM Zone: 37S
Central Meridian: 39 00000000
Datum: Arc 1960
Linear Unit: Meter
This Map was prepared by Mr Ongwae
using the CETRAD database
for his MSc programme.

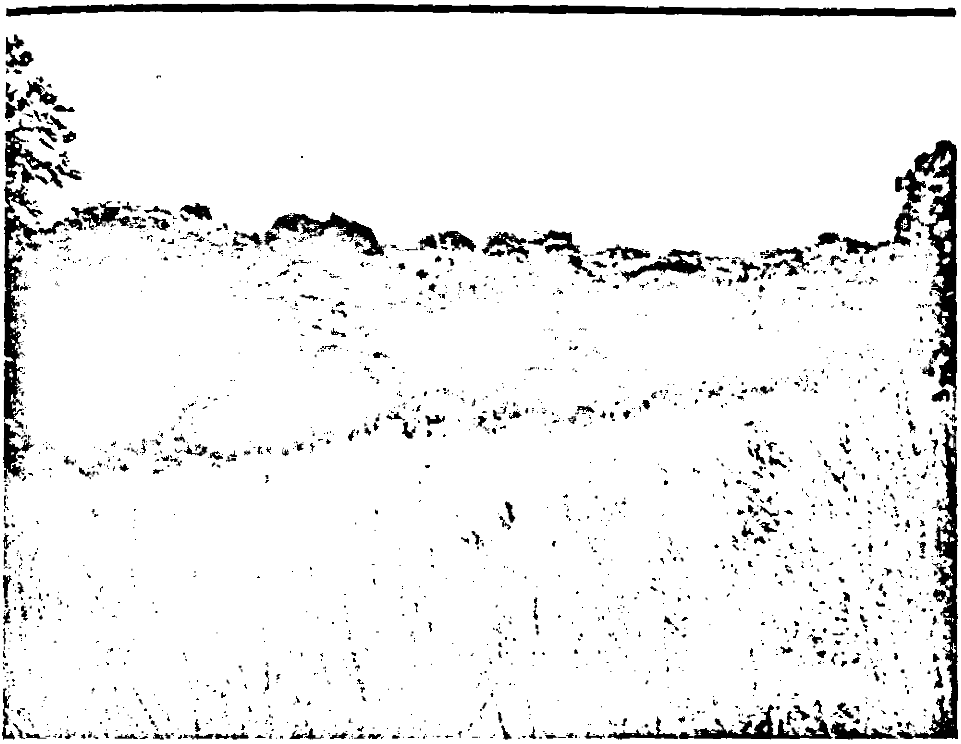


Plate 2.3: Grassland/ Bush land

Between 2,500 - 3,000 meters, there is a band of bamboo; the extent of this varies with rainfall. Few other species live in the bamboo forest, as the dense bamboo suppresses the growth of other plants. Bamboo is unpalatable to most animals, so although they pass through to the moorlands above, few animals live in this zone.

Above the bamboo zone there is a timberline forest zone. This is found between 3,000 - 3,500 m. The trees are smaller and sparser than in the montane forest, and many flowers grow here.

The timberline forest gradually disperses into heath land and chaparrel, between 3,200 and 3,800 m. Heath land grows in the wetter areas, towards the east, and is dominated by *giant heathers*. In the chaparrel, the plants are smaller and shrubbier. The ground in this zone is often waterlogged, although fires are easily started in the dry grasses that are common here. Many animals visit the heath land and chaparrel zone but few live here permanently.

The Afro-alpine zone starts at around 3,800 m. The plants and animals that live here are adapted to the daily freeze-thaw cycle and are extremely specialized. The Afro-alpine zone can be found right to the peak of the mountain, although it is interspersed with the nival zone above 4,500 m. The Nival zone is not continuous; it is where there has not yet been any colonization by plants, nothing lives here.

2.3 Water Resources

Water sources in the area include rainwater, surface water and groundwater. It is determined by the seasonal variation in rainfall, catchment protection and intensity of river water abstractions. The water resources and drainage pattern of the area is shown in figure 2.2. The area has intensive hydro - meteorological network whose water has been monitored over 30 years today.

The area is characterized by erratic rains and frequent droughts, thus frequent water scarcities are experienced (Berger, 1989). Most water sources in the area depend on rainfall from the highlands (Mt. Kenya and Aberdare Ranges which act as two water towers) for replenishment of both surface and groundwater. Rivers in the area originate from these highlands and drain through the available drainage channels and some of the water infiltrates to the ground to recharge the aquifers.

During drought, down stream populations as well as wildlife and related tourism get heavily affected by loss of their key natural resources (Wiesmann *et al,* 2000). In effort to mitigate the effects of this water level changes, some methods have been applied especially in Laikipia East by trying to harness rainfall water through installation of underground tanks, water jars, rock catchment, earth dam construction, and subsurface sand storage dams in the river channels among others.

Water resources can broadly be divided into two: Surface and ground water hydrology.

2.3.1 Surface Water Hydrology

Surface water hydrology is a field that encompasses all surface waters of the globe. Surface water hydrology relates the dynamics of flow in surface water systems (rivers, canals, streams, lakes, ponds, wetlands, marshes, oceans, etc.).

Generally, surface water is available in the form of rivers and streams (figure 2. 2). This is one of the most important sources in the area. However, it faces a lot of challenges in apportionment and allocation of available water. According to hydrological data, rivers of this area and the basin at large suffers from daily and seasonal fluctuations as influenced by rainfall and such flows are characterized by flood flows and base flows

The study area experiences dry seasons that are known to run in cycles of 2.4 years (Berger 1989). However, there are three to four months when it becomes very dry, that is, between December to March with February being the driest month with no flow of water (Ewaso Ng'iro River) especially at Archer Post which is used by CETRAD as a monitoring station for the upper Ewaso Ng'iro Basin. Data obtained from this station shows that back in the 1960s, the flow of Ewaso Ng'iro River was 9 m^3 per second which dropped to 4.5m^3 per second in 1970. In 1980s, 1.2m^3 per second was recorded and 0.9 m^3 per second in late 1990s. In 2000 it was recorded as 0.211m^3 which is one of the dry years recorded, figure 4.13.

According to (WRAP 1987), it was reported that, seasonality of rainfall in the area makes most streams highly ephemeral; with a lot of sand deposits at their river beds which acts as a good source of groundwater recharge.

Ewaso Ng'iro river system rises from the north-western slopes of Mt. Kenya and the North-Eastern slopes of the Aberdares and flows to the Northern direction. Figure 2.2 illustrates the main tributaries from the two highlands.

The tributaries join up to form the main 'Ewaso Ng'iro' which is later joined by Ewaso Narok from Nyandarua and Ngara Mara from Nyambene Hills and finally drains into the arid parts of Eastern Province of Lorian swamp where it disappears underground. It is important to note that most of the tributaries rising on the Upper and Middle Volcanic Slopes are perennial while tributaries rising on the volcanic of Laikipia Plateau are ephemeral which reveal much on status of the groundwater recharge.

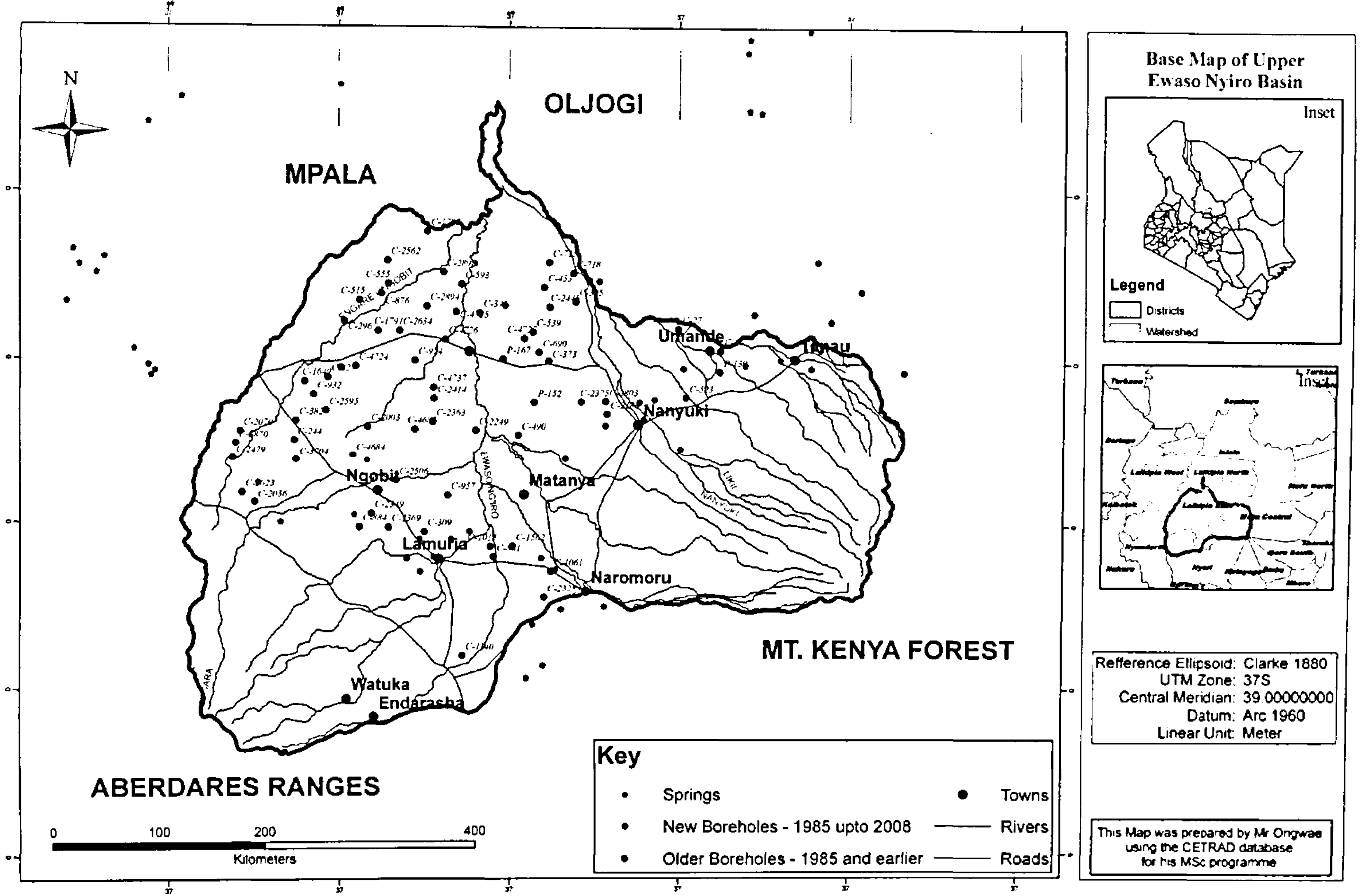


Figure 2.2: Map of the study area showing water resources

Source: CETRAD data base (2009)

2.3.2 Groundwater Hydrology

There are two types of aquifer systems in the area:

- Regional aquifer system that covers mostly the volcanic rocks and in the region between Mt. Kenya, Laikipia Plains, and Suguroi area
- Local aquifer system found in the area is around Mpala ranch and Mutara area, covered mainly by metamorphic rocks.

Groundwater exploited in the area has been there since 1930s and over 256 boreholes have been known drilled by the time of this study (CETRAD, 2009) data base. Some more boreholes are still being sited for drilling (WRMA, 2009). The boreholes in the area can be grouped into several categories: equipped and operational, equipped but in good condition. Cased but blocked and those boreholes that appear in records but can not be traced on the ground. Groundwater is replenished directly by rainfall that passes through geological formations (Todd, 1980). The rainfall infiltration rate values for different types of geological formations are shown on Table 2.1.

Table 2.1 : Rock formations and Rainfall infiltration

Formations	**Rainfall infiltration (%)**
Alluvial areas in sandy areas	20 - 25
Higher clay content	10 - 20
Semi-consolidated sandstones Friable and highly porous	10 - 15
Hard rock (Granitic terrain: Weathered and fractured)	10 - 15
Un weathered Basaltic terrain	5 - 10
Vesicular and jointed basalt	10 – 15
Weathered basalt	4 – 10
Phyllites, limestones, sandstones, quartzites, shales	3 - 10

Source: Kironchi *et al.,* 1992

2.4 Geology

Geology of the area is presented in figure 2.3; it shows the distribution of the lithological units found in the area. A brief summary has been presented in table 2.2

2.4.1 Area Stratigraphy

Table 2.2: Simplified Area Lithostratigraphic Table

		FORMATION		LITHOLOGY	THICKNESS Maximum
QUATERNARY	PIOCENE PLEISTOCENE/RECENT	Alluvium Glacial Deposits		Loam, silt, clay, gravel	6-40
		MT KENYA & ABERDERS VOLCANIC SERIES	UPPER (parasitic vents)	Basaltic pumice, Nanyuki formation	60- 100
			MIDDLE	Trachytes, olivine basalts,	500
TERTIARY			LOWER (main eruptive episode)	Nepheline syenite at the plug	>600
				Kenytes, phonolites. Pyroclasts,	>530
				Phonolites and trachytes, Porphyritic Phonolites	130
				Unexposed volcanics	3000
		Unconformity			
		Laikipian Basalts		Basalts, basanites, olivine,	130
	MIOCENE	Thomson's Falls Phonolites		Phonolites, Nyeri tuffs	85
		Rumuruti Phonolites		Phonolites and trachytes	>300
		Simbara Volcanic Series Sub-		Basalts and agglomerates	>300
PRE-CAMBRIAN		Basement System		Gneisses, schist's, quartzite's, marbles	

Adapted from: Geology of the Nyeri area by Shackleton 1945 and Geology of Mount Kenya area by. Baker 1967.

A description of rock formations in the area are is as follows:

2.4.2 Basement

The Basement System consists of metamorphic gneiss and schist. The rocks form the foundation of the area that is overlain by the Tertiary volcanics. In some areas, basement system forms inliers within the Simbara series of the basalts and agglomerates that outcrops in many valleys such as at Sirimon, Kailewa and in the northern parts of the study area (Baker, 1967).

2.4.3 Tertiary Volcanics and Sediments

The Tertiary volcanics can be grouped into two the lower and the upper based on the time scale of their formation. The lower lava deposits are the oldest volcanic rocks (Miocene age) and that overlie the Metamorphic rocks of the Basement System. They are composed of Simbara volcanic series, Rumuruti phonolites and Thomson's Falls phonolites. This formation has mainly been found in the Aberdare Massif and outcrop along the Satima scarp (Shackleton 1945). The lavas are perceived to have originated in many separate flows, which are usually interbedded with tuffs and sediments in some areas.

In the Eastern wing of the study area, the Simbara series rest on the Basement System rocks which are overlain by the Nyeri Tuff, which in return are overlain by the upper lavas (Laikipian Basalts) (Baker, 1967).

The upper lava groups (Laikipian Basalts) are considered to be of the Upper Miocene series that erupted and flowed to cover most parts of the study area with their thickness decreasing to the east (Baker, 1967). They lie uncomfortably on the plateau Phonolites as they are called the Thomson's Falls Phonolites. These forms the uppermost group of lavas east of Thomson's Falls and extend southwards of the area to as far as Mutara area and Gobit where they become concealed by the Tuffs. The group consists of several flows, one of which reaches a thickness of over 85 meters at the Thomson's Falls (Baker, 1967).
The other flow is Ndaragwa-Ngobit Tuffs; that forms continuous series of tuffs and Ignimbrites and extends from Ndaragwa, immediately North of Aberdares, to Ngobit plateau. To the north of the Aberdare massif a thin succession of this tuff formation extends eastwards in a series of discontinuous outliers at Ndaragwa. The easternmost recorded exposure of tuffs (figure 2.3) is in the Nairitua River near Ngobit (Shakleton, 1946).

2.4.4 Quaternary Volcanic and Sediments

The Quaternary volcanics are thought to have formed after a long disconformity during the Pliocene and extended up to the Pleistocene. These volcanic deposits are called the Mount Kenya and Aberdares Suite which are divided into two parts, the volcanics of the main eruptive episode and the volcanics of the satellite vents. Rocks from the first episode were mainly porphyritic phonolites and pyroclasts. Those of the second period are mainly basalts, trachytes and agglomerates. The most important representatives of the main volcanic episode are the porphyritic phonolites and agglomerates around Nanyuki area, Lamuria and some parts of Kieni division (Baker 1967). This formation is referred to as the Nanyuki Formation that was also confirmed by studies by (Charsley and Kagasi, 1982) and later by (Hackman, 1988) as a glaciofllluvial sequences derived from the Mount Kenya massif. These formations form the upper and recent form of Mt. Kenya suite. The thickness of the Nanyuki Formation is believed to vary up to about 60-100 meters.

Recent alluvial deposits tend to vary in thickness (6 - 40 meters) according to the nature of the underlying geology. On the phonolitic plateau, valleys are floored with silt or clay with fewer boulders. In the volcanic zones colluvium is more extensively developed especially from the more resistant fine – grained basalts and trachytes. The less coherent coarser basalts and pyroclastics have been preferentially eroded (Baker, 1967). Along the river banks, gullies and along road cuttings considerable thicknesses of soils (laterites and ashes) are exposed composed of a varied series of superficial deposits. Laminated silty sediments are also common in river valleys forming the fluviatile deposits (Decurtins, 1992).

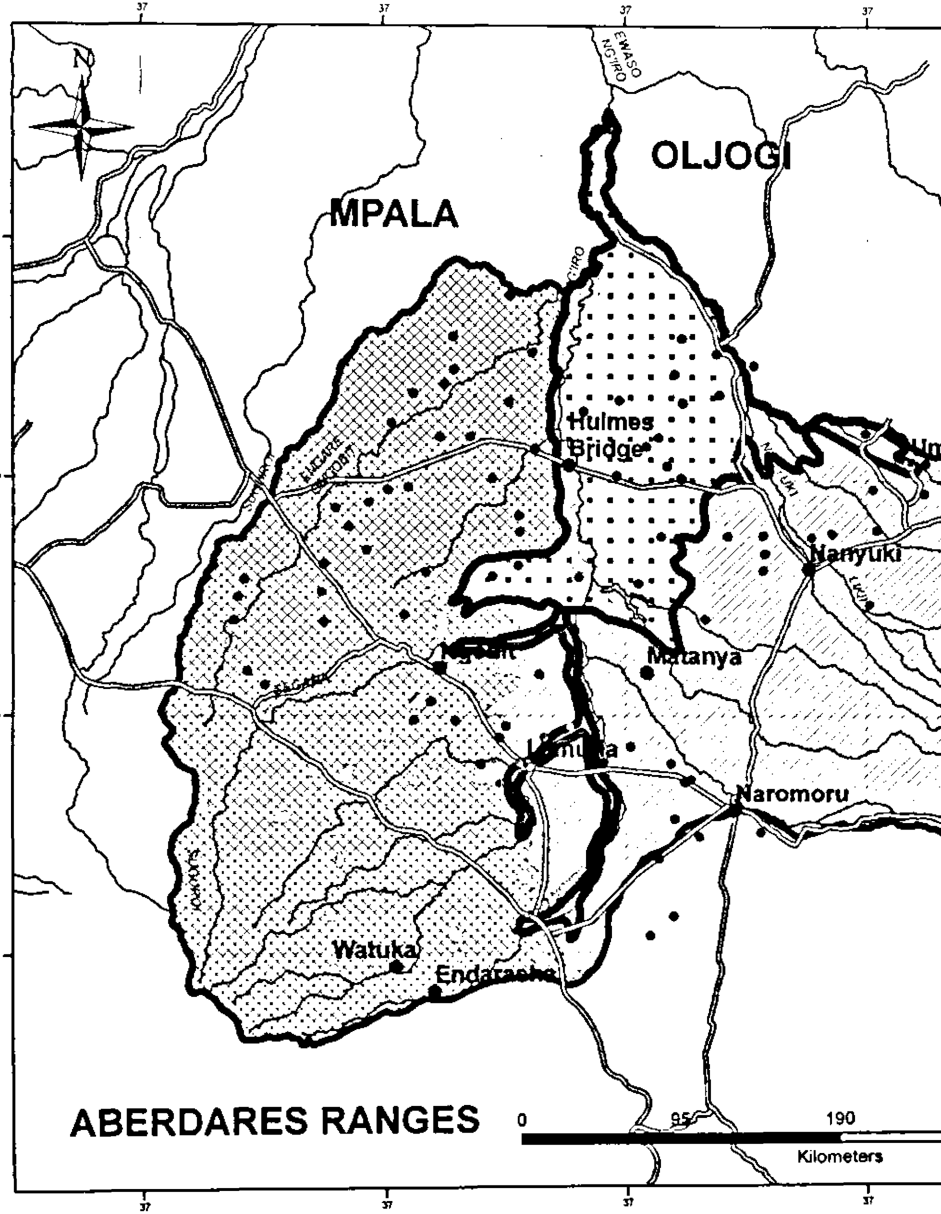
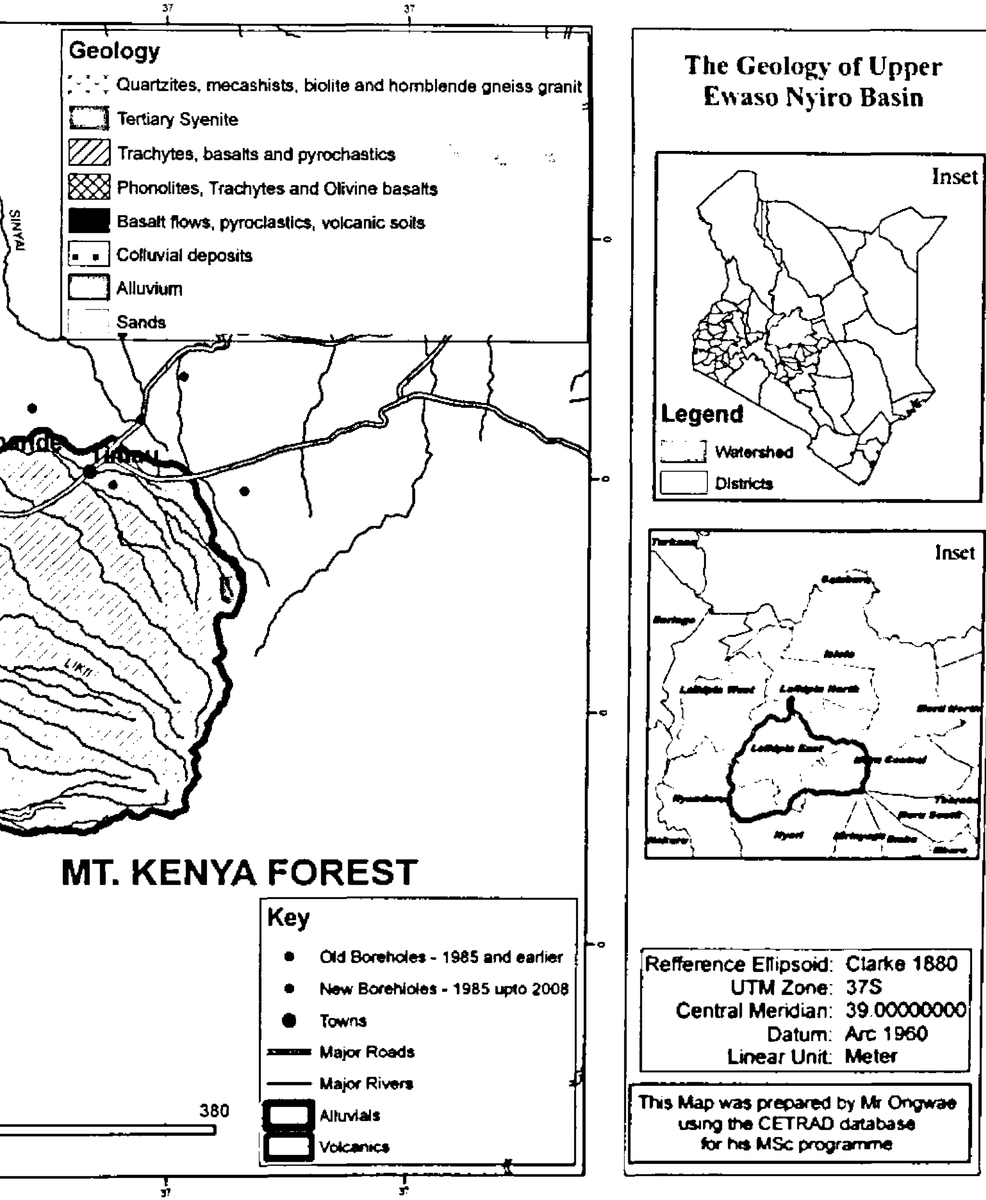


Figure 2.3 : Geology of the area

Source: CETRAD Database (2009)



The Geology of Upper Ewaso Nyiro Basin
Geology
Quartzites, mecashists, biolite and hornblende gneiss granit
Tertiary Syenite
Trachytes, basalts and pyrochastics
Phonolites, Trachytes and Olivine basalts
Basalt flows, pyroclastics, volcanic soils
Colluvial deposits
Alluvium
Sands
SINYAI
LIKII
MT. KENYA FOREST
Inset
Legend
Watershed
Districts
Inset
Key
Old Boreholes - 1985 and earlier
New Boreholes - 1985 upto 2008
Towns
Major Roads
Major Rivers
Alluvials
Volcanics
380
Refference Ellipsoid: Clarke 1880
UTM Zone: 37S
Central Meridian: 39.00000000
Datum: Arc 1960
Linear Unit: Meter
This Map was prepared by Mr Ongwae using the CETRAD database for his MSc programme

2.4.5 Geological Structures

Structures associated with Basement system are noted at Suguroi river valley (Mutara) where gneisses and schists strike to the north-north east and lineation plunge to the north at low angles. Foliations are seen at Basement system exposed along the river beds.

The Aberdare Ranges are as a result of a series of eruptive craters whose lavas (phonolites and trachytes) overwrapped to produce the Range that stand out today (Shakleton, 1946). According to Baker (1967) a series of faults may have occurred in the area, as the lay out of the formation show some displacement of the major central volcanics and eruptions of the tuffs and lava of Ndaragwa –Ngobit tuff. Due to subsequent lava flow of Mt. Kenya suite, the faulting episodes are not evident on the surface. Within the area are also some swampy river beds which are as a result of gradient reduction by tilting and as a result of isostatic sinking of the Aberdare massif (Shackleton, 1946).

2.4.6 Physiography

The physiography of the area is dominated by edifices, which are mainly volcanic in nature. The main physiographic units in the study are:

(i) The volcanic edifices of Mount Kenya and the Aberdares

(ii) The Central Laikipia Plateau

The volcanic edifice of the study area can be divided into the upper and the Lower Volcanic Slopes. The upper Volcanic Slopes are covered with forests and enjoy the highest rainfall supplying a substantial part of the perennial runoff. The terrain is often rugged and the rivers have deeply incised valley (Shackleton, 1946). These upper volcanic slopes happen to be the groundwater recharge and transmission areas and at lower elevations many springs occur. On the Aberdare side, strong springs are more common than on the Mount Kenya side where diffuse effluence is a general feature.

The Lower Volcanic Slopes are used for rainfed agriculture and are among the most productive lands in the area. The terrain is steep sloping with stream incision generally decreasing downstream, so is rainfall (Decurtins, 1992).

2.5 Soils of the Area

The distribution of soil types in the study area of upper Ewaso Ng'iro Basin is as shown on figure 2.4 and is related to relief, geological formations on which they lie and climate which have influenced their weathering and development (Sombroek *et al*, 1982 ; Mbuvi *et al*, 1994). The study area can be divided into three zones based on topography (mountain slopes, foot slopes and basement area) and their soils are described as follows.

2.5.1 Mountain Slopes

This is a zone on the highlands (Mt. Kenya and Aberdares) that has an altitude more than 2000 m above sea level and is dominated by deep clay loam soils on the volcanic rocks (Trachytes). The trachytes are mainly of olivine type, comprising of stony mollic cambisols and mollic andosols of medium (50 – 80 cm) depth in the upper slopes, while in the middle parts are deep Mollic Andosols and in the lower parts are deep to very deep humid Alisols (FAO classifications, 1986). The soils have favorable moisture storage capacity and aeration conditions which enables them to allow water to pass through easily. The general soil characteristics in these zones are summarized in Table 2.3.

Table 2.3 : Mountain Slopes Soil Characteristics

Characteristics	**Soil Types**			
	Mollic Andosols	Humic Alisols	Humic Acrsols	Mollic Cambisols
Occurrence	Upper Part	Middle Part	Lower Part	Valleys
Soil Depth	Moderately-deep	Deep-very deep	Deep-very deep	Shallow – moderate
Texture	Clay loam	Clay	Clay	Loam – clay loam
Drainage class	Well drained	Well drained	Well drained	Well drained
AWC	100 – 150	150 - 180	150 – 180	30 – 50

Sources: Mainga and Mbuvi 1994; Kironchi, 1998

Available water capacity (AWC) is defined as the amount of water (cm^3 water/100 cm^3 soil) retained in the soil between the "field capacity" and the "permanent wilting point"

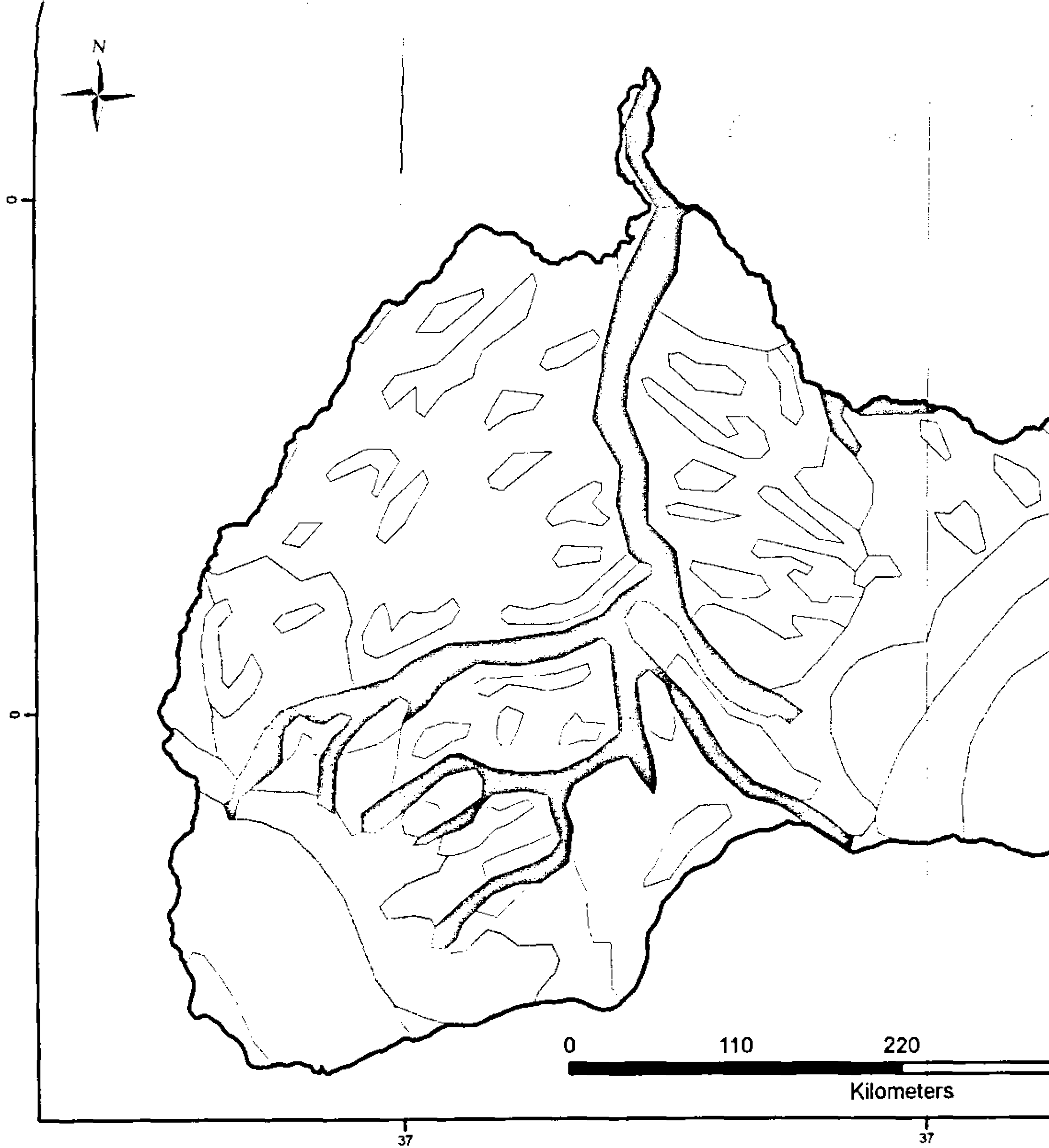
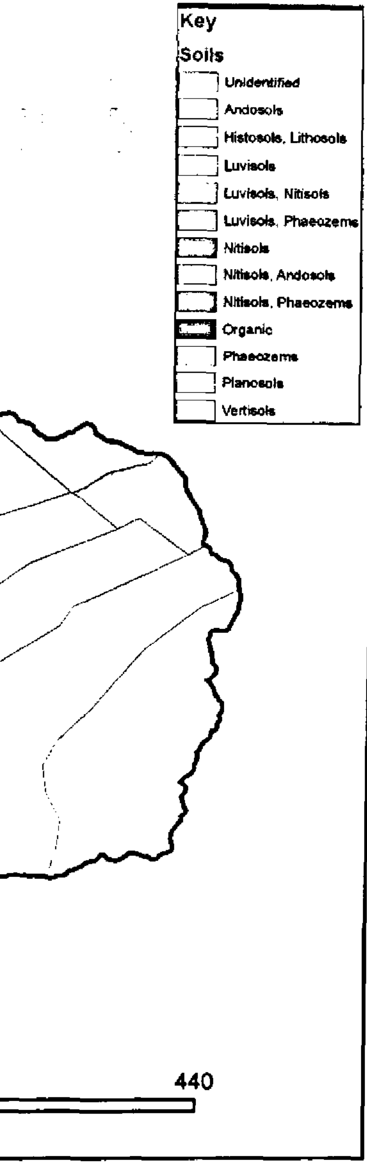
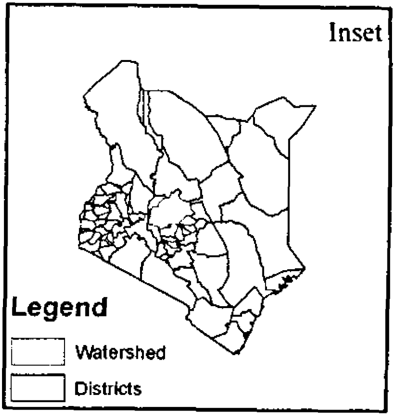


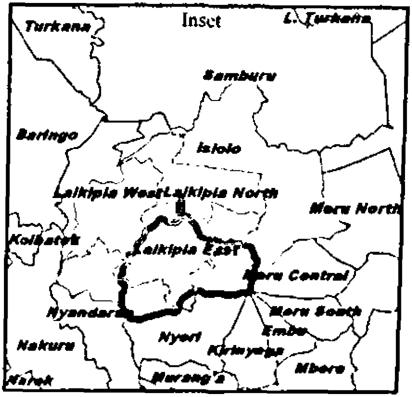
Figure 2.4 : Soil Map of the area

Source: CETRAD – by T. Kling, (1993)



A Soil Map of Upper Ewaso Nyiro Basin





Refference Ellipsoid: Clarke 1880
UTM Zone: 37S
Central Meridian: 39.00000000
Datum: Arc 1960
Linear Unit: Meter

This Map was prepared by Mr Ongwae using the CETRAD database for his MSc programme.

2.5.2 Foot Slopes

The soils of the foot slopes and plateau are underlain by phonolites from Mt. Kenya volcanoes and their distribution is influenced mainly by land forms. These include lavisols and phaeozens which are well drained while vertisols and planosols are imperfectly drained and crack during the dry season as they shrink, while during the wet season the soils swell up. Whereas the infiltration rate of the dry soil is very high due to the cracks, permeability drops to very low values once the soils are saturated table 2.4.

Table 2.4 : Soil types and their Characteristics in the Foot Slopes and Plateau

Characteristics	**Soil Types**			
	Ferric Luvisols	Luvic/vertic Phaeozems	Eutric Vertisols	Aortic Planosols
Occurrences	Ridges, convex slopes	Flat parts	Flat concave slopes	Flat parts
Soil depth	Deep – very deep	Deep – very deep	Deep	Deep
Texture	Clay	Clay	Clay	Sand clay
Bulk density	1.0 – 1.4	1.0 – 1.3	1.0 – 1.2	1.0 – 1.3
Organic matter	1 – 3%	2 – 4%	2 – 4%	2 -5%
AWC mm $100cm^{-1}$	180 – 200	150 - 180	150 - 180	140 – 160
Drainage Class	Well drained	Well drained	Imperfectly drained	Imperfectly drained

Sources: Mbuvi *et al.,* 1994.

2.5.3 Basement Area

The area is covered by basement system. The soils that have developed from these metamorphic rocks found are around Mpala- Oljogi area extending to the lower part of Mutara Agricultural Development Cooperation (ADC) farms and comprise mostly of chromic cambisols and ferric-chromic luvisols, which are grouped into Ferric Luvisols, Chromic luvisols, Chromic cambisols, and Eutric leptosols Table 2.5.

Table 2.5 : The major soil types on the basement area

Characteristics	Soil Types			
	Ferric Luvisols	Chromic luvisols	Chromic cambisols	Eutric Leptosols
Occurrences	Uplands	Uplands	Valleys, eroded parts	Steep slopes, hills
Soil depth	Moderately deep to deep	Moderately deep to deep	Shallow to moderately	Very shallow to shallow
Texture	Sand clay	Sand clay	Sand loam clay	Loamy sand
Bulk density	1.2 – 1.4	1.1 -1.5	1.1 – 1.4	1.3 – 1.4
Organic matter	0.6 – 2.4	0.5 – 1.9	0.8 – 2.3	1.0 – 4.2
AWC	70 – 100	70 – 100	30 - 50	5 – 10
Drainage Class	Excessive - well drained	Well drained	Excessive - well drained	Well drained

Source: Kironchi *et al*, 1992

Generally these soils are of low organic matter and high content of silica mineral. They have of low porosity and relatively high bulk densities, hence have poor water storage capacity and tend to form strong surface seals. The soils are well to excessively drained hence have high runoff properties (Kironchi *et al*, 1992).

Selected representative sites for the zones that are discussed above within the study area are Karuri, Kalalu and Ol jogi whose soils are specifically summarized in Table 2.6.

Table 2.6 : A summary of soils in the Karuri, Kalalu and Ol jogi

Characteristics	**Forest area (Karuri)**	**Foot slopes (Kalalu)**	**Basement (Mpala-ol Jogi to lower Mutara)**
Location	$1^0$05'N/$35^0$44'E	$0^0$05'N/$37^0$10'E	$0^0$23N/$37^0$04E
Elevation (m)	2900	2020	1780
Agroclimatic zone	III (sub humid)	IV (semi-humid to semi arid)	V (semi-arid)
Rainfall (mm/year)	800 –1000	650 – 750	400 – 500
Geology	Volcanic rocks: Trachytes	Volcanic rocks: Phonolites	Basement system: Gneisses
Soils (FAO/UNESCO) classification	Mollic Andosol	Ferric Luvisol	Chromo – Ferric Lixisol
Slope (%)	10 – 14	5	4 – 7
Vegetation	Montane forest Podocarpus and Olea species	Clearing from dry cedar montane sclerophyll forest	Acacia bushland: Etbica, Mellifera and Tortilis dominant
Land use	Forest reserve, grazing, partly cleared for small scale farming e.g. potatoes	Small scale mixed farming. Maize, beans, potatoes and wheat	Communal grazing by Masai pastoralists

Source: Sombroek *et al.*, 1982.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Data collection

The process of data collection started with a desk study and base map preparation. It was, followed by preliminary field survey (reconnaissance) from 12^{th} to 15^{th} May 2009. The preliminary field survey was done with the aid of topographical and geological maps. Boreholes and rainfall stations within the area were identified that served as data collection points.

Four different approaches were involved to obtain the required data; three of these were for primary data and one for secondary data.

3.1.1 Primary Data (Field Work)

This is the original (raw) data, which was obtained from the field by the researcher. The Primary data collection methods involved administration of questionnaire, field observations and measurements.

3.1.2 Questionnaire

A standard questionnaire was used during the survey. A set of questions drawn to meet the objectives of the study were administered to respondents who included the borehole owners, farm managers, managers or water officers in charge of the boreholes that were identified. Both open-ended and structured questions were used to facilitate the whole process of data collection (Appendix 1). A questionnaire was prepared and pilot tested and eventually administered from 6^{th} June to 7^{th} July 2009. The data was then extracted from the filled questionnaires for analysis.

From the results obtained, several subjects came up that included drying up of boreholes, drop of water levels, reduced yields, 24 hrs pumping, abandoned boreholes and drilling of new boreholes among other issues. The survey was carried out in a period of four weeks.

3.1.3 Observation

During the fieldwork, observations were made; using a digital camera pictorial records on status of vegetation and rivers and water rest level measurements (plate 2.1, 2.2 and Appendix 3) were taken.

3.2 Field Measurements

3.2.1 Water Rest Levels

A dipper; Heron dipper-T Water Level Meter (600 m) was used to measure the water rest levels in the selected data collection points; (boreholes) in the field. The depth measurements were recorded in field notebook which were later converted in the office to levels above sea levels and used to produce a vector map (figure 4.2b) through gridding method (Kriging Type) to show the groundwater flow, by applying Golden software (Surfer 8 program).

3.2.2 Direction, Position and Altitude

Global Positioning System (GPS) (Model Garmin-GPS12xl): was used to record the direction, altitude and positions of sampling points. Field records were transferred and entered into Computer. Using ArcGIS 9.2. stations' points were fixed and are shown on a geo-referenced map figures 3.1 and 4.36.

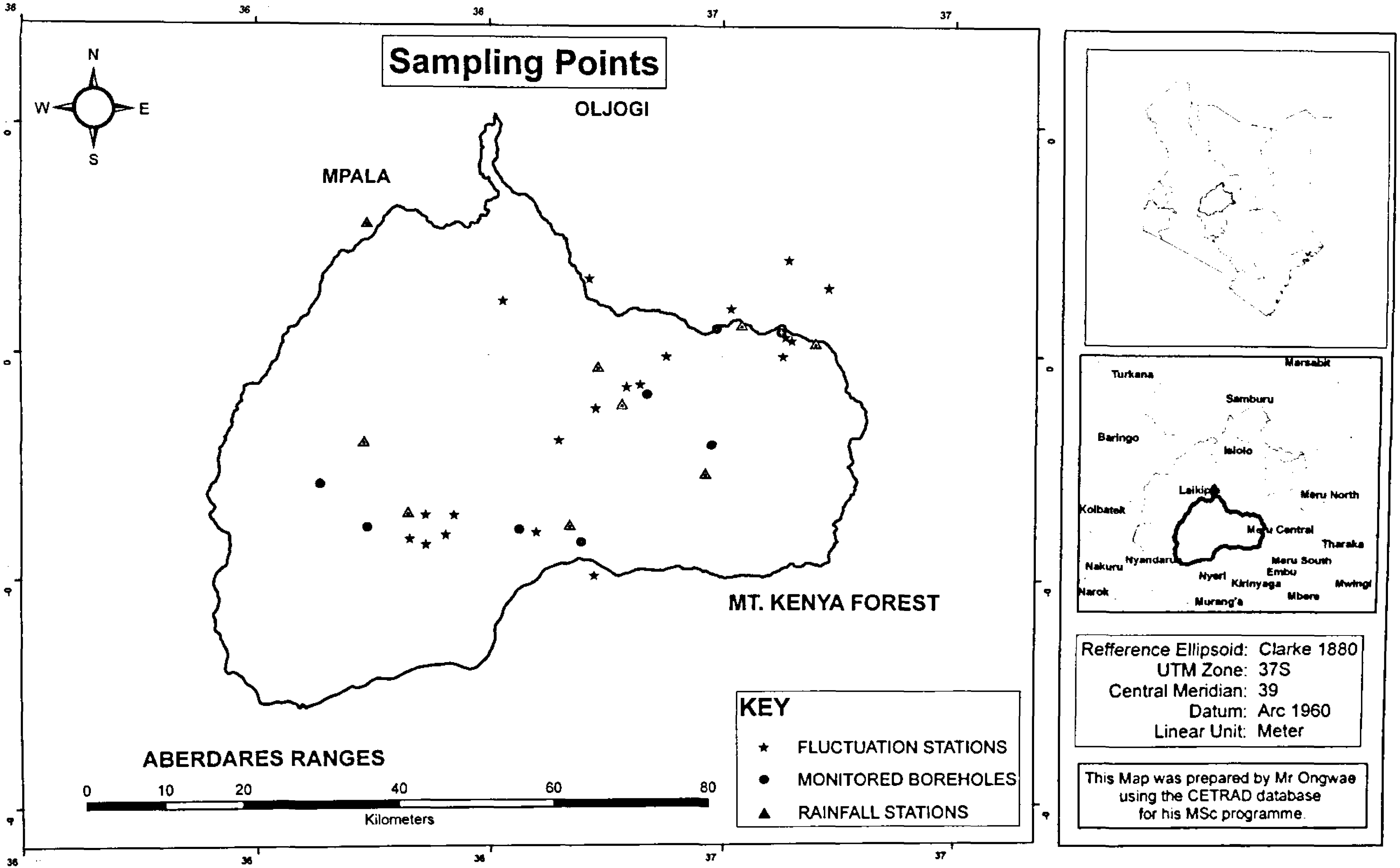


Figure 3.1: Sampling Points

3.3 Secondary Data

A wide range of secondary data was used including: GIS and remote sensing maps, geological maps and reports Nos 79, 12 and 11, water and land use publications, thesis, among others.

3.3.1 Rainfall Data

Ten Rainfall stations were selected during the preliminary survey. Annual and monthly rainfall records spanning from 1983 to 2008 were collected from the identified stations within the study area. Data gaps were addressed using Spatial Correlation Method (3.2.1). The data obtained was used to determine the correlation with the ground water fluctuations. The data used, was normalized by converting the values into standard form (Appendix 5). Data from the selected rainfall stations had records stalled at some point, to update the records the researcher had to liaise with Metrological station where need be described methods were applied to fill the gaps.

3.3.2 Rainfall and groundwater recharge relationship

Long term trends of rainfall and moving averages were determined for each of the selected stations as shown on figures 4.4 to 4.12 Correlation coefficient for untransformed and logarithm transformed data were compared and results given on figure 4.15 to 4.25. This method was to establish the relationship between the nearest rainfall station and far off stations in the Mount Kenya and Aberdares, that is Ontulili and Shamata stations respectively.

The most commonly used transformation in water resources is the logarithm. Logs of water discharge, hydraulic conductivity, or concentrations are often taken before statistical analyses are performed (Helsel and Hirsch, 2002)

3.3.3 Rainfall - Groundwater Fluctuations Temporal Relationships

Temporal relationships were established between groundwater fluctuations derived from borehole water rest levels, appendix 3 and monthly rainfall, appendix 5 to produce plots shown on figures 4.26 to 4.33. Moving averages were applied to mimic the relationship for the ten stations. Moving averages methods are used to provide an objective measure of trend direction by smoothing available data. In this method it was preferred to apply shorter length moving averages as they are more sensitive and identify new trends earlier, for longer moving averages could be more reliable but less responsive, could be useful when only picking up the big trends.

3.3.4 Method for drawing the rainfall distribution map

Data of 25 (Appendix 6) rainfall stations distributed in the area were obtained. Their data range was 25years from 1983 t0 2008. Data was converted to annual mean for each station. The means were extrapolated using GIS extrapolate method of Kriging type to produce rainfall distribution map figure 2.1

3.3.5 Homogeneity Test

The method used to test the homogeneity of the rainfall data is the Single Mass Curve, whereby, the data is cumulated forwards in time.

This technique was used to correct in-homogeneity in rainfall data and water rest levels; it was also applied to extrapolate months or years without data.

3.4 Data Quality Control

Data Quality control was important to be carried out in order to detect any discontinuities in the data that could have occurred from non- natural influences like changes in observational schedules and methods, instrumental changes, shifting of station sites, and other human processes (WMO, 1996). Data cleaning is a condition to ensure that a quality data is used for the study; some analysis had to be done on it to ascertain that it was homogeneous and consistent.

3.4.1 Missing Data

(i) **Spatial correlation method** estimating missing data was adopted. This was done by correlating the mean monthly parameters over the given years of the missing station with another station within the same climatic zone and linear regression used to estimate the missing data where a high correlation exists. A few stations reported missing data in the year of 1998; this was attributed to El-Nino rains that disrupted the measurement process. Estimation of the missing rainfall data was carried out using this method. A simple linear relationship between the variable with missing records, X_t and a related parameter, Y_t is expressed as:

$$Y_t = aX_t + b$$

Where a and b are coefficients estimated from the available data. Where no significant correlation was found arithmetic mean was used to approximate the missing data.

ii Arithmetic Mean method

Where there was any missing records of the data provided, then the missing parts of the missing data were estimated using the arithmetic mean method.

$$X_m = \left[\frac{\overline{x}}{\overline{Y_a}}\right] Y_a$$

Where X_m is the missing data

Y_a is the available data of the station with highest correlation with whose data is missing data.

$\overline{X}$ is the mean value for the station with missing data

$\overline{Y_a}$ is the mean value of station with complete data

3.5 Determination of Groundwater Flow Directions

Water rest levels data appendix 3 were identified and converted to peziometric levels (that is altitude minus water rest level). The data was then entered into Surfer program to produce peziometric curves showing flow direction (figure 4.2b).

3.5.1 Determination of Rainfall Characteristics and Groundwater Fluctuations

Rainfall characteristics were obtained by plotting normalized annual and monthly data as shown on figures 4.13 and 4.14 respectfully so as to identify extreme events. Rainfall trend for stations used in the study are illustrated on figures 4.4 to figures 4.12.

Normalization was performed on the data to ensure that a database structure is suitable for general-purpose querying and free of certain undesirable characteristics; insertion, update, and deletion anomalies that could lead to a loss of data integrity. Standard score was used to show how many standard deviations an observation or datum was above or below the mean (Richard *et al,* 2000).

The standard score is:

$$z = \frac{x - \mu}{\sigma}$$

where:

x is a raw score to be standardized;

μ is the mean of the population;

σ is the standard deviation of the population.

The quantity z represents the distance between the raw score and the population mean in units of the standard deviation. z is negative when the raw score is below the mean, positive when above. Observations between -1 and 1 (within 1 standard deviation of the mean of 0) imply normal observation, while observations below and above this range are regarded to be below and above normal respectively as illustrated on figure 4.14. The normalized outcome was categorized into four groups known as quadrants abbreviated as Q. Where Q_1 ranges from infinity to -1, Q_2 from -1 to 0 while Q_3 from 0 to 1. The last quadrant; Q_4 spans from 1 to positive infinity. First quadrant represents rainfall below normal, the second and third represents the normal while the fourth represents the above normal.

The monthly rainfall data for the selected ten stations were plotted against WRL fluctuations. Eight of these are nearest to monitored boreholes shown on appendix 3 and the other two rainfall station are further up in the forest shown on figure 4.36. The degree of correlation was determined for each and is presented on figure 4.15 to figures 4.25 where results for both untransformed and log transformed data are compared. This was necessary because water resources data should undergo Transformation methods for three purposes: to make data more symmetric, to make data more linear, and to make data more constant in variance (Helsel and Hirsch, 2002).

3.5.2 Significance Test

Student t-test was performed to determine the significance rainfall trends as well as correlation to WRL. Estimating significance between two means was applied. The means were divided into two equal numbers of years, their means and respective standard deviations calculated. The relation;

$$t_r = \frac{\overline{x_2} - \overline{x_1}}{\left[\frac{S_2^2}{n_2 - 1} + \frac{S_1^2}{n_1 - 1}\right]^{\frac{1}{2}}}$$ was used, where:

$\overline{X_1}$, $\overline{X_2}$ are sample means for the two periods

S_1, S_2 are sample standard deviations for the two periods

$n_1 = n_2 = 13$ years

t_r = t – statistic at the r % level of significance

The results for the difference in mean rainfall in the two periods 1983 to 1995 and 1996 to 2008 for all stations compared (t-calculated and t-tabulated) at 0.01 and 0.05 (1% and 5%) significance levels presented on table 4.2.

3.5.3 Estimation of Groundwater Recharge in Six Sub-Regions

The study area was divided into six regions figure 4.1 based on geological and topographical similarity. Rainfall stations of every region were considered, to estimate the recharge. Assumptions are that other variables are held constant. However, according to both Simmers (1987) and Bredenkamp *et al.*, (1995), methods used to estimate recharge rates were found have limitations. Every single estimation technique gave suspect results. However, using their advantages and disadvantages, it was possible to judge their accuracy and reliability.

For this study, Empirical and Cumulative Rainfall Departure (CRD) Methods have been used to estimation possible recharge for the six regions. These have been used because they are simple and powerful for groundwater recharge estimation. CRD can account for rainfall series with trends and is more accurate. Both methods do not require large amounts of spatial data.

3.5.4 Empirical Method:

3.5.4.1 Chaturvedi Formula

Based on the water level fluctuations and rainfall amounts in Ganga-Yamuna doab, Chaturvedi in 1936 derived an empirical relationship to arrive at the recharge as a function of annual precipitation (Chaturvedi, 1973).

$$R = 2.0\,(P - 15)^{0.4}$$

Where,

R = Net recharge due to precipitation during the year, in millimeters;

P = Annual precipitation, in millimeters.

This formula was later modified by further work at the

U. P. Irrigation Research Institute, Roorkee, (Kumar, 2006) and the modified form of the formula is

$$R = 1.35\,(P - 14)^{0.5,}$$

3.5.4.2 Bredenkamp Formula

Bredenkamp1978 and 1990 plotted recharge estimates from a dolomitic aquifers in different areas, and showed that a linear relationship is obtained a above an annual rainfall of 313mm. this was adjusted to give the following formula (Bredenkamp *et al.* 1995)

$$R = 0.32(MAP - 360)\text{mm}$$

Where

MAP- Mean Annual Precipitation

3.5.4.3 Cumulative Rainfall Departure (CRD)

Cumulative rainfall departure (CRD) was calculated using the method below, (Bredenkamp, *et al.*, 1995): $CRD = \sum_{n=1}^{i} R_n - \kappa \sum_{n=1}^{i} R_{av}$ $(I = 0,1,2,3.......N)$

Where R is rainfall amount with subscript "i" indicating the i-th month, "av" the average and $k = 1 + (Q_P + Q_{out})/(AR_{av})$. K=1 indicates that pumping does not occur and $k > 1$ if pumping and /or natural outflow takes place.

It is assumed that a CRD has a linear relationship with a monthly water level change. Bredenkamp *et al.* (1995) derived the relationship in which:

$\Delta h_i = (r/S)({}^{1}_{av}CRD)$ (I = 1, 2, 3....N) where 'r' is a percentage of the CRD which results in recharge from rainfall, S is aquifer storativity (Specific Yield). 'h' is water level change. From this only the ratio r/s can be determined through water level simulation.

The above equation may be used to estimate the ratio of recharge to aquifer storativity through simple regression between **CRD** and Δh (Bredenkamp, *et al.* 1995), where 'r' is the gradient.

Procedure of CRD Method

Two rainfall stations (Ontulili on Mt. Kenya, and Shamata on the Aberdare ranges) were used to calculate recharge to different boreholes using the ground water fluctuations.

- Specify the period of study
- Determine mean annual rainfall for each station for the period in mm.
- Determine the deviation from the mean -CRD
- Adopt CRD positive deviation values only
- Determine groundwater fluctuations Δh that correspond to the positive CRD
- Run a simple regression between CRD and Δh in mm
- Gradient of the regression equation is the recharge - R

Example working for Kararu Station (C12497)

Kararu Pry School Borehole C12497 Location –Timau VS Ontulili rainfall station; average is 69.7mm

Period	Ri	Av	CRD	Δh mm
Oct.2005	32.1	69.7	-37.6	2200
Nov.2005	65.9	69.7	-3.8	1400
Dec.2005	16.1	69.7	-53.6	-3100
Jan.2006	11	69.7	-58.7	-800
Feb.2006	0	69.7	-69.7	2650
Mar2006	84.4	69.7	14.7	-2080
Apr2006	151.3	69.7	81.6	-7570
May2006	125.5	69.7	55.8	9800
Jun2006	49.1	69.7	-20.6	4600
Jul2006	35	69.7	-34.7	0
Aug2006	104.4	69.7	34.7	1400
Sep2006	59.4	69.7	-10.3	-13340
Oct2006	117	69.7	47.3	-10010
Nov2006	148	69.7	78.3	9850
Dec2006	63	69.7	-6.7	12400
Jan2007	18.6	69.7	-51.1	4970
Feb2007	4	69.7	-65.7	-17000
Mar2007	61.6	69.7	-8.1	-2920
Apr2007	147.1	69.7	77.4	7650
Jun2007	163.8	69.7	94.1	-490
Jul2007	80.8	69.7	11.1	-270
Aug2007	71.6	69.7	1.9	930
Sep2007	113.4	69.7	43.7	-7670
Oct2007	78.6	69.7	8.9	-7530
Nov2007	72.2	69.7	2.5	10
Dec2007	48.4	69.7	-21.3	80
Jan2008	11	69.7	-58.7	14180
Feb2008	55	69.7	-14.7	8930
Mar2008	0	69.7	-69.7	-15670
Apr2008	16	69.7	-53.7	-7530
May2008	64.8	69.7	-4.9	10
Jun2008	121.6	69.7	51.9	14530
Jul2008	0	69.7	-69.7	-270
Aug2008	96.2	69.7	26.5	930
Sep2008	43	69.7	-26.7	4330
Oct2008	125.9	69.7	56.2	-9550
Nov2008	140.6	69.7	70.9	-2970
Dec2008	121.9	69.7	52.2	5080
			-69.7	2190

Positive CRD

CRD(mm)	Change in WRL (mm)
14.7	-2080
81.6	-7570
55.8	9800
34.7	1400
47.3	-10010
78.3	9850
77.4	7650
94.1	-490
11.1	-270
1.9	930
43.7	-7670
8.9	-7530
2.5	10
51.9	14530
26.5	930
56.2	-9550
70.9	-2970
52.2	5080

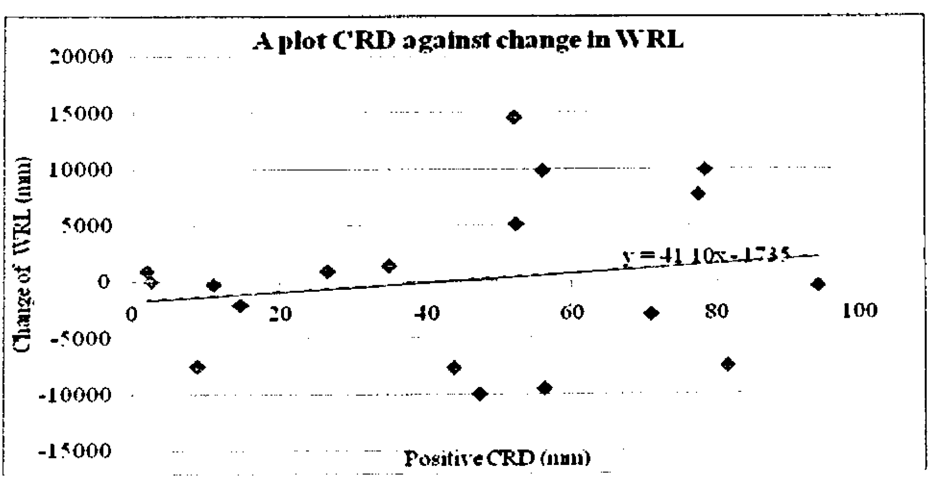


Figure 3.2: A plot of CRD against change in WRL

CHAPTER FOUR

4.0 RESULTS AND INTERPRETATION

This chapter summarizes field and statistical analysis results of the collected data.

4.1 Water Flow Characteristics

The rivers shown on (Figure 4.1) flow from the North Eastern flank of Mt. Kenya and the North West of the Aberdares.

Rivers Ewaso Ng'iro and Nanyuki with their tributaries formed the boundaries of the study area. Their areas of sub -catchment are 3421 km^2 and 1179 km^2 respectfully (CETRAD Database 2009). The total length of Ewaso Ng'iro river is 60 km while the total length of all rivers in the Ewaso Ng'iro Sub catchment is 635 km. Annual rainfall quantity (volume) in the sub - catchment is 346,400,000 m^3. The average annual rainfall in the catchment is 800mm with a range of 950-690 mm. In the Ewaso Ng'iro sub catchment Nanyuki River is 42 km long while the total length of all rivers in Ewaso Ng'iro sub catchment is 107 km. Annual rainfall quantity (volume) in the sub- catchment is 76,000,000 m^3. The average annual rainfall in the catchment area is 1,020 mm and ranges from 680-1350 mm. Ewaso Ng'iro river has 310 recorded abstraction points and Nanyuki river has 34 recorded abstraction points CETRAD Database (2009). On the highlands, river water flows quite fast and the speed reduces with reducing altitude. Rivers that start on the plateau normally dry out faster than those that start in the forest. Volume of river water changes with seasons, more in the rain season and less or none in the dry season. It is possible that river water recharges the ground aquifers but studies will be required to confirm that. The two rivers: River Nanyuki and Ewaso Ng'iro River have their water mixing around Matanya and further down at Impala- Ol Jogio area (figure 4.1).

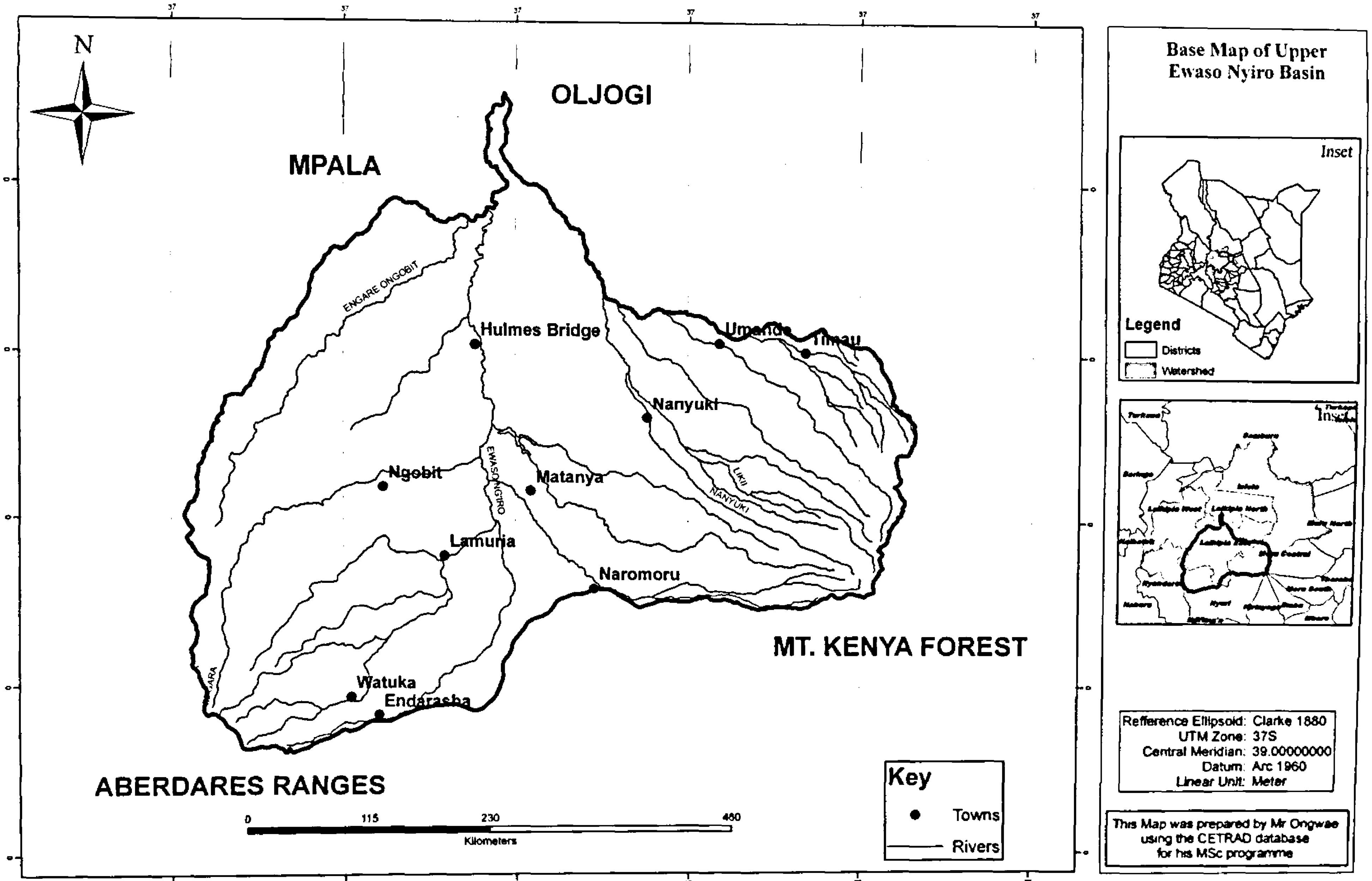


Figure4.1: Surface Water Flow Directions

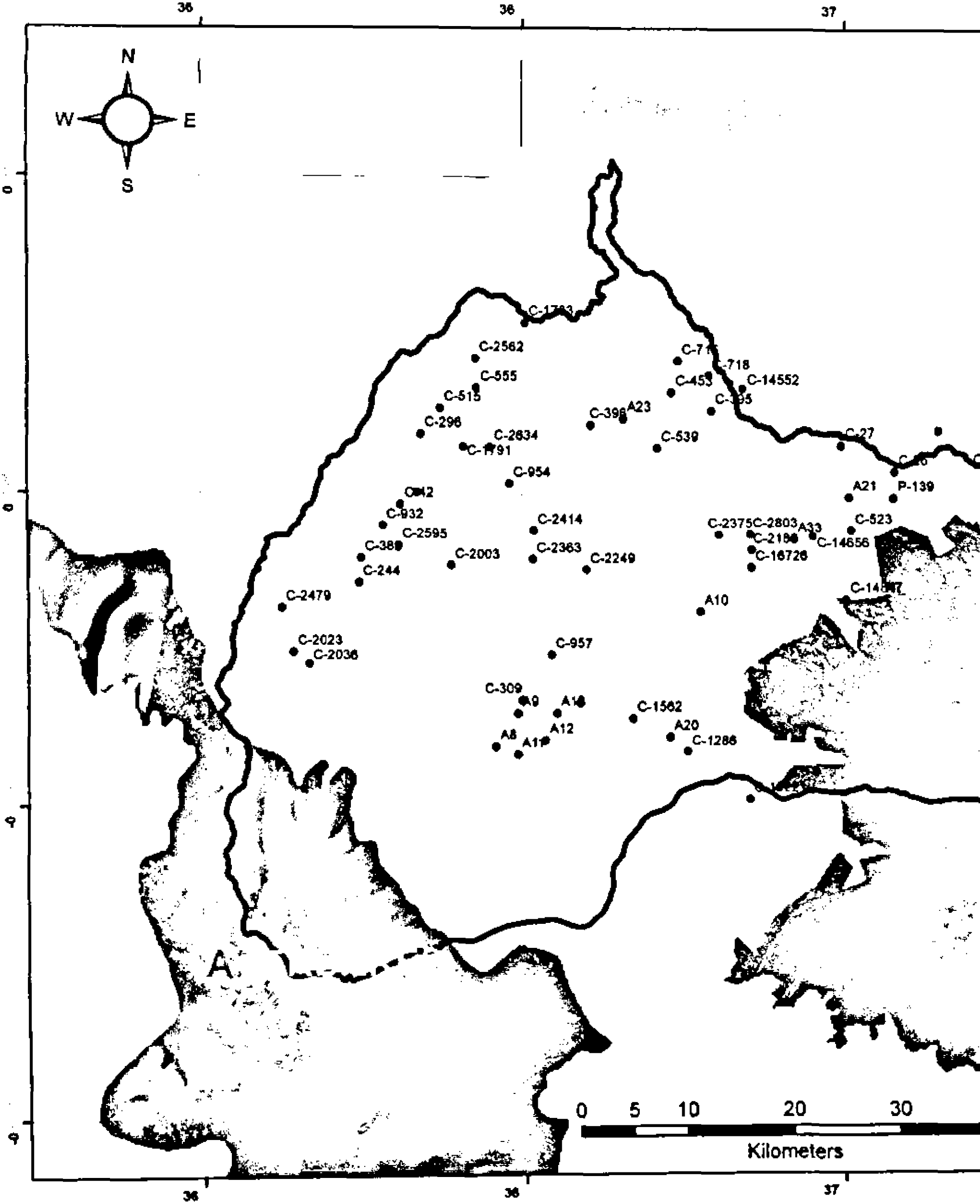
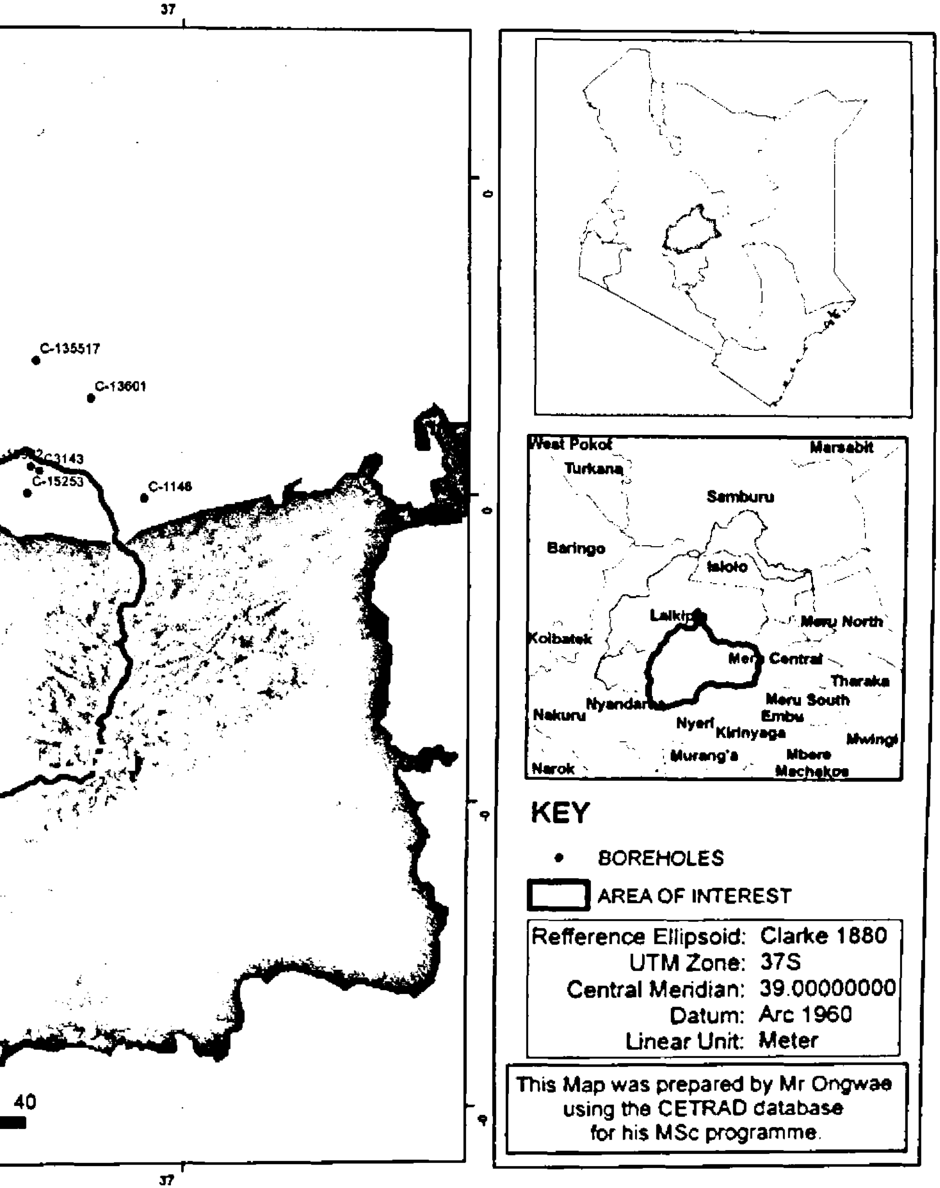


Figure 4.2 (a): Recharge and discharge areas


37
C-135517
C-13601
C3143
C-15253
C-1146
40
37
West Pokot
Marsabit
Turkana
Samburu
Baringo
Isiolo
Laikipia
Meru North
Koibatek
Meru Central
Tharaka
Meru South
Nakuru
Embu
Nyeri
Kirinyaga
Mwingi
Murang'a
Mbere
Narok
Machakos
KEY
BOREHOLES
AREA OF INTEREST
Refference Ellipsoid: Clarke 1880
UTM Zone: 37S
Central Meridian: 39.00000000
Datum: Arc 1960
Linear Unit: Meter
This Map was prepared by Mr Ongwae using the CETRAD database for his MSc programme.

Several boreholes (Appendix 4) have been drilled in the area as shown in figure 4.2. Those with geo-referenced data (Table 4.1) have been used to determine the pieziometric levels using the method stated section 3.2.1 to produce the vector map (Figure 4.2b).

Table 4.1 : *Pieziometric Levels*
a.s.l - above sea level

B_HOLE_COD	B_Hole	Location	NORTHINGS	EASTINGS	WRL IN METRES(a.s.l)
C-1286	Aikman	Naromoru	-0.161	36.977	1891
C-650	Ol Ndonyol	Timau	0.133	37.199	2311
C-1148	Timau Marania	Timau	0.072	37.357	2404
C3143	Lolmarik	Timau	0.038	37.238	2251
C-10922	Lolmarik	Timau	0.083	37.242	2277
C-13601	Ole Naishu (Kamwaki)	Loldaiga	0.157	37.312	1949
C-135517	Ole Naishu (Kamwaki)	Loldaiga	0.189	37.266	1957
C-14847	Mutimayu	Kangaita	-0.141	37.054	2167
C-15253	Greenlands Agroproducers	Timau	0.076	37.259	2114
C-17107	Lengetia Farm	Ol Pejeta	-0.133	36.879	1826
C-15221	KHE Quadco	Naromoru	-0.0924	37.0051	1399
C-14552	KHE	Naibor/ Muramati	0.167	37.035	1751
C-14656	Vegpro K	Kalalu	0.0418	37.0937	1934
C-16726	Nanyuki District Hospital	Nanyuki	0.01386	37.04209	1924
A11	Wamura	Lamuria	-0.149	36.845	2050
A8	Kijabe	Lamuria	-0.135	36.831	2058
A9	Segera 1	Lamuria	-0.114	36.845	2105
A12	Imenti 1	Lamuria	-0.137	36.868	2151
A13	Imenti 2	Lamuria	-0.114	36.878	2152
A20	Kihato	Kihato	-0.134	36.973	1975
A10	Sweetwaters	Sweetwaters	-0.025	36.999	1858
A21	E. Laikipia -1	Ethi	0.0759	37.124	1987
A23	Rugutu-1	Mutirithia	0.141	36.935	1854
A33	Mukima-2	Nkando	0.039	37.078	1876

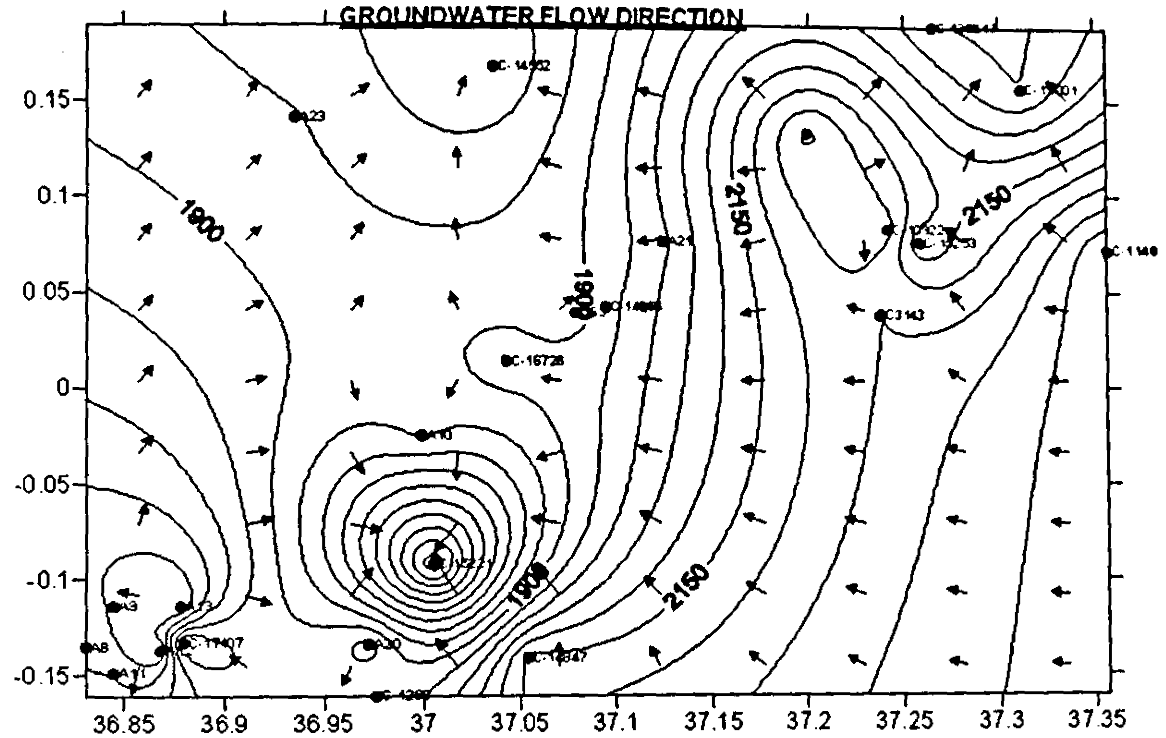


Figure 4.2 (b): Recharge and discharge areas

Summary

The surface water flows in a South – North directions, while ground water flows from South East to North – North West from Mt. Kenya and South West to North – North East in Aberdares. Mt. Kenya and Aberdare zones are recharge areas while the Northern lowlands serve as the discharge zone in the catchment.

4.2 RAINFALL - GROUNDWATER RECHARGE RELATIONSHIPS

4.2.1 Long Term Rainfall Characteristics (1983-2008)

The long term rainfall trends were found to be variable, with increasing trends (1983 – 2008) for Lolmarik, Naromoru, Ol Donyo, Satima, Ol-Pejeta, and Tharua and decreasing trends for Nanyuki, Sirimon, and Ontulili (Figures 4.4, to 4.11). Students T-tests indicate that the most significant trends are Lolmarik, Naromoru and OL Donyo (increasing) and Nanyuki (decreasing). Thus, on the long – term, rainfall is increasing in the highland (recharge) area and decreasing in the lowland (discharge) area. This could, therefore, reflect the impact of land use in the lowlands e.g. vegetation clearing which reduces the effective role of vegetation in the hydrological cycle.

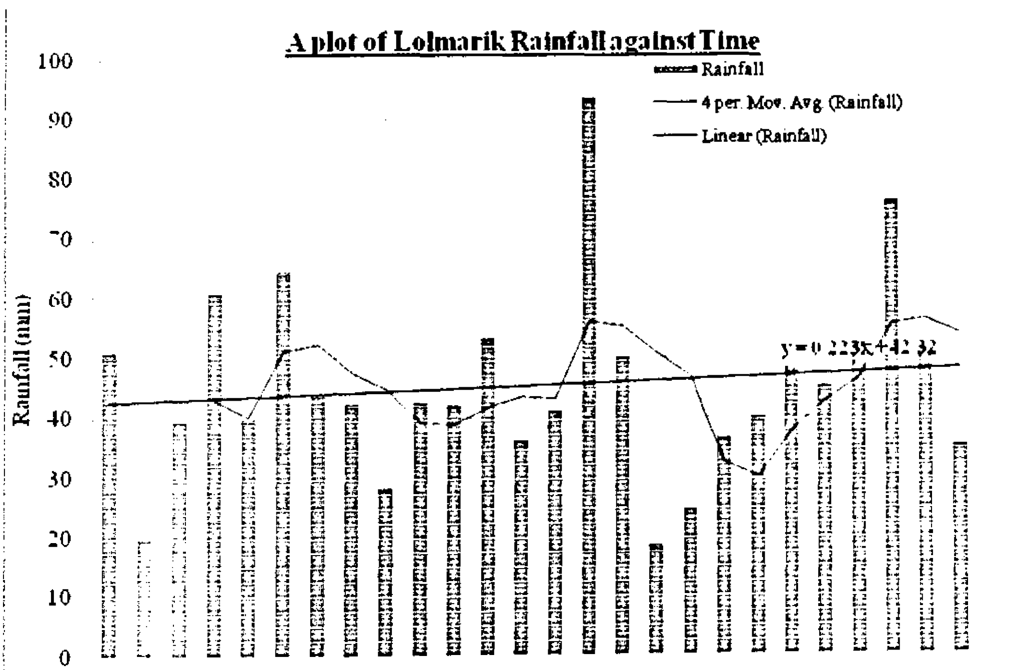


Figure 4.3: Rainfall Trend at Lolmarik

In Lolmarik area has been monitored since October 2005 using borehole C11311. The WRL fluctuations range hardly exceed ±0.5 m, (figure 4.34) implying that the aquifer/ recharge is steady.

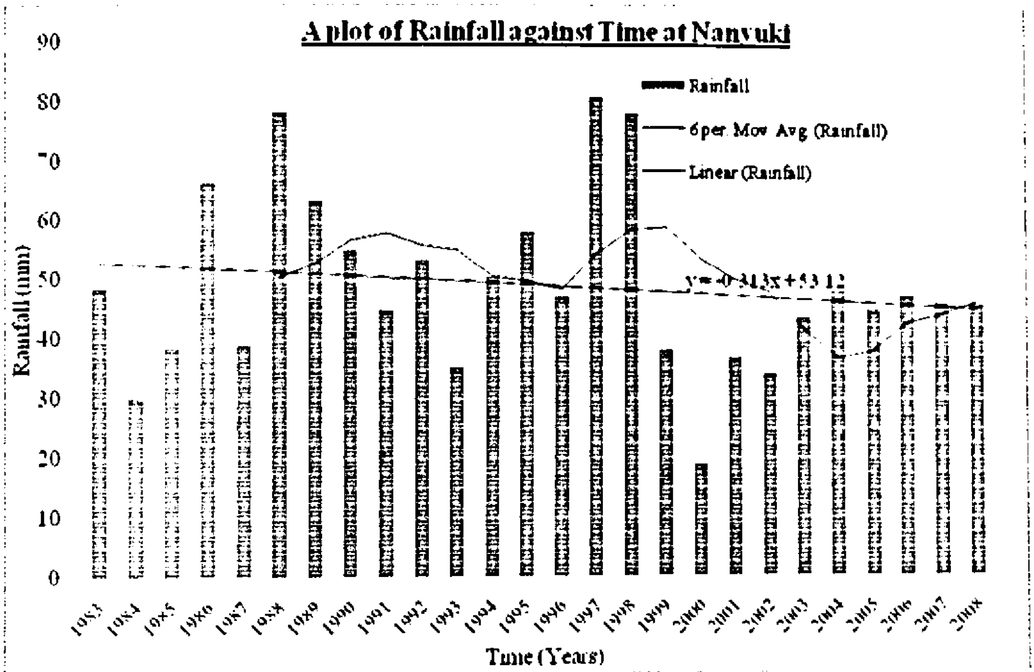


Figure 4.4 : Rainfall Trend at Nanyuki

Rainfalls at Nanyuki show a slight declining tread, which possibly would be due to vegetation/ land cover change resulting from human activities. Mean annual rainfall for the area is 929.94 mm. Nanyuki children centre borehole C11934 has been used to monitor WRL. Fluctuations of ±1.6m (27.38-25.78 m) have been recorded in the recent past of four years. The 6 month moving average for WRL correlates best with the rainfall trend.

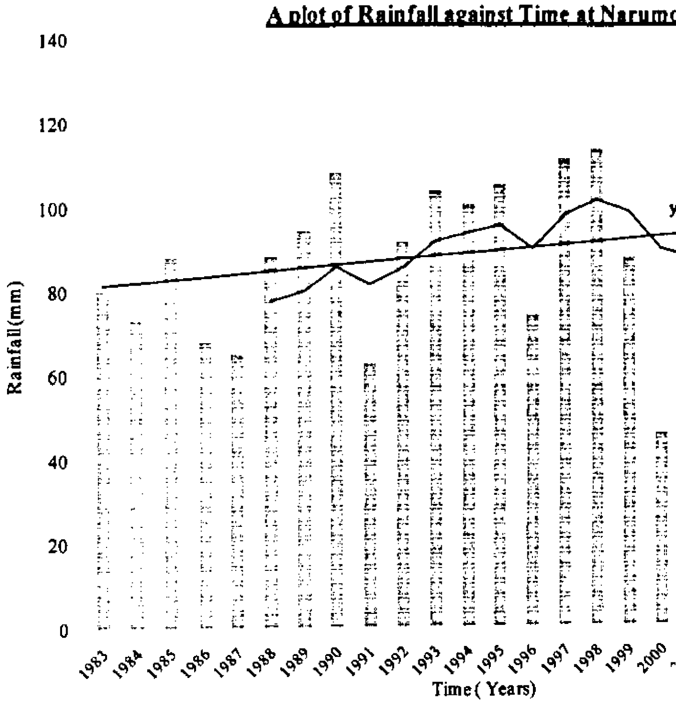


Figure 4.5 : Rainfall Trend at Naromoru

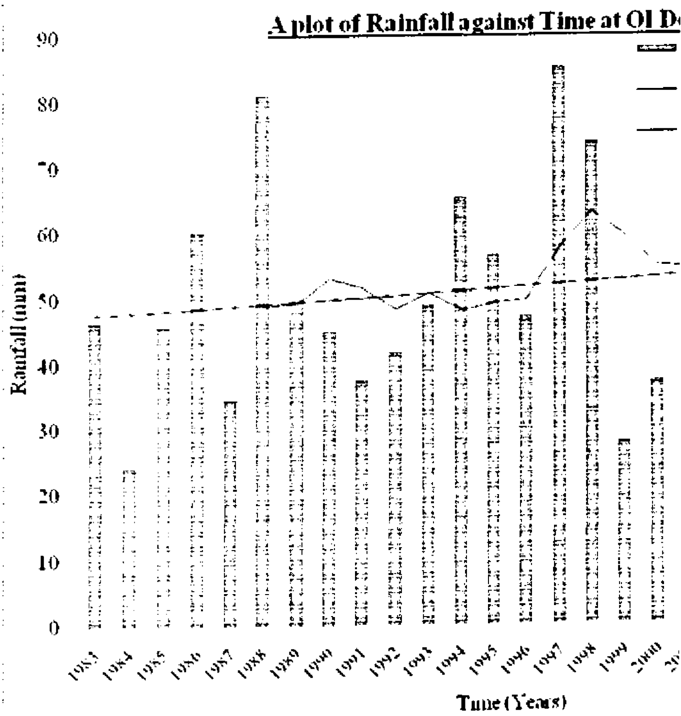


Figure 4.6 : Rainfall Trend at Ol Donyo

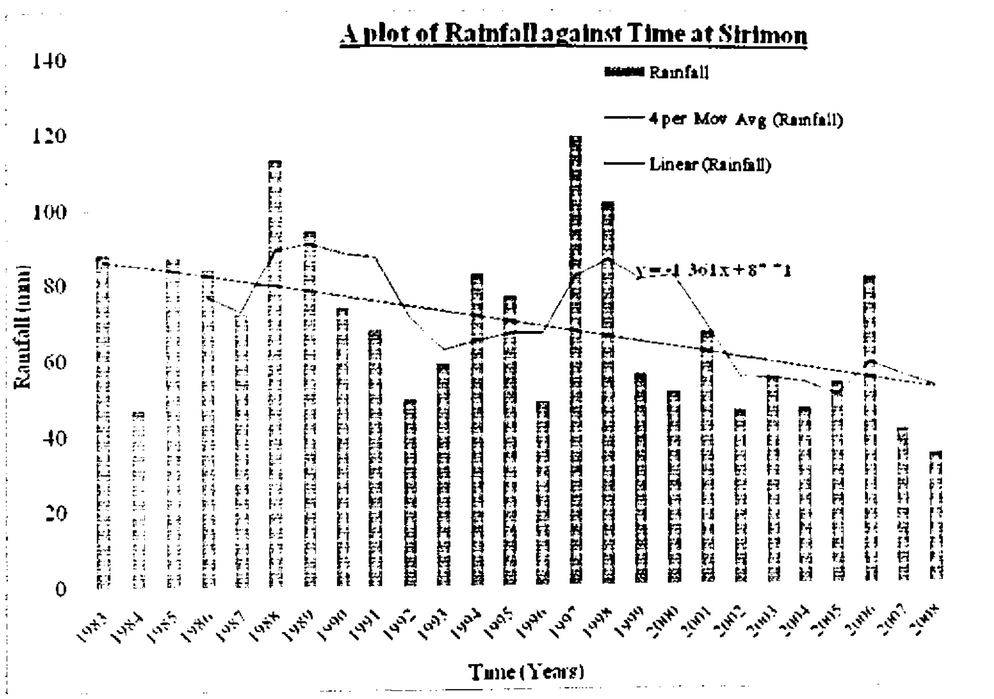


Figure 4.7 : Rainfall Trend at Sirimon

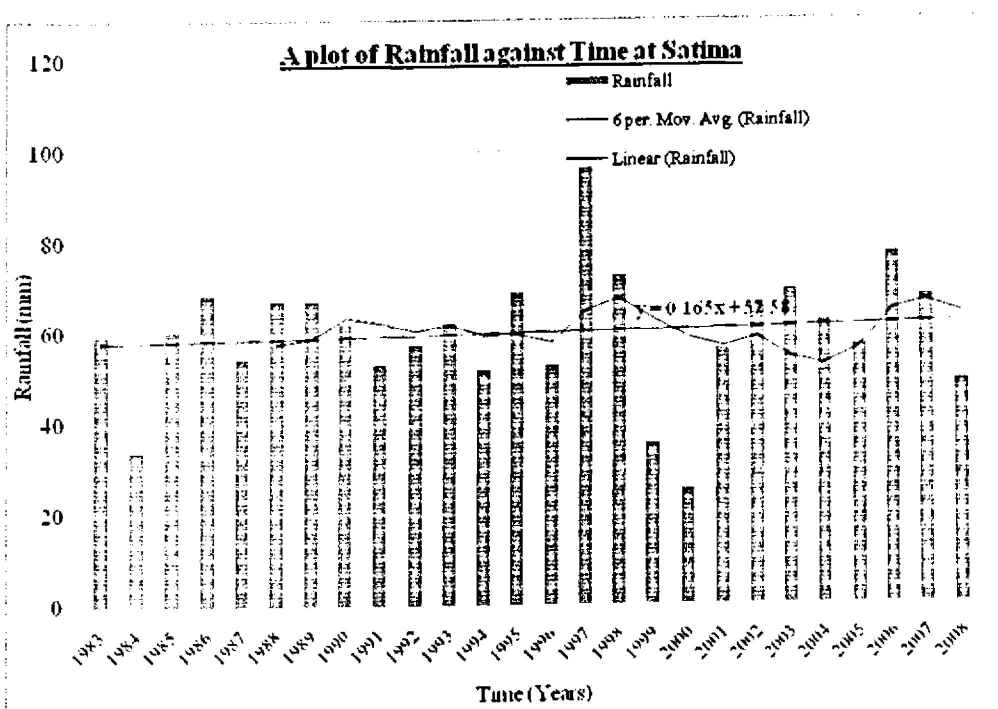


Figure 4.8 : Rainfall Trend at Satima

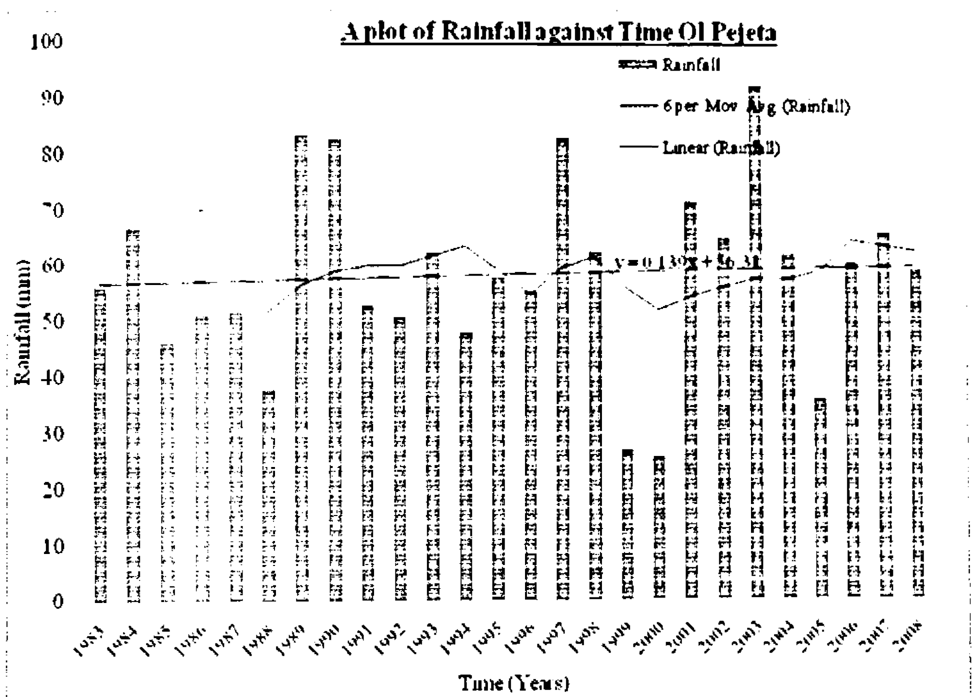


Figure 4.9 : Rainfall Trend at Ol Pejeta

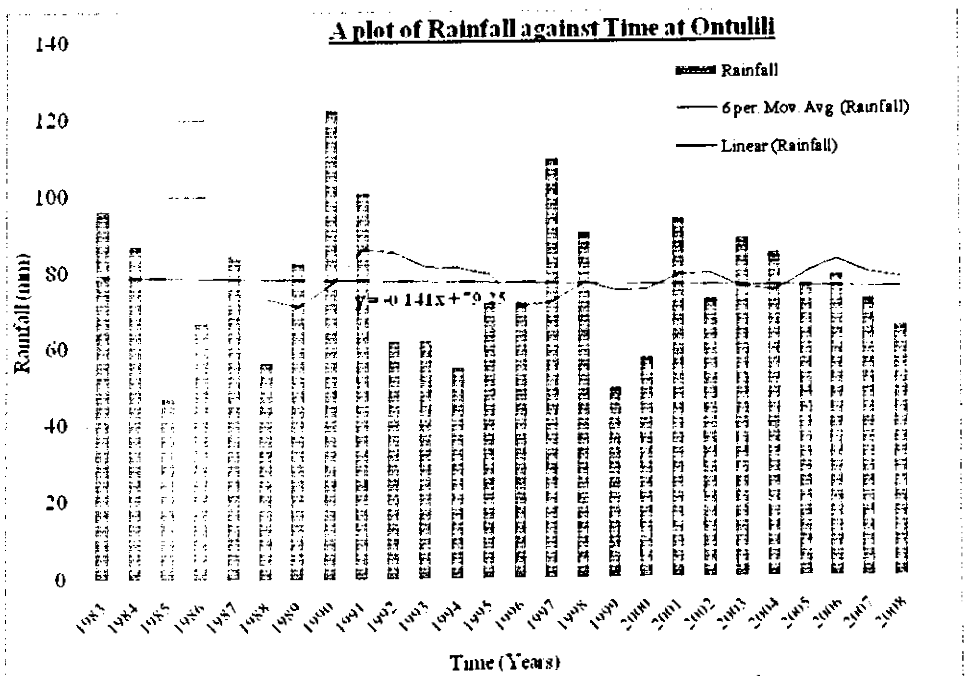


Figure 4.10 : Rainfall Trend at Ontulili

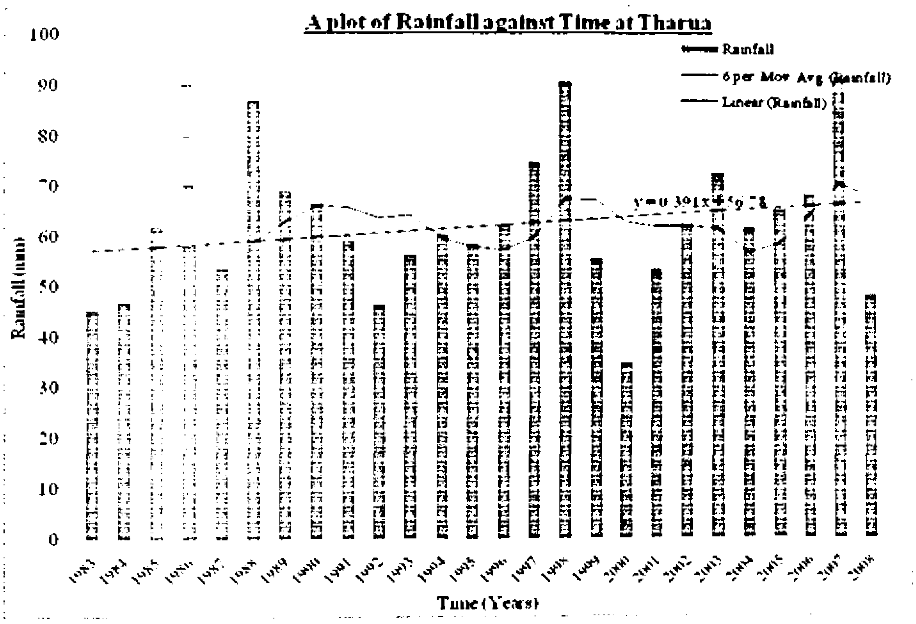


Figure 4.11 : Rainfall Trend at Tharua

Table 4.2 : t - test for long term rainfall trend

Station	t- calculated	t- tabulated - 99%	Conclusion
Lolmarik	0.56975193	0.332050911	significant
Nanyuki	-0.6441781	0.332050911	Significant
Naromoru	0.71149629	0.332050911	Significant
Oldonyo	0.75250665	0.332050911	Significant
Sirimon	-1.6637874	0.332050911	Not significant
Satima	0.25059874	0.332050911	Not Significant
Ol Pejeta	0.21165071	0.332050911	Not Significant
Ontulili	0.15096329	0.332050911	Not Significant
Tharua	1.00848591	0.332050911	Not Significant
Shamata	1.04068828	0.332050911	Not Significant
Station	**t - calculated**	**t - tabulated - 95%**	**Conclusion**
Lolmarik	0.56975193	0.351581575	Significant
Nanyuki	-0.6441781	0.351581575	Significant
Naromoru	0.71149629	0.351581575	Significant
Oldonyo	0.75250665	0.351581575	Significant
Sirimon	-1.6637874	0.351581575	Not Significant
Satima	0.25059874	0.351581575	Not Significant
Ol Pejeta	0.21165071	0.351581575	Not Significant
Ontulili	0.15096329	0.351581575	Not Significant
Tharua	1.00848591	0.351581575	Significant
Shamata	1.04068828	0.351581575	Significant

4.2.2 Annual Rainfall Characteristics

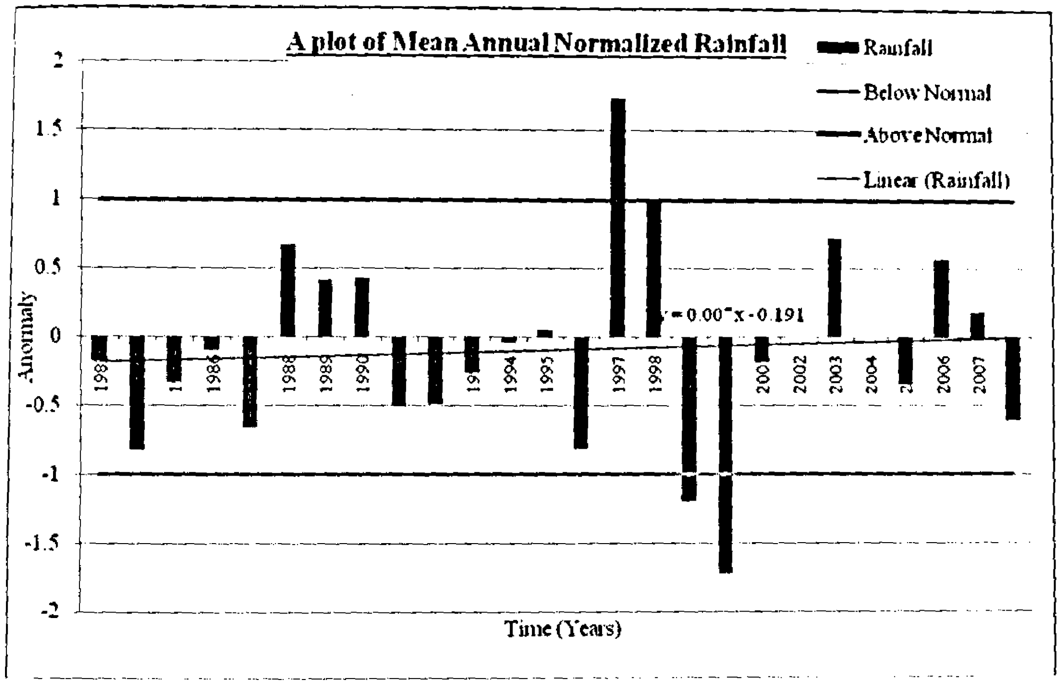


Figure 4.12 : Annual Rainfall Characteristics of Upper Ewaso Ng'iro Basin

The "0" value is 65.0 mm while σ was found to be 11.3 mm. The the years whose values lies within ± σ (quadrants 2 and 3) are considered to be within the normal range. The other years; more than ± 2σ (quadrants 1 and 4) are considered to be above or below normal. Figure 4.12 represents the annual rainfall records under investigation that span for 25years, from the year 1983 to 2008.

All the years under study were found to have experienced normal rainfall with an exception of 1999 and 2000 that recorded below normal rainfall *'La-nina'*- related drought, and 1997 and 1998 when above normal rains ; *'El- Nino'* were experienced .

4.2.3 Rainfall Monthly Characteristics

Upon normalization of mean monthly rainfall data, it was found that the month of February records below normal rainfall while April and November records above normal rainfall in the year. The other months records normal rainfall. Significant aquifer recharge in the area would therefore be expected to occur in the months of April and November.

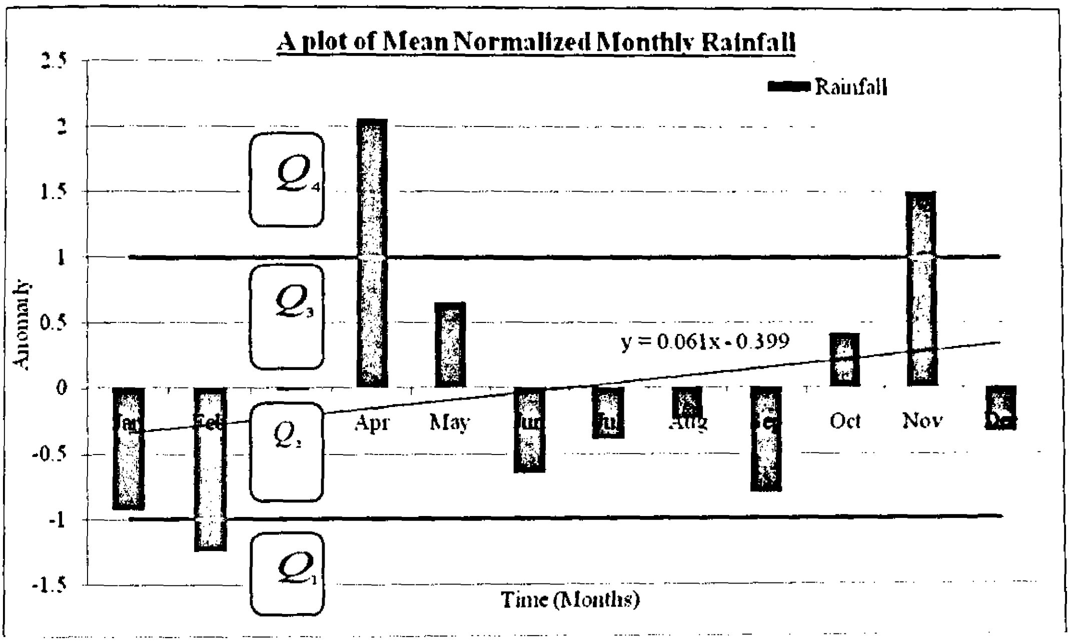


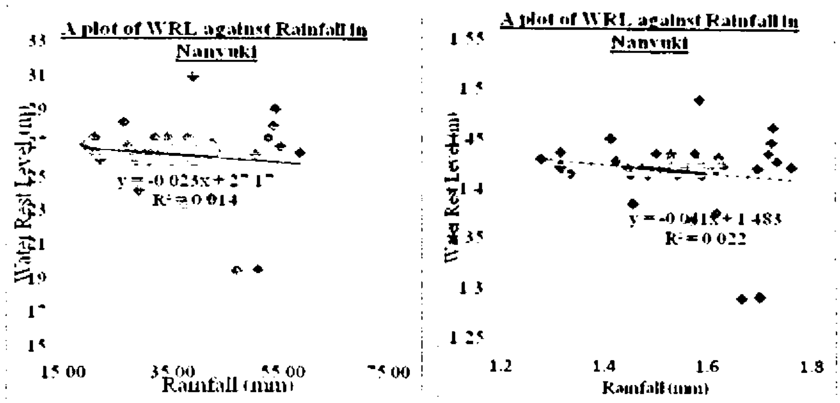
Figure 4.13: Monthly Rainfall Characteristics

The rainfall is found to increase across the year, though in small magnitudes evidenced by a gentle slope of 0.06, this is a clear implication that the last months of the year are generally wetter than the first months.

The months whose values lies within $\pm \sigma$ (quadrants 2 and 3) are considered to be within the normal range. The other months; more than $\pm 2\sigma$ (quadrants 1 and 4) are considered to be above or below normal.

4.2.4 Rainfall – Groundwater Level Fluctuations Relationship (2005-2009)

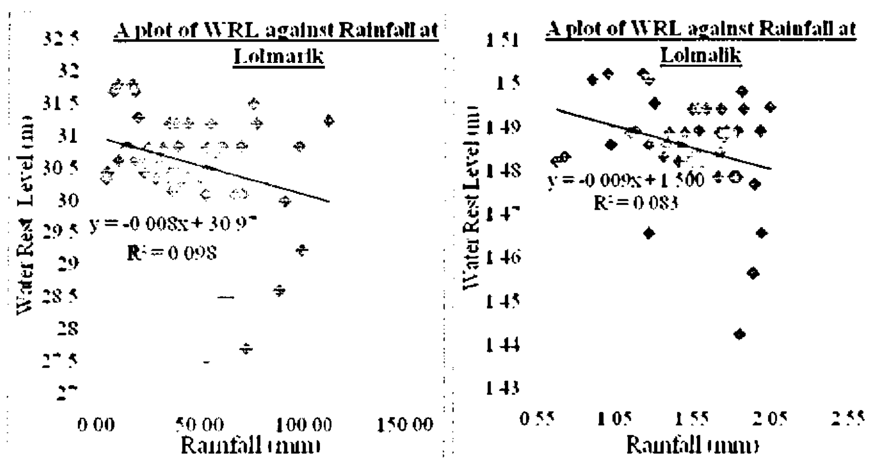
Given the short time span for groundwater monitoring (2005 to 2009), groundwater level flactuations are related to rainfall data only for this period. Therefore, the extreme events of 1997/98 (El Nino) are excluded, thus the trends recorded capture the so called 'normal' rainfall regime. It is evident that there is correlation between rainfall and water rest levels (figures 4.15 to 4.25) at all stations. it is further clear that the two parameters are negatively correlated though weakly; an increase in rainfall leads to a decrease in water rest levels.



a) Untransformed b) Log Transformed

Figure 4.14 : Water rest levels against rainfall in Nanyuki

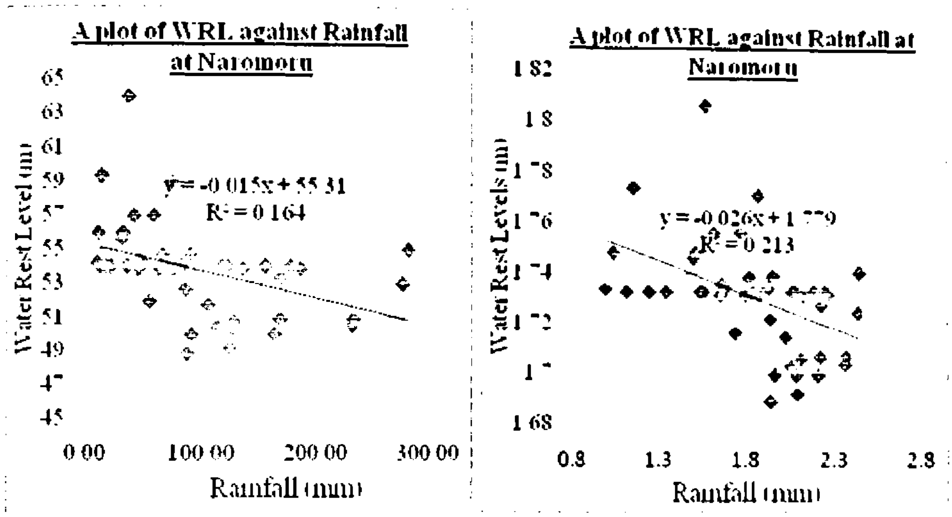
The correlation coefficient for the plot figure 4.15 untransformed data is -0.12119 while that of log transformed data -0.14912 the coefficient of determination (R^2) is 0.014 and 0.022 respectively for untransformed and transformed data section 3.6.



a) Untransformed b) Log Transformed

Figure 4.15 : Water rest levels against rainfall at Lolmarik

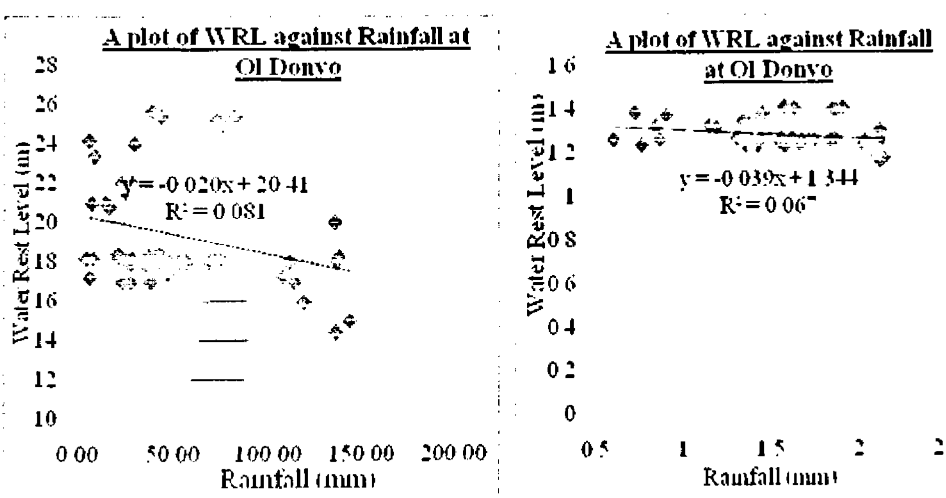
Correlation coefficients were found to be -0.3133 and -0.2888 for untransformed and transformed data respectively, the coefficients of determination were found to be 0.098 and 0.083 respectively.



a) Untransformed b) Log Transformed

Figure 4.16 : Water rest levels against rainfall at Norumoru

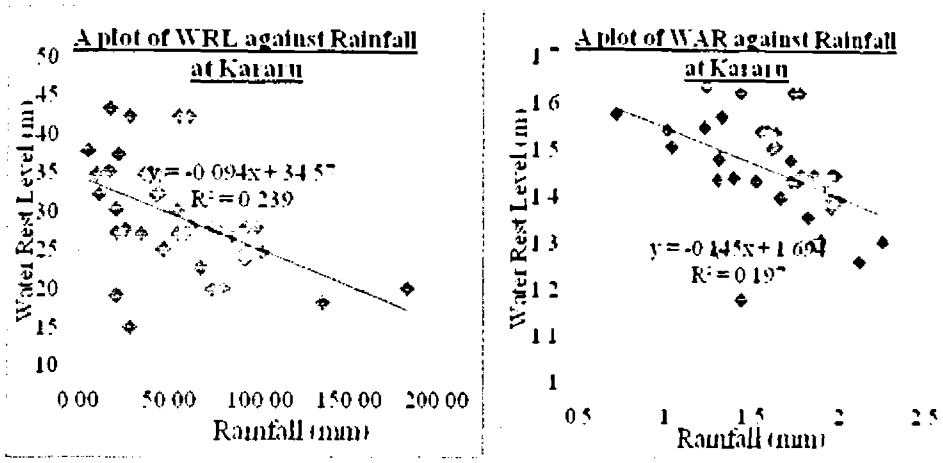
The correlation coefficients of -0.4052 and -0.46151 for untransformed and transformed data were realized in the analysis, their respective coefficients of determination were 0.164 and 0.213.



a) Untransformed b) Log Transformed

Figure 4.17 : Water rest levels against rainfall at Ol Donyo

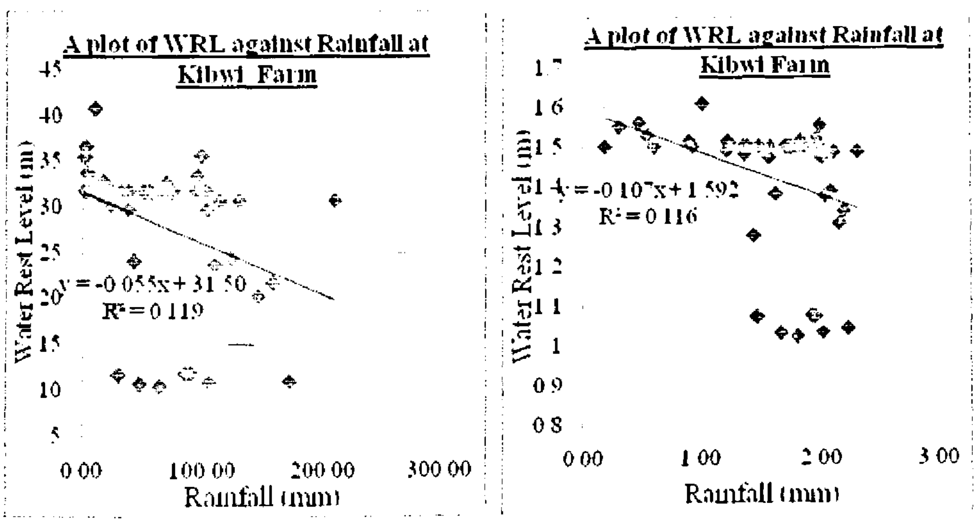
The coefficient of determination of -0.28611 for untransformed data and -0.25885 for log transformed data were obtained. The coefficients of determination were as high as 0.081 for untransformed data and 0.067 for transformed data.



a) Untransformed b) Log Transformed

Figure 4.18 : Water rest levels against rainfall at Sirimon

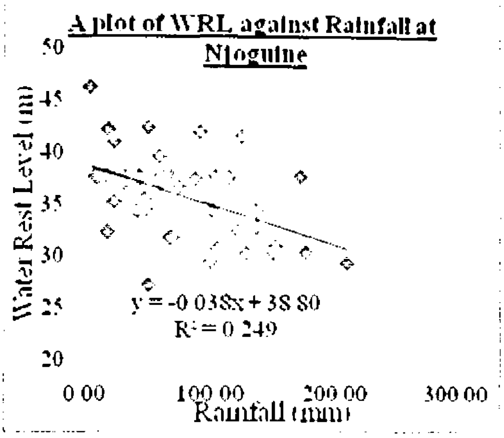
The values -0.45953 and -0.44478 were the coefficients of correlation between the water rest levels and rainfall recorded at Sirimon. The coefficient of determination of water rest levels by the rainfall at the station were 0.239 and 0.197 respectively.



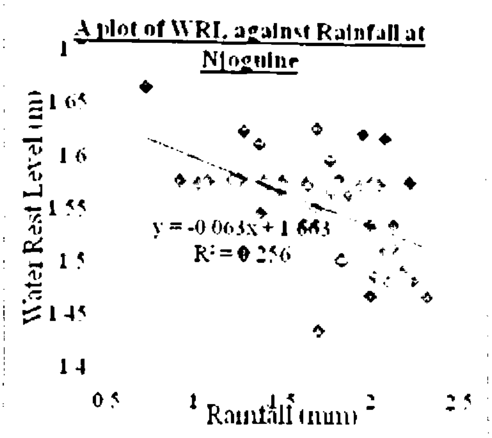
a) Untransformed b) Log Transformed

Figure 4.19 : Water rest levels against rainfall at Satima

The coefficient of correlation of -0.34538 and -0.34184 for untransformed and log transformed data were obtained, their respective coefficients of determination were 0.119 and 0.116 respectively.



a) Untransformed



b) Log Transformed

Figure 4.20 : Water rest levels against rainfall at Ol Pejeta

Upon correlation of rainfall and water rest levels at Ol Pejeta, -0.49943 and -0.50664 were obtained as correlation coefficients for untransformed and transformed data respectively. The determination coefficients of water rest levels using rainfall at the station were found to be 0.249 and 0.256.

4.2.4.1 Rainfall Station at Ontulili (Mt. Kenya Forest area)

Two rainfall stations Ontulili and Shamata were selected (section 4.1). The rainfall was correlated to groundwater levels of two boreholes of varying distances from Ontulili rainfall station. The degree of rainfall effect on groundwater fluctuations was found to be correlated to the distance of borehole from the recharge area. It is clear that the correlation coefficient is higher at closer proximity than further off as evidenced by figures 4.22 to 4.25.

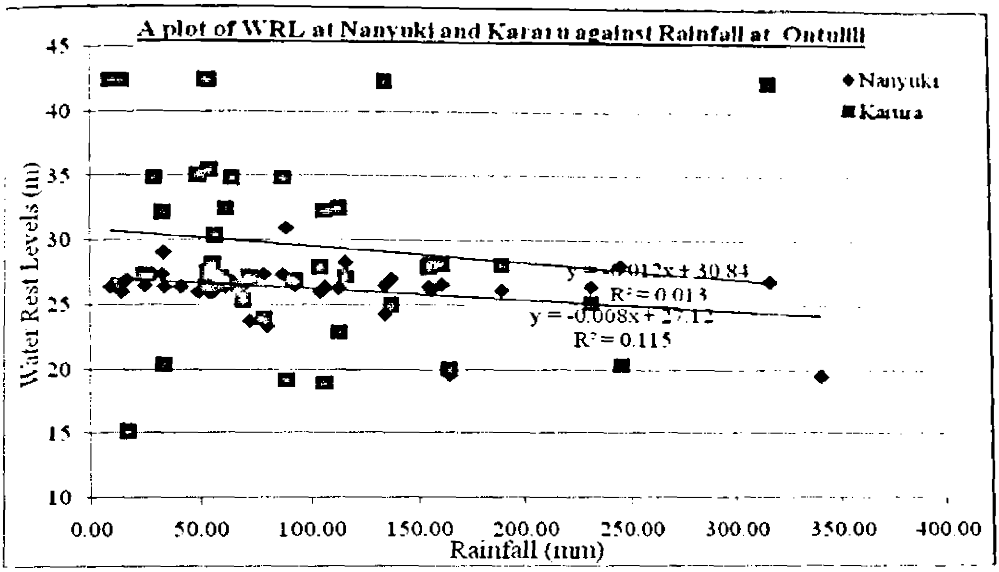


Figure 4.21 : Water rest levels at Nanyuki and Kararu against rainfall at Ontulili

Using untransformed rainfall data at Ontulili station and two boreholes at Nanyuki and Kararu, the coefficient of determination between rainfall and water rest levels was found to be -0.117 and -0.340 respectively for Nanyuki and Kararu. Kararu borehole being closer as compared to Nanyuki from Ontulili is a clear show that the effect of rainfall on water level decreases with increase in distance between the water source and the borehole, log transformed rainfall and water rest levels data also re-affirmed the above.

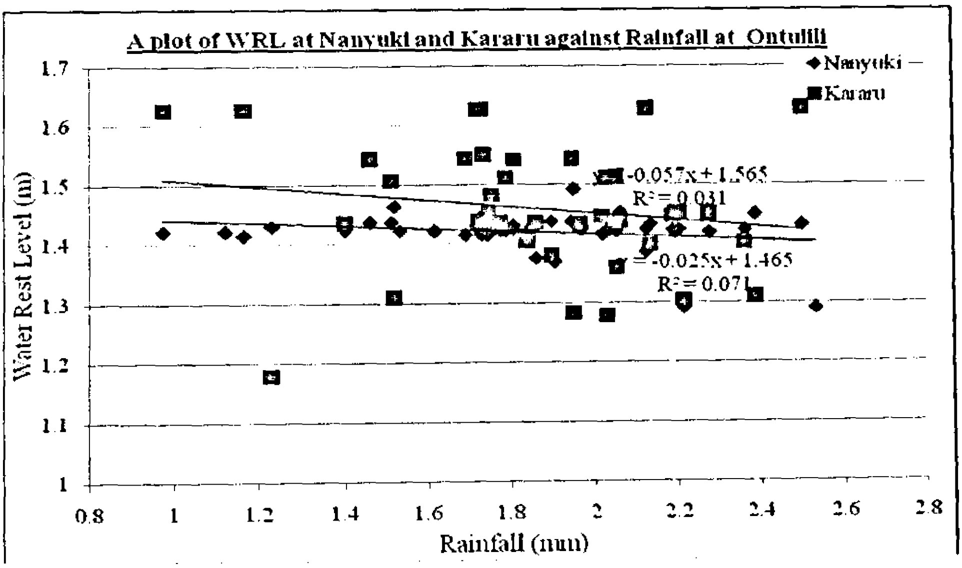


Figure 4.22 : Water rest levels at Nanyuki and Kararu against rainfall at Ontulili (Log transformed)

The coefficient of determination was found to be as high as -0.177 between rainfall at Ontulili/Kararu as compared to -0.267 for Ontulili/Nanyuki.

4.2.4.2 Rainfall Station at Shamata (Forest Aberdare Area)

Shamata rainfall Station is located at the Aberdares forest. It has been used to highlight the connection between rainfall and groundwater levels fluctuations at different proximities. The borehole at Karemeno is closer to Shamata as compared to the one at Njoguine.

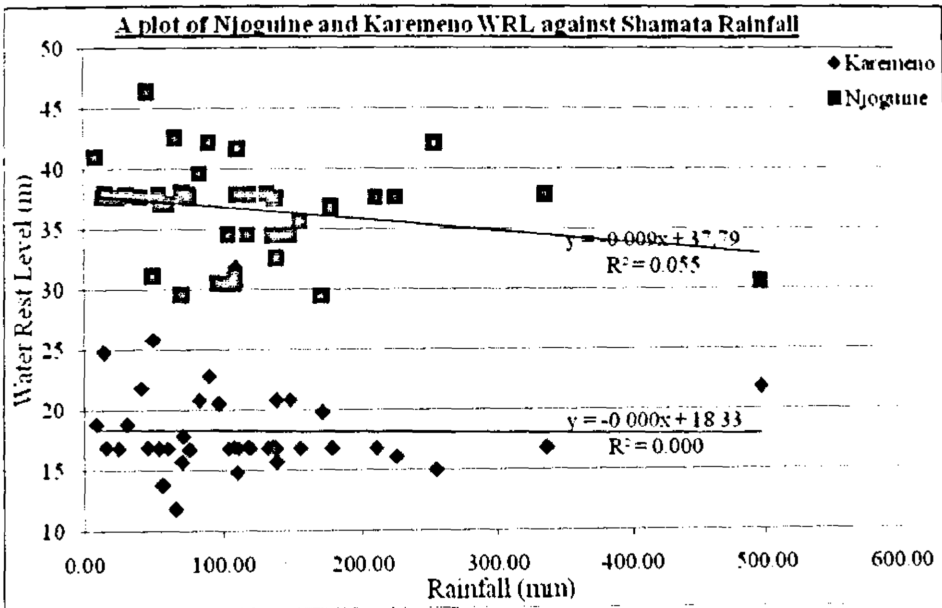


Figure 4.23 : Water rest levels at Njoguine and Karemeno against rainfall at Shamata

The correlation of rainfall at Shamata and water rest levels in Karemeno borehole reveals a correlation coefficient of 0.44712 while that of water rest levels at Njoguine and rainfall at Shamata was found to be 0.313835. The effect of rainfall on water rest levels becomes more evident to be reducing with distance of seperation between the two.

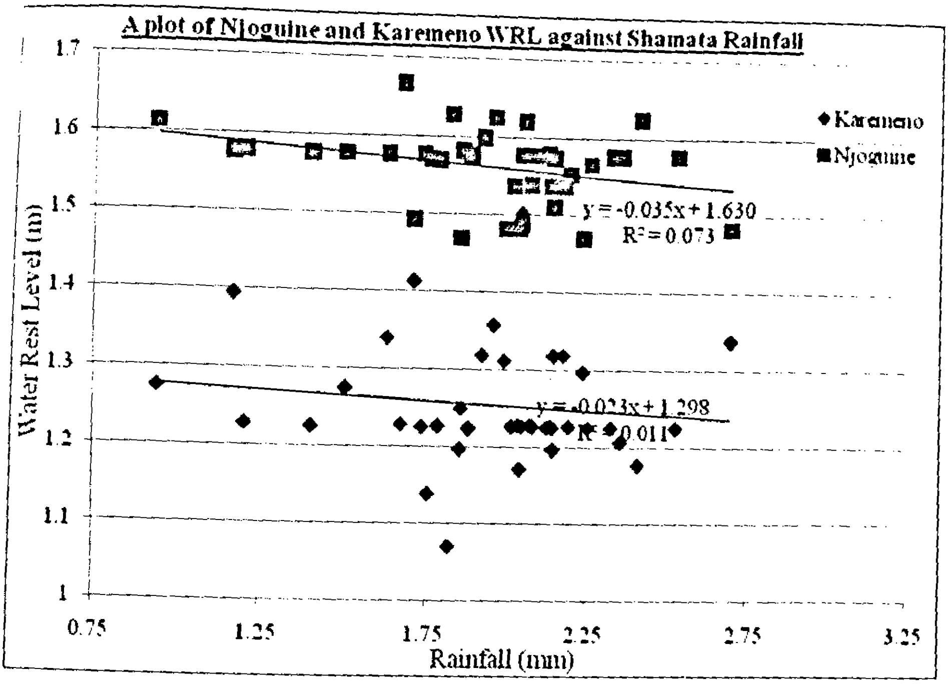


Figure 4.24 : Water rest levels at Njoguine and Karemeno against rainfall at Shamata (Log transformed)

The analysis using log transformed data further ascertains that; the further away a borehole is from the recharge the lesser is effect/recharge felt on the water rest levels. Geology has to be considered for different formations transmit water differently. The effect however increases with an increase in time lag; it gives water time to move from the source to the borehole points.

Summary

Table 4.3 : WRL - Rainfall Relationship

Station	Sub - Region	Correlation (R)	
		Untransformed data	Transformed data
Nanyuki	Nanyuki – Kangaita	-0.121	-0.149
Lolmarck	Timau	-0.313	-0.289
Naromoru	Naromuro-Solio-Lamuria	-0.405	-0.462
Oldonyo	Timau	-0.286	-0.259
Sirimon	Timau	-0.459	-0.445
Satima	Naromuro-Solio-Lamuria	-0.345	-0.342
Ol Pejeta	Ol pejeta-Mutara	-0.499	-0.507
Kararu - Ontulili	Nanyuki-Kangaita	-0.117	-0.177
Nanyuki - Ontulili	Nanyuki-Kangaita	-0.340	-0.267
Karameno - Shamata	Suguroi- Olpajeta	-0.023	-0.107
Njoguine - Shamata	Suguroi- Olpajeta	-0.235	-0.272

This table is a summary of the correlation coefficient (R). The data show that the nearer the rainfall station to the groundwater monitoring station, the better the correlation.

Table 4.4 : Significant Test of WRL/ Rainfall Correlation

Rainfall Station	WRL Station	t- calculated	t- tabulated - 99%	Conclusion
Lolmarik	C12826	1.685542	0.327468	Significant
Nanyuki	C241	3.667904	0.327468	Significant
Naromoru	C12497	2.143876	0.327587	Significant
Oldonyo	C11934	2.830896	0.327468	Significant
Satima	C11311	2.429036	0.327468	Significant
Sirimon	C861	2.377731	0.328604	Significant
Ol Pajeta	C7426	2.307044	0.327468	Significant
Rain3WRL4	C932	1.886098	0.327468	Significant
Rain2WRL1	C12826	2.151924	0.327468	Significant
Station	**WRL**	**t - calculated**	**t - tabulated - 95%**	**Conclusion**
Lolmarik	C12826	1.685542	0.674655	Significant
Nanyuki	C241	3.667904	0.674655	Significant
Naromoru	C12497	2.143876	0.674889	Significant
Oldonyo	C11934	2.830896	0.674655	Significant
Satima	C11311	2.429036	0.674889	Significant
Sirimon	C861	2.377731	0.676881	Significant
Ol Pajeta	C7426	2.307044	0.674655	Significant
Rain3WRL4	C932	1.886098	0.674655	Significant
Rain2WRL1	C12826	2.151924	0.674655	Significant

4.2.5 Rainfall - Groundwater Fluctuations Temporal Relationships

The dispalys below bring out the relation between the two parameters and appling moving averages. The time lag varies from station to another.

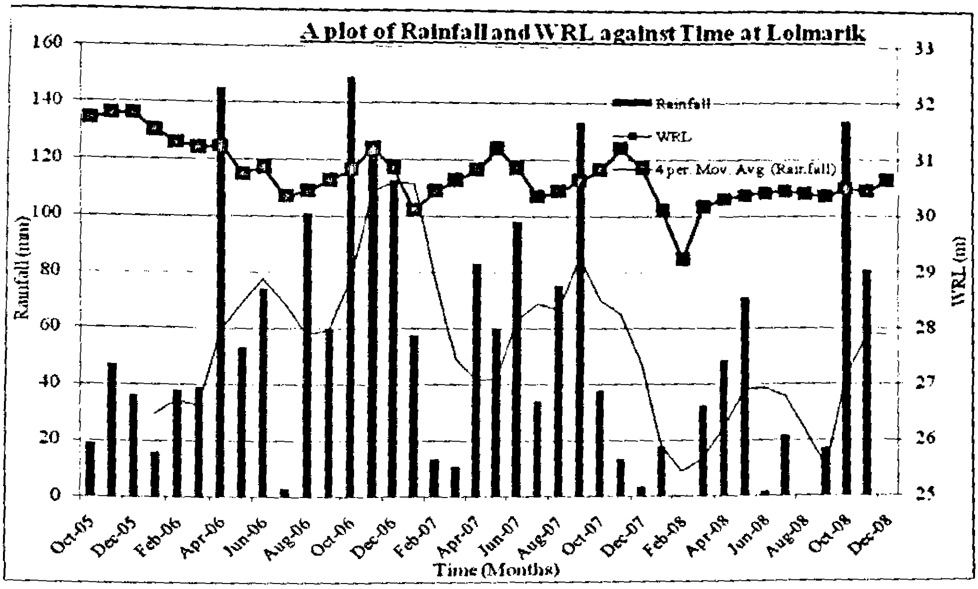


Figure 4.25: Rainfall and WRL against Time at Lolmarik

The best fit relationship for rainfall and WRL at Lolmarik is derived with a four moving average suggesting that the time lag between rainfall and groundwater rest level response is four months.

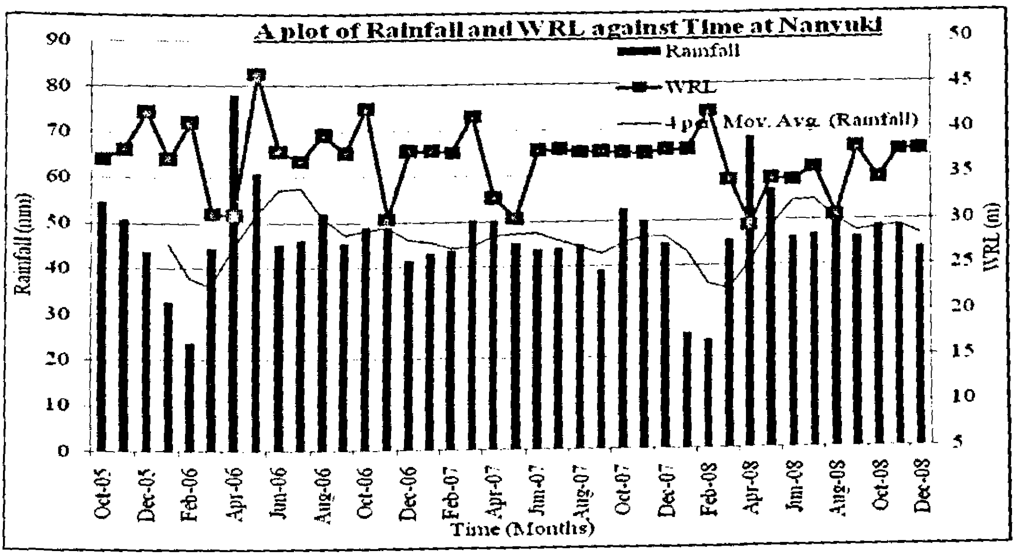


Figure 4.25 : Rainfall and WRL against Time at Nanyuki

Figure 4.26: Rainfall and WRL against Time at Nanyuki

The time lag between rainfall and water rest levels is four months.

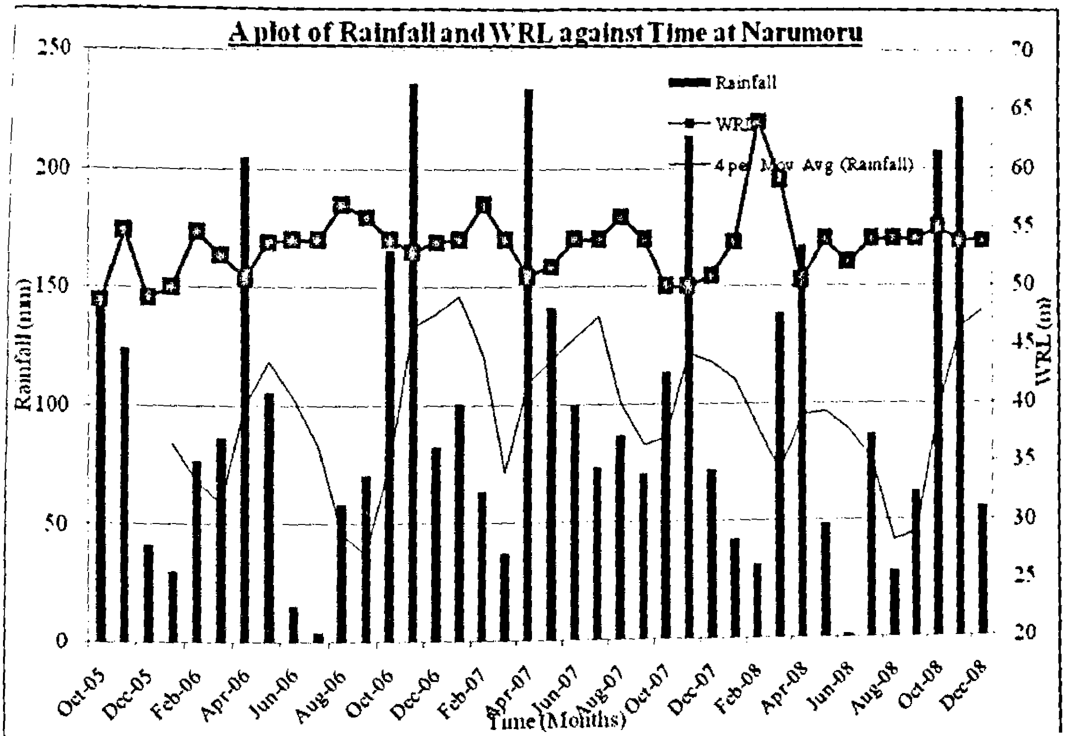


Figure 4.26 : Rainfall and WRL against Time at Narumoru

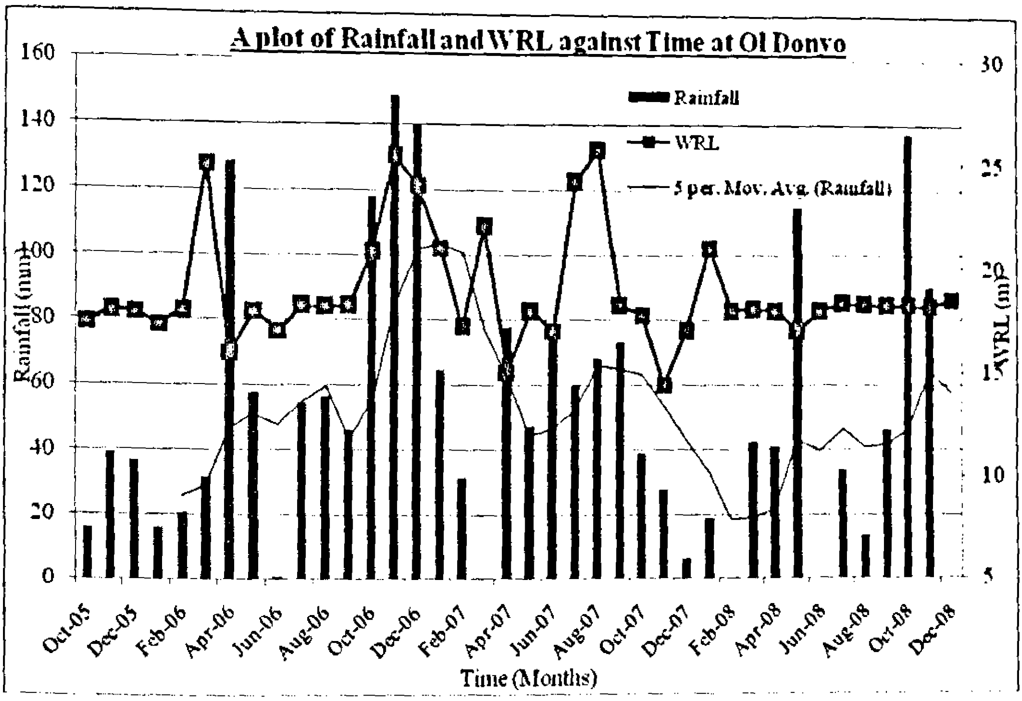


Figure 4.27 : Rainfall and WRL against Time at Ol Donyo

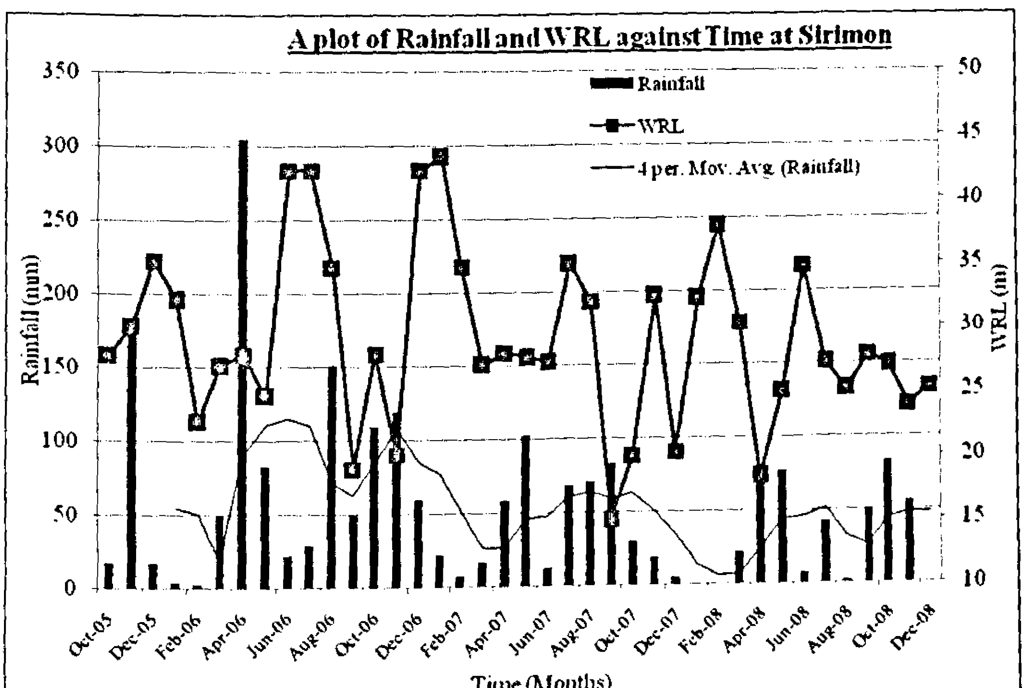


Figure 4.28 : Rainfall and WRL against Time at Sirimon

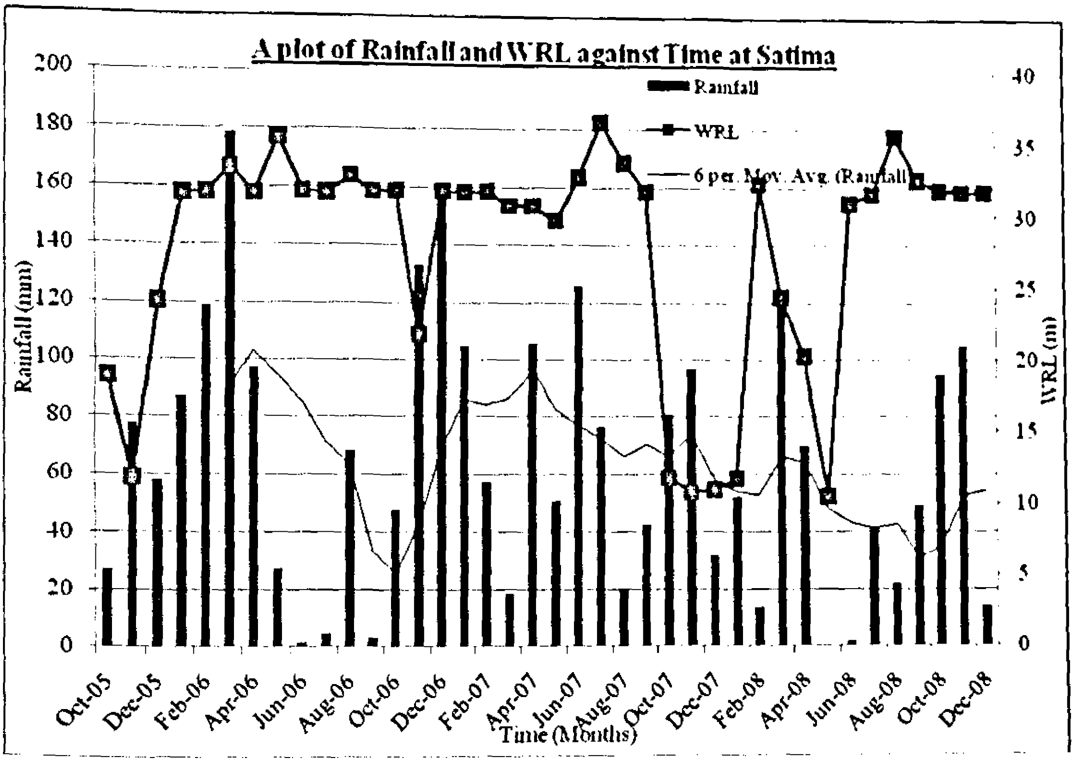


Figure 4.29 : Rainfall and WRL against Time at Satima

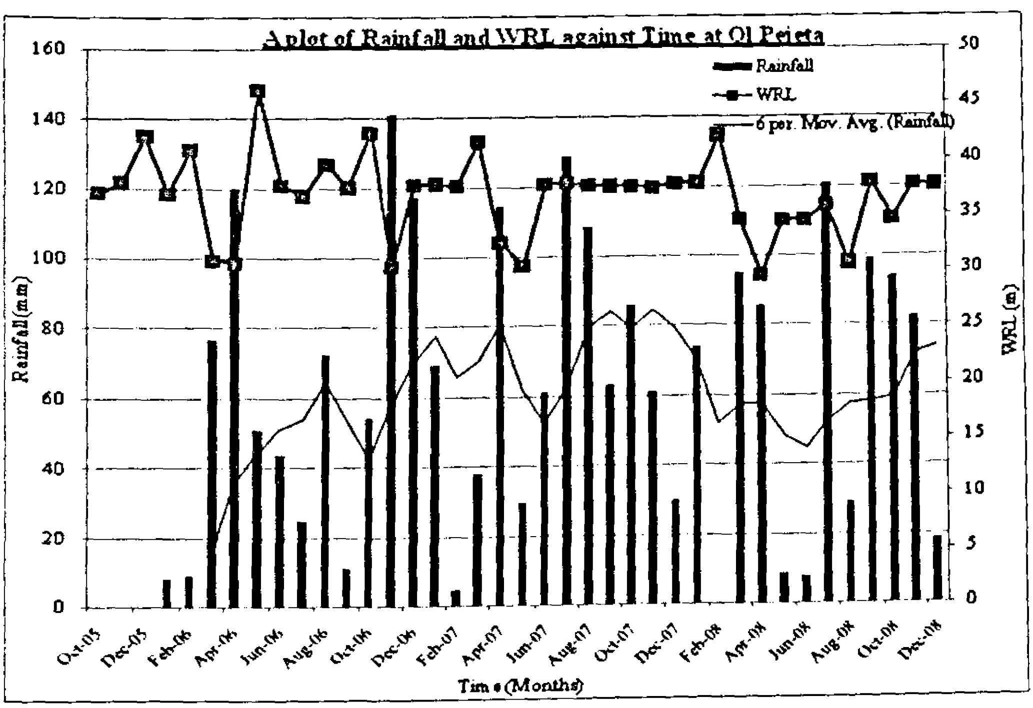


Figure 4.30 : Rainfall and WRL against Time at Ol Pejeta

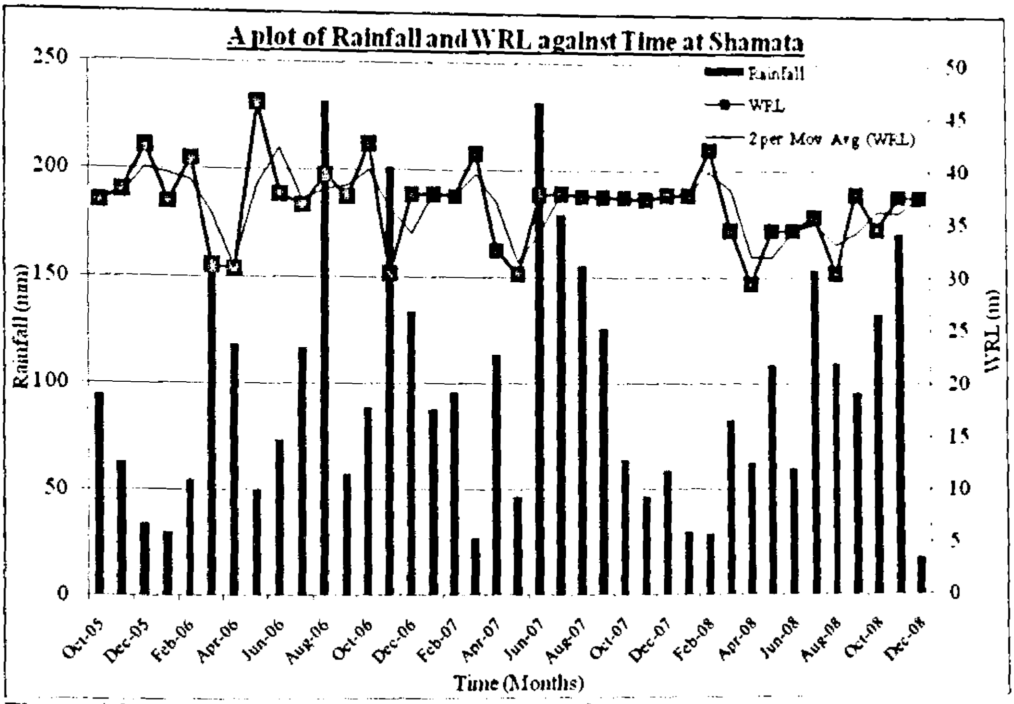


Figure 4.31 : Rainfall and WRL against Time at Shamata

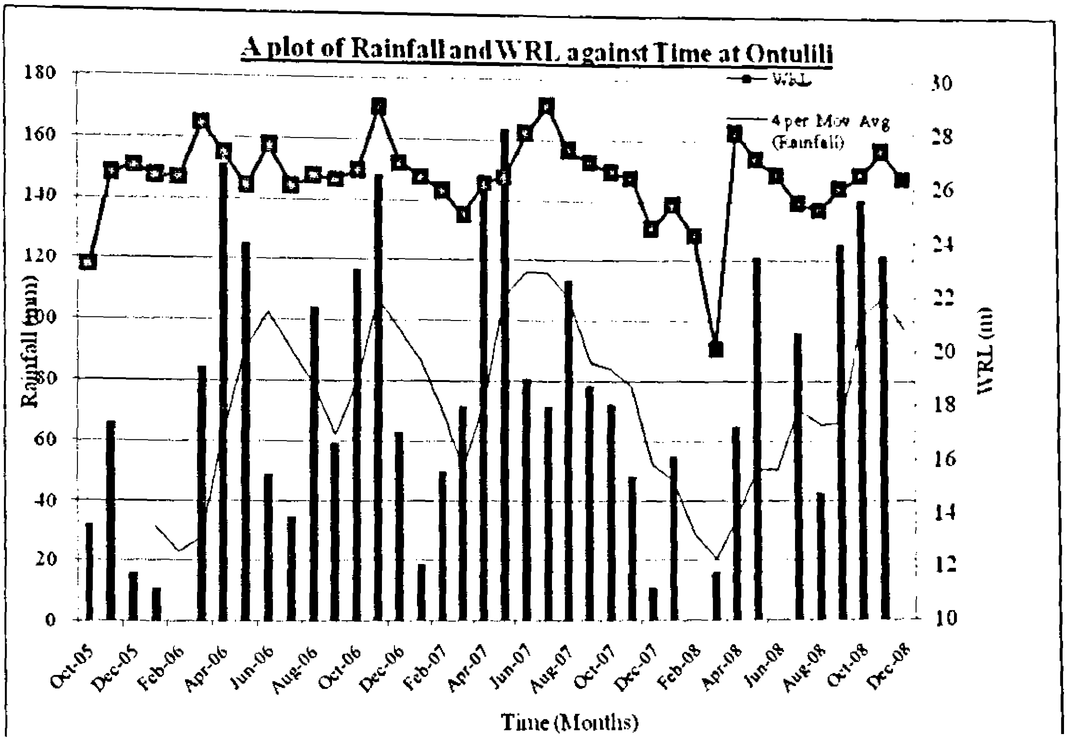


Figure 4.32 : Rainfall and WRL against Time at Ontulili

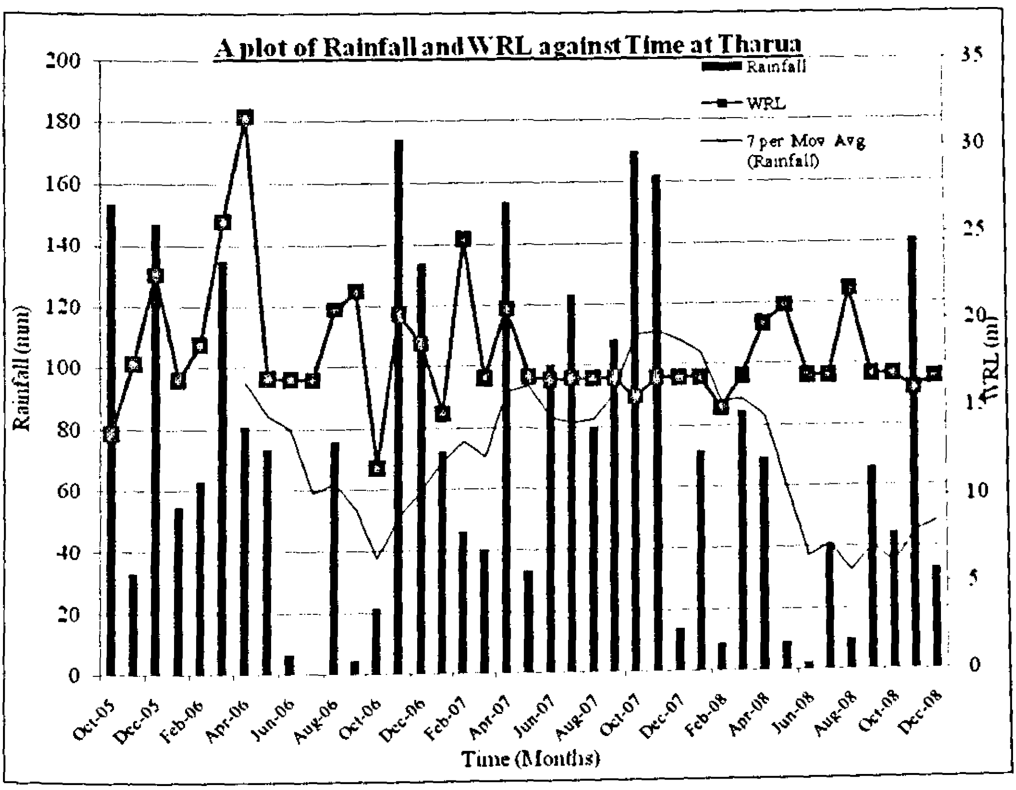


Figure 4.33: Rainfall and WRL against Time at Tharua

Table 4.5 : Time Lag and respective Distances from recharge areas

Station	Time lag	Approximate distance from recharge area	Rock type
Shamata	3	<1	2
Ontulili	4	<2	1
Naromoru	4	<4	1
Olndoyo	5	<4	1
Sirimon	4	<5	1
Lolmarik	4	<6	1
Nanyuki	4	<7	1
Satima	6	<7	1
Tharua farm	6	<7	2
Ol Pajeta	6	<10	2

1 - Trachytes ,basalts and pyroclatics

2 - Phonolites,trachytes and olivine basalts

The correlation between the time lag and the respective distances from the stations to recharge areas is 0.74. The time lag of recharge increases with increase in distance from the recharge area.

4.2.6 Ground Water Monitoring in Graphic Summary

Hydrographs for the monitored boreholes between Timau and Nanyuki have been presented below running from October 2005 to August 2009 in the Timau -Nanyuki sub- regions.

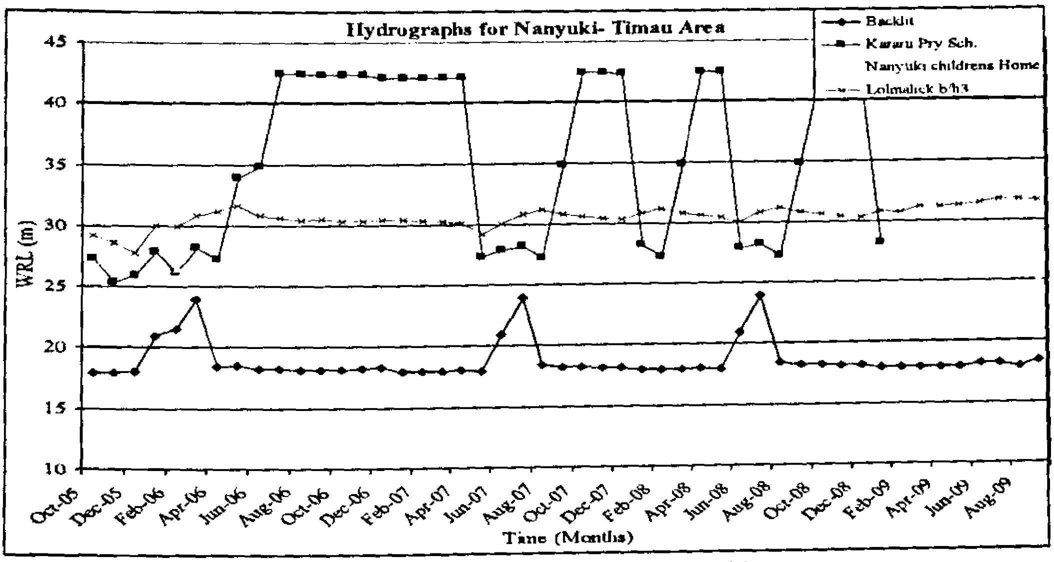


Figure 4.34 : Monitoring Hydrographs between Timau -Nanyuki area

The aquifers in this region maintained high levels other than for Kararu primary. School borehole **C12497** which has maintained a depressed level. The cause of this drop has not been conclusively established. The borehole was drilled and completed on 20/09/1999. It has a total depth of 140 meters and a yield of 10.5m^3/hr. Water struck level and water rest level were 92M and 34 M respectfully. These boreholes (Kararu C12497 and Lormarick C11311) are deeper and have higher yields than the surrounding boreholes in the area (Appendix 4). Their high yields are possible because the two are tapping from high yielding deeper aquifers than the rest that tap shallow aquifers. The school depends on the borehole water for irrigation on kitchen gardening and agro forestry around the school.

4.2.7 Hydrographs for Boreholes between Nanyuki - Lamuria Sub-region Area

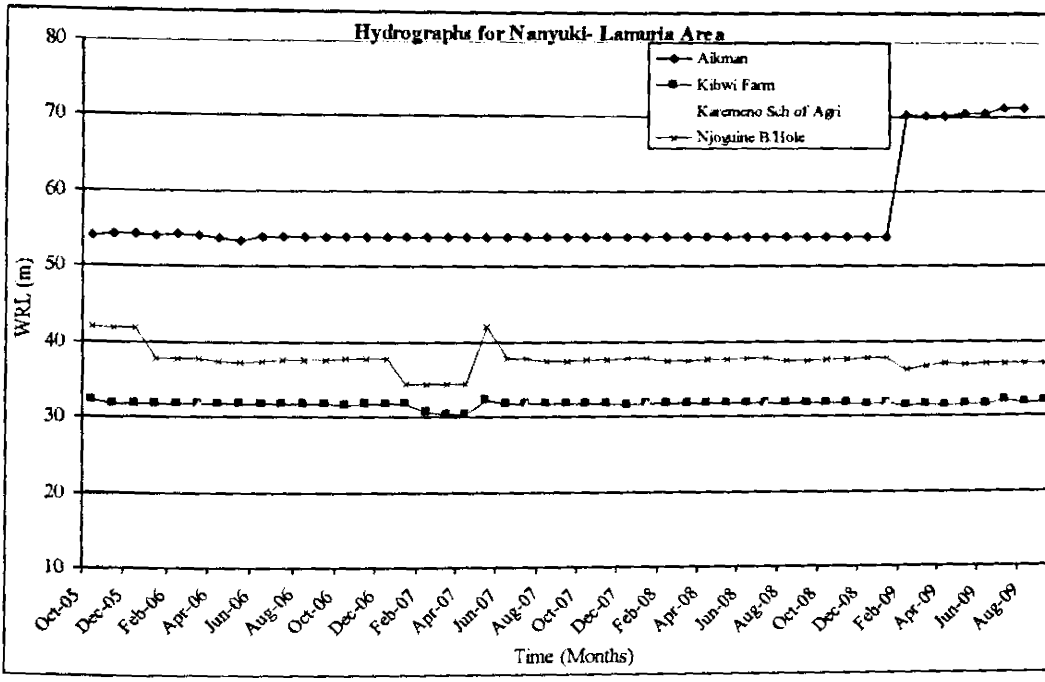


Figure 4.35 : Monitoring Hydrograph for Nanyuki - Lamuria - Mutara

Boreholes between Nanyuki - Lamuria Sub-region have maintained almost constant levels throughout the period of monitoring implying good recharge from the recharge areas. Njoguini and Karemeno boreholes were not in use by the time of the study because their pumps were not working; therefore the small fluctuations registered are due to response to precipitations. Borehole C 12826 Aikman show a huge drop of water rest level from 53.87M in January 2009 to 70.38M February 2009 a drop of (16.51M). This kind of drop could be possibly be due to a borehole that was drilled and completed in December 2008 in a nearby farm. The borehole seems to have stabilized at about 70M.

4.3 ESTIMATION OF GROUNDWATER RECHARGE IN SIX SUB-REGIONS OF UPPER EWASO NGI'RO NORTH RIVER BASIN

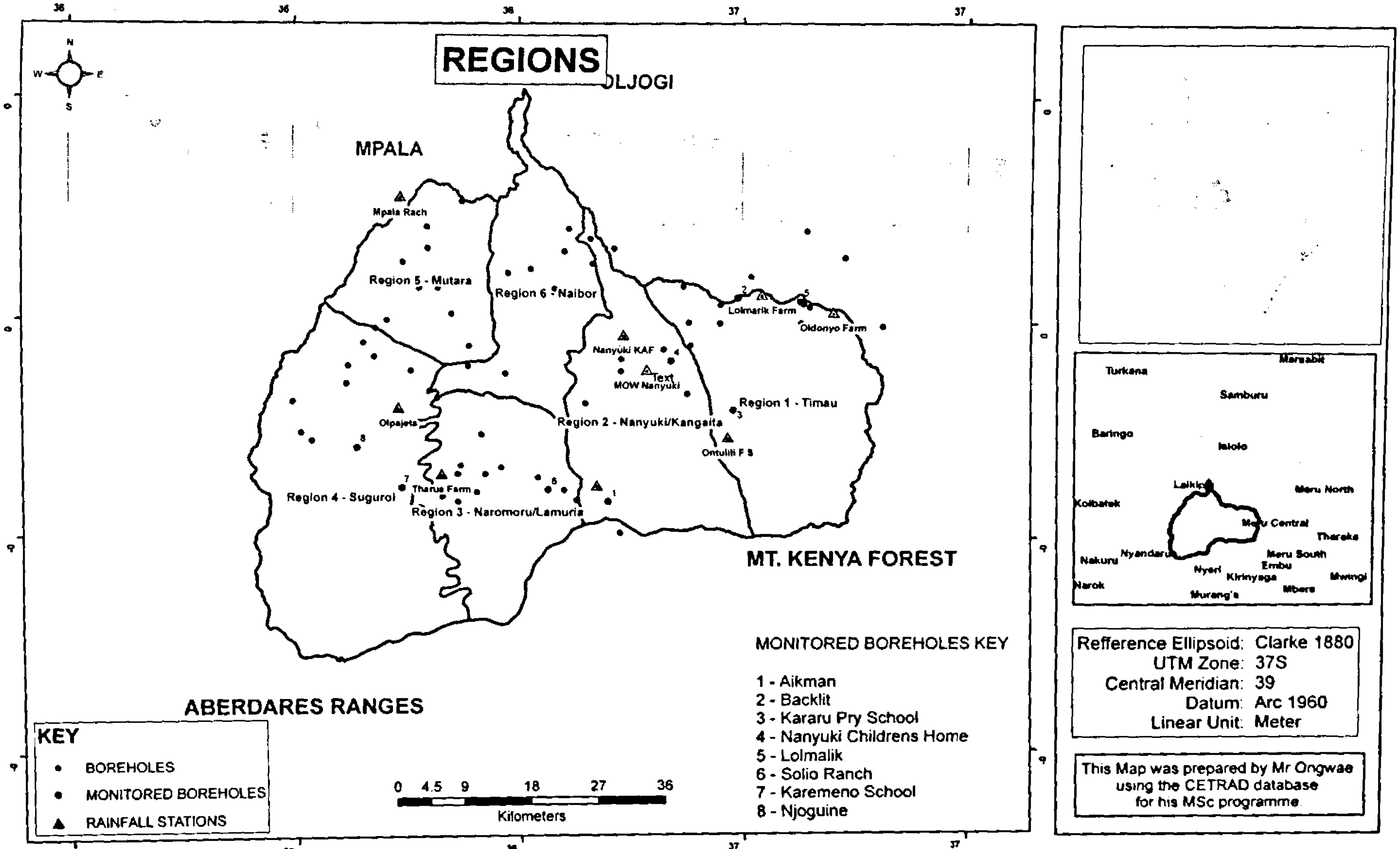


Figure 4.36: Sub-Regions of Upper Ewaso Ngi'ro North River Basin

4.3.1 Groundwater Recharge Estimation

4.3.1.1 Recharge from Rainfall (Ri)

Groundwater Recharge Estimation methods applied in other parts of the world were adapted and applied in the area of study, the Upper Ewaso Ng'iro Basin, because the annual rainfall recorded in the region are above the 360mm as per the literature review. The mean annual precipitation totals for station stations were: 567.3 mm for Lolmarik, 612.3 mm for Nanyuki, Narumoru recorded 1096.7 mm; Ol-Pejeta recorded 715.0 mm. The other stations: Oldonyo recorded 628.8 mm, 918.3 mm for Ontulili, 693.7 mm for Satima, Shamata had 1084.93 mm, Sirimon 829.8 mm while Tharua farm had 1480.2 mm.

Applying the formula section 3.5.4, the recharge values for respective areas are as shown on table 4.5:

Table 4.6 : Recharge values

Sation	**Geo**	**Soils**	**Land use**	**M.A.P**	**Recharge** (Chaturvedi, 1973).	Bredenkamp *et al.* 1995)	**Recharge (CRD)**	**Recharge as % of Ri** (Chaturvedi, 1973).
Lolmarik	volc	Lavisols	Agriculture	567.3	66.3	72.555	35.6	11.7
Nanyuki	volc	Mollic Andosols	Urban stlement	612.3	80.7	88.305	41.1	13.2
Naromoru	volc	Luvisols	Agriculture	1096.7	235.8	257.845	10.73	21.5
Ol Pejeta	volc	Lavisols andphaeo	Agriculture & bush land	715.0	113.6	124.25	16.86	15.9
Ol Donyo	volc	Lavisols	Agricture	628.8	86.0	94.08	35.6	13.7
Ontulili	volc	Feriric Luvisols	Forest	918.3	178.7	195.405	35.6	19.5
Satima	volc		Bushland	693.6	106.8	116.76	10.73	15.4
Shamata	volc	Humic Acrosols	Forest	1084.9	232.0	253.715	16.86	21.4
Sirimon	volc	lavisols	Agriculture and Bushland	829.8	150.3	164.43	41.1	18.1
Tharua Farm	volc	lavisols	Agricture	1480.2	358.5	392.07	10.76	24.2
Total					1608.4/10	1759.1/10	[illegible]	174.6/10
Possible Average Annual(R)					160.8	175.9		17.46%

M.A.P-Mean Annual Precipitation

The three methods applied show different values as the period also differ. Chaturvedi (1973) is taking into consideration total annual precipitation while Bredenkamp *et al.* (1995)

considers the long term mean annual rainfall and Bredenkamp *et al.* (1995) (CRD) considers the monthly precipitation and fluctuation per month. When each method is considered in respect to recharge values in relation to precipitation, they conform to the percentage range of 10% to 25% as per literature review.

Summary

A continuous monitoring of groundwater levels has indicated that aquifers in the area can be said to be more or less steady, with minor fluctuations of less than 5 meters except for Aikman borehole. Karumeno and Kararu Schools appear to use water excessively that causes to fluctuate with seasons.

CHAPTER FIVE

5.0 DISCUSSION

The study has touched on several aspects ranging from climate, geology, and hydrology, economic and social activities to realize its objectives.

5.1 Surface and Groundwater flow

The surface water flow in the area is generally in the Northerly direction (Figure 4.1). The drainage intensity is higher in the North East of Mt. Kenya and North West of Aberdares ranges as compared to other areas.

Groundwater flow direction (Figure 4.3) also shows clearly that the water follows the direction of the pieziometric contours which generally reduces northwards. The boreholes that are in the Southern zone of the area have higher water levels as compared to those in the northern wing, for example, borehole; C16726 in the south and has WRL of 1924m while C14552 in the north has WRL of 1752 m (Table 4.1) confirming the flow direction.

It is clearly apparent that the groundwater follows the direction of the topographical flows of the surface water (Figure 4.1) that generally flows northwards. A centrifugal flow is evidenced in some spots (e.g. areas around BH C 15221 with WRL of1399m which is lower than the surrounding BHs A10, A20 and C14847, see table 4.1) implying a change in flow direction compared to the general flow. The BH C15221 has WRL at a depth of 72.2m, when compared to surrounding BHs mentioned above; with depths of 18m, 18.25m and 33.3m to WRL respectively, indicating that BH C15221 taps water from a deeper aquifer. In the same direction the upper aquifers can be said to have no influence to the borehole as it taps from the deeper aquifer. It's also possible that geology of the area revealed of basement inliers likely to contribute to such flow behavior.

5.2 Rainfall and groundwater fluctuations

The rainfall long term trend was to vary within the area, some were positive i.e. rainfall increased with time for Lolmarik, Naromoru, Oldonyo, Satima, Ol Pejeta, Tharua and Shamata. All stations showed significant t-test at both 95% and 99% significance levels. The rest: Nanyuki, Sirimon, and Ontulili, recorded insignificant change over the same period at 95% and 99% significance levels.

A period between 2005 and 2009 was considered to determine the relationship between rainfall and water rest levels; the time span was constrained of availability of monitored data on water rest levels. The study also showed a negative relationship between the two in that increase in rainfall to a decrease in WRL depths. Smoothening of rainfall graphics display a moving average method was used to bring out time lag between rainfall and the water rest levels response; the time lag range from 2 – 6 years for almost all the stations. The data was further used to compute correlation between the rainfall and WRL; their correlations were found to be low, in the range of 0.2 to 0.6. The degree of determination of WRL using rainfall was equally low; r^2 was equal to 0.08 to 0.27. Rainfall Stations close to Borehole stations and those far in the forest area (Mt. Kenya and Aberdares ranges Figure 5.1) were correlated and results tabulated (table 5.1).

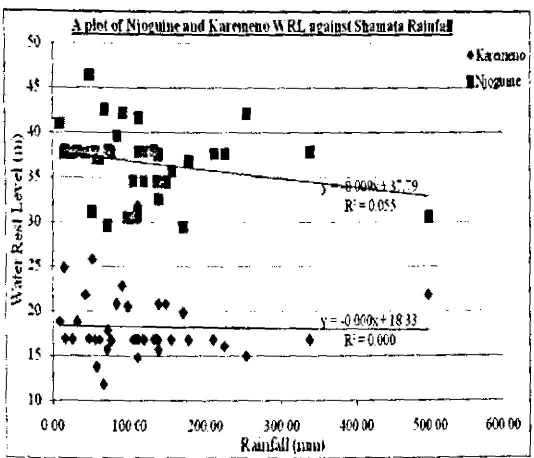


Figure 5.1a : Water rest levels of BHs at Njoguine (further from station) and Karemeno (near to station) against rainfall at Shamata station

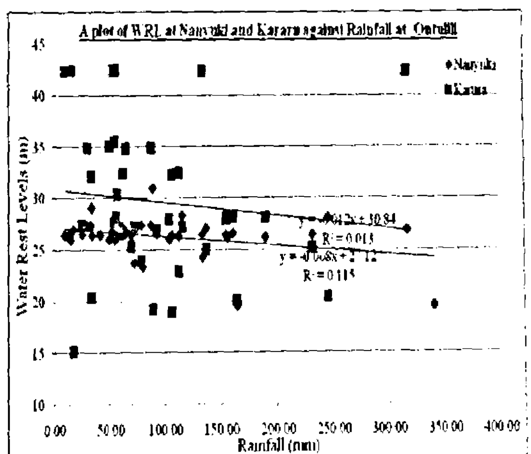


Figure 5.1b : Water rest levels at Nanyuki (further from station) and Kararu (near to station) against rainfall at Ontulili station

Table 5.1a : WRL in BHs versus rainfall correlation

Rainfall station	**BH**	**Sub-Region**	**Correlation(R)**	
			Untransformed data	Transformed data
Ontulili	Kararu	Nanyuki-Kangaita	-0.117	-0.177
Ontulili	Nanyuki	Nanyuki-Kangaita	-0.340	-0.267
Shamata	Karameno	Suguroi- Olpajeta	-0.023	-0.107
Shamata	Njoguine	Mutara	-0.235	-0.272

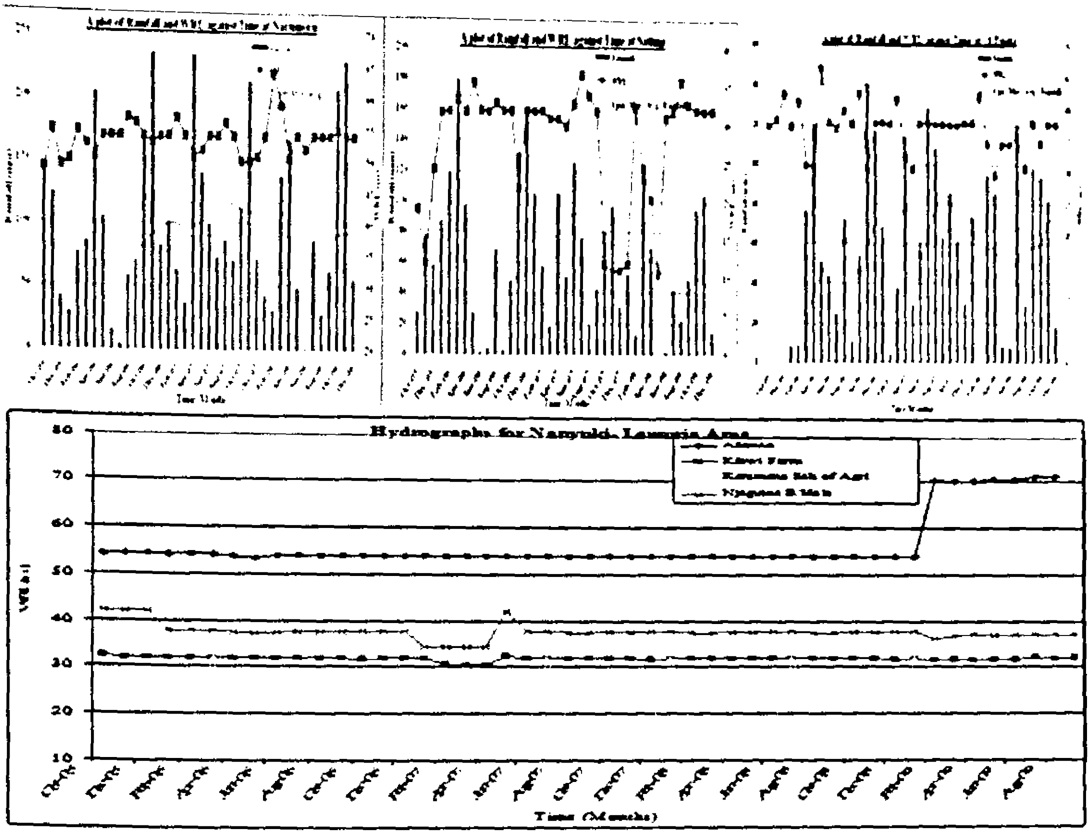


Figure 5.2 : Showing comparison of the rainfall versus water rest levels fluctuations

Table 5.2: WRL in BHs versus rainfall correlation

Rainfall station	**BH**	**Sub-Region**	**Correlation(R)**	
			Untransformed data	Transformed data
Ontulili	Kararu	Nanyuki-Kangaita	-0.117	-0.177
Ontulili	Nanyuki	Nanyuki-Kangaita	-0.340	-0.267
Shamata	Karameno	Suguroi- Olpajeta	-0.023	-0.107
Shamata	Njoguine		-0.235	-0.272

5.3 Estimation of groundwater recharge

The three methods applied in the estimation of groundwater recharge gave different output. Two of the three methods: Chaturvedi (1973) and Bredenkamp *et al.* (1995), however, gave almost similar results with correlation coefficient of 1, and thus either of the two can be adopted for groundwater estimation in Upper Ewaso Ng'iro basin. Each station has different amounts of recharge as shown on the (table 5.2). Average recharge in the Upper Ewaso Ng'iro can be given as 168 mm annually.

Table 5.3 : Recharge estimates from Rainfall values

Sation	**Mean Annual Precipitation**	**Recharge** (Chaturvedi, 1973).	**Recharge as % of Ri using Chaturvedi, (1973)**	Bredenkamp *et al.* (1995)	**Recharge as % of Ri using** Bredenkamp *et al.* **(1995)**
Lolmarik	567.3	66.3	11.7	72.555	12.8
Nanyuki	612.3	80.7	13.2	88.305	14.4
Naromoru	1096.7	235.8	21.5	257.845	23.5
Ol Pejeta	715.0	113.6	15.9	124.25	17.4
Ol Donyo	628.8	86.0	13.7	94.08	15.0
Ontulili	918.3	178.7	19.5	195.405	21.3
Satima	693.6	106.8	15.4	116.76	16.8
Shamata	1084.9	232.0	21.4	253.715	23.4
Sirimon	829.8	150.3	18.1	164.43	19.8
Tharua Farm	1480.2	358.5	24.2	392.07	26.5
Total	8626.9	1608.4	174.6	1759.1	190.9
Possible Average Annual (R)	862.7	160.8	17.46%	175.9	19.09%

The rainfall values in the areas, show a close correlation to recharge estimates calculated using Formulas as per (Chaturvedi, 1973) and Bredenkamp *et al.* 1995.

Table 5.4 : Recharge estimates using CRD

Station	**Mean Annual Precipitation**	**Recharge as % of Ri**	**Recharge (CRD)**
Lolmarik	567.3	35.6	6.275339
Nanyuki	612.3	41.1	6.712396
Naromoru	1096.7	10.73	0.97839
Ol Pejeta	715	16.86	2.358042
Ol Donyo	628.8	35.6	5.661578
Ontulili	918.3	35.6	3.876729
Satima	693.6	10.73	1.547001
Shamata	1084.9	16.86	1.55406
Sirimon	829.8	41.1	4.953001
Tharua Farm	1480.2	10.76	0.726929

CRD method (table 5.4) gave negative correlation with the other two methods, of approximately 0.5 and proved unaplicable in the area of study. The results do not concurs with literature review of this study; CRD method is best applicable in a dolomitic formation of rocks which are not present in the area of study.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATION

6.1 Introduction

The drainage, rainfall characteristics and estimation of groundwater recharge in the study area have been discussed at length as stipulated in the objectives. This chapter therefore reviews and summarizes the various conclusions that have been arrived at and further puts forth some recommendations in respect to rainfall and groundwater recharge.

6.2 CONCLUSIONS

Following the results obtained in this study, the objectives were met in that the ground water flow was successfully obtained and direction shown by vector map, the correlation and time lags between rainfall and water rest levels for the boreholes were determined. The degree of correlation was however very low.

Rainfall amounts at specific stations were found to be on decrease, a scenario not very clear but evident in the short run that leads to decrease in water levels in the short run. Given similar mean precipitation, water availability is expected to increase in rivers whose parts of the catchment have urbanization and/ or grazing land. The increase is projected to be due to higher surface run off and increased actual evapotranspiration, however, this is contrary to ground water yields are expected to decline. This trend is not felt by now as the confined condition still has a lot of effect, revealed by water rise upon borehole drilling. .

Groundwater movement from recharge area to discharge area depends on the available recharge and the aquifer characteristics and the mode of discharge. In the study area, therefore, these conditions are not uniform, mainly due to great variation in rainfall distribution and geological conditions of the subsurface that affects groundwater recharge in the Mount Kenya and the Northern Aberdares area. The recharge areas were determined to be high in the forest but you can not rule out direct recharge possibly due to geology of the area.

6.3 RECOMMENDATIONS

Relevant recommendations can also be deduced in connection with the outcome; owing to the time and resources constrains, the present study could not manage to investigate every bit of aspect arising from the grand research problem in details, thus some aspects of the investigation were omitted in an attempt to keep the study to manageable limits. It is therefore against this background that the following areas have been identified and recommended for future investigation.

- Data available from stations considered for borehole water rest levels monitoring for a period of less than 5years (2005 to 2009) was short. For more conclusive results, more time should be applied to a full investigation of rainfall-groundwater recharge considering the drought cycles occurring in the area. I therefore recommend longer data sets to be considered in the future studies for more findings to be obtained in the area of study.

- Aquifer yields in this confined regional aquifer can be another issue that will need to consider for future study. Earlier boreholes seem to have low yields and most of them are drying or have dropped their water levels than the most recent one; hence this study recommends a study on Aquifer yields.

- It could be of interest to find out why different stations showed different time lag in relating rainfall regimes and water rest levels even when the stations are located within similar soil type and formation. Recommend an investigation on Transmissivity of the area.

- A number of boreholes have had decline of water rest levels even at the same rate of usage, i.e. the Nanyuki Sport Club borehole for example has dropped WRl by 40m below, Aikman borehole Naromoru C12826 has dropped 16m, at Ardencaple, Timau, and two boreholes have recently dried. It could of interest to investigate what could be causing such unexpected behavior.

- Effects of urbanization on the surface runoff and groundwater recharge were not addressed in this study, although their contribution is usually significant according literature review especially to the surface flow and infiltration which are key components of the hydrological cycle. Although studying these effects would be more demanding, given that the study will involves the use of additional components, e.g. constructions of structures, tarmacing of roads and traffic flow , this should be incorporated in future research upon availability of funds, the results would be more comprehensive from which sound planning polices can be drawn.

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APPENDICES

APPENDIX 1: Borehole Information Questionnaire

INTRODUCTION

An investigation on the groundwater recharge in the area between Kisima and Ndaragwa area is being carried out using Boreholes. The behavior of the Boreholes will reveal the potential. Together with these out come it will be possible to establish whether the Recharge to the groundwater in the area is enough to be dependable for future needs.

Therefore we request you to give the relevant and accurate information to assist the study. The information will be treated strictly confidential "***Without information we can ruin our Environments***"

QUESTIONNAIRE TO BE FILLED BY THE BOREHOLE OWNER, MANAGER OR WATER OFFICER I/C WITHIN THE STUDY AREA BETWEEN KISIMA AND NDARAGWA

Equipments-a GPS, a Camera, Stationery

GPS Reading..................................Altitude..

Respondent (position)..

1. Name of the Borehole(BH)...
2. Location..Farm/Area.............................
3. Ownership.................................Private/Community.............................
4. Borehole No../or Authorization No......................
5. Total Depth in (M)..
6. Water Struck Level ....
   a. Water Rest Level..
   b. Yield in M^3/hr........................../or lpm...
7. Usage of the water from the Borehole (Domestic, irrigation, livestock and others)
8. No of hours pumping per day.......................weekly..............monthly..............

9. Have you been checking the water level

a) Yes/No............

Levels Wet season...

Levels Dry season...

Date of completion ....Records available (Yes/No)..........

b) Any information since it started operational...

....

Is the yield same, reduced, or dried ....

....

....

10. Do you pump continues or you must stop to give room for the borehole to recover?

....

....

How many Boreholes are near by? Give approximate distance

....

11. Does the BH (s) provide adequate water for your need?

....

.

14. Give your general comment on the BH (s)

....

....

....

...rds for monitored boreholes

...n	ZONE	UTM x	UTM y	Altitude	Completion Date	Total Depth	Yield (M3/HR)	SWL	[illegible] WBL
...ru	37N	278382	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	37N	281455	[illegible]	[illegible]	[illegible]	122	[illegible]	[illegible]	[illegible]
	37N	295685	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
...a	37N	286490	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	37N	281462	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]
...a	37N	272165	[illegible]	[illegible]	[illegible]	91	[illegible]	[illegible]	[illegible]
...a	37N	252550	[illegible]	[illegible]	[illegible]	89	10.8	36	14
[illegible]	37N	246523	[illegible]	2100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX 3: Groundwater monitoring using a dipper

Borehole monitoring data

Monitoring Data													
BHs Names	**Bh No.**	**Alti (M)**	**Oct-05**	**Nov-05**	**Dec-05**	**Jan-06**	**Feb-06**	**Mar-06**	**Apr-06**	**May-06**	**Jun-06**	**Jul-06**
Aikman	C12826	1951	54.2	54.38	54.38	54.2	54.38	54.2	53.7	53.43	53.87	53.9
Backlit	C241	2345	18	18.02	18.0436	21	21.56	24	18.4	18.492	18.28	18.22
Kararu Pry Sch.	C12497	2060	27.4	25.3538	25.9109	27.89	26.21792	28.16	27.23	33.8813	34.9	42.43
Nanyuki childrens Home	C11934	1940	26.3	28.6657	27.7979	26.4	26.4688	26.52	26.4	26.4688	26.58	26.98
Lolmalick b/h3	C11311	2320	29.23	28.6657	27.7979	30.1	30.0038	30.85	31.2	31.6956	30.82	30.63
Kibwi /Tharua Farm	C861	1859	32.34	31.7997	31.7887	31.72	31.78709	31.79	31.78	31.7883	31.79	31.79
Karemeno Sch of Agri	C7426	2100	16.7	16.705	16.71	16.9	16.905	31.78	16.84	16.845	16.83	16.825
Njoguine B/Hole	C932	1960	42.03	41.9106	41.9106	37.8	37.7356	37.78	37.4	37.3408	37.52	37.58

Monitoring Data											
BHs Names	Bh No.	Alti (M)	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06	Jan-07	Feb-07	Mar-07	Apr-07
Aikman	C 12826	1951	54	54	54	54	54	54	54	54	54
Backlit	C241	2345	18.16	18.2088	18.2	18.256	18.32208	18.02	18	18.01	18.03
Kararu Pry Sch.	C12497	2060	42.42	42.3406	42.34	42.341	42.0677	42.1	42.13	42.13	42.05
Nanyuki childrens Home	C11934	1940	27.38	26.51	26.02	26.453	26.47102	26.5	27.08	28.07	25.78
Lolmalick b/h3	C11311	2320	30.44	30.5267	30.35	30.388	30.44721	30.42	30.37	30.31	30.16
Kibwi /Tharua Farm	C861	1859	31.8	31.7887	31.68	31.786	31.78844	31.77	30.82	30.34	30.46
Karemeno Sch of Agri	C7426	2100	16.82	16.825	16.76	16.765	16.77	16.775	16.78	16.785	16.79
Njoguine B/Hole	C932	1960	37.63	37.5678	37.87	37.805	37.74023	34.41	34.43	34.45	34.48

Monitoring Data												
BHs Names	Bh No.	Alti (M)	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08
Aikman	C 12826	1951	53.87	53.9	54	54	54	54	54	54	53.87	53.9
Backlit	C241	2345	18	21	24	18.4	18.28	18.22	18.16	18.2	18.02	18
Kararu Pry Sch.	C12497	2060	27.4	27.89	28.16	27.23	34.9	42.43	42.42	42.34	28.16	27.23
Nanyuki childrens Home	C11934	1940	26.3	26.4	26.52	26.4	26.58	26.98	27.38	26.02	26.52	26.4
Lolmalick b/h3	C11311	2320	29.23	30.1	30.85	31.2	30.82	30.63	30.44	30.35	30.85	31.2
Kibwi /TharuaFarm	C861	1859	32.34	31.72	31.79	31.78	31.79	31.79	31.8	31.68	31.79	31.78
Karemeno Sch of Agri	C7426	2100	16.7	16.9	31.78	16.84	16.83	16.825	16.82	16.76	31.78	16.84
Njoguine B/Hole	C932	1960	42.03	37.8	37.78	37.4	37.52	37.58	37.63	37.87	37.78	37.4

Monitoring Data												
BHs Names	Bh No.	Alti (M)	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08	Oct-08	Nov-08	Dec-08
Aikman	C 12826	1951	54	54	54	53.9	54	54	54	54	54	54
Backlit	C241	2345	18.01	18.03	18	21	24	18.4	18.28	18.22	18.16	18.2
Kararu Pry Sch	C12497	2060	34.9	42.43	42.42	27.89	28.16	27.23	34.9	42.43	42.42	42.34
Nanyuki childrens Home	C11934	1940	26.58	26.98	27.38	26.4	26.52	26.4	26.58	26.98	27.38	26.02
Lolmalick b/h3	C11311	2320	30.82	30.63	30.44	30.1	30.85	31.2	30.82	30.63	30.44	30.35
Kibwi/tharua Farm	C861	1859	31.79	31.79	31.8	31.72	31.79	31.78	31.79	31.79	31.8	31.68
Karemeno Sch of Agri	C7426	2100	16.83	16.825	16.82	16.9	31.78	16.84	16.83	16.825	16.82	16.76
Njoguine B/Hole	C932	1960	37.52	37.58	37.63	37.8	37.78	37.4	37.52	37.58	37.63	37.87

Monitoring Data											
BHs Names	Bh No.	Alti (M)	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Sep-09
Aikman	C 12826	1951	53 87	70.38	70 23	70 23	70 56	70 56	71 29	71 37	
Backlit	C241	2345	18 02	17 95	17 95	18	18	18 3	18 3	18	18 4
Kararu Pry Sch.	C12497	2060	28 16								
Nanyuki childrens Home	C11934	1940	26 52	26.01	26 2	26 31	26 32	26 34	27 4	25 42	25 1
Lolmalick b/h3	C11311	2320	30 85	30.75	31 24	31 2	31 3	31 5	31 8	31 8	31 7
Kibwi Tharua Farm	C861	1859	31 79	31 5	31 65	31 43	31 68	31 6	32 12	31 84	31 92
Karemeno Sch of Agri	C7426	2100	31 78								
Njoguine B/Hole	C932	1960	37.78	36.3	36 8	37 05	37 01	37 03	37 2	37 1	37 09

APPENDIX 4: Regional Borehole Drillage Time series

Region 1: Timau Area

YEAR RANGE	**Area**	**Bh Nos*[3]**	**Completion date**	**T. Depth (M)**	**WSL (M)**	**WRL (M)**	**Yield (M^3/Hr)**
1930-40		P139	1-3-31	55	35	30	13
		C27	1-5-37	54	32	27	3.6
		C26	5-5-37	37			Dry
1940-50	Timau	**C241**	10-43	122	82	21	1.08#
		C523	1-4-47	79	70	40	9.06
		C523	25-04-47	79	70	40	9.06
		C694	11-06-48	86	84	52	6.78
1950-60		C1679	17-02-52	66	62	53	6.72
		C2314	11-54	92	31,85	31, 27	1.44
		C2315	17-11-54	73	65	32	10.92
1960-70							
1970-80							
1980-90							
1990-2000		A21	14-09-99	52.6	7.86	28	1.76
	Lormalick	**C11311**	06- 02-1999	140	53, 98	28.94	10.6 #
	Timau	**C12497**	20-09-1999	140	49, 92	34	10.5 #
2000-10	Greenland	C15253	09-2006	114	18	5.8	8.82
	Ngushishi	C17105	12-2007	200	50,92,134,164, 182	35.33	9.98
	Ethi	WRMA /GW/1113	12-2007	140	72,96,124,	17.32	9.7

- Monitored boreholes

Region 2- Nanyuki-Kangaita area

	Area	Bhs Nos 1985	Completion date	T. Depth (M)	WSL (M)	WRL (M)	Yield M^3/Hr
1930-40		P163	18-09-31	34	18	15	5.68
		P167	29-10-31	64	52	43	6.55
1940-50	Nki KCC	C149	02-41	122	101	55	3.24
		C1619	15-11-41	159	131	23	14.76
		C290	18-12-43	128	126	37	4.08
		C291	22-02-44	109	88	24	3.3
		C718	07-48	132	69,119	50	0.90
		C922	08-49	110	95	48	6.00
1950-60		C1563	10-51	154	114,15 2	67	3.78
		C2188	03-54	153	109,14 2	43	4.24
		C2375	01-55	128	67,72	61	1.68
		C2682	08-04-57	105	94	41	9.06
		C2803	05-58	92	35,58	32	1.32
1960-70							
1970-80							
1980-90	Nki Base	C5019	11-80	180	74	40	4.26
		C5019	11-11-80	180	40,100	40.42	0.05
1990-2000		A33	28-9-99	112	50.32	32	2.00
	Sweetwaters Njoguine 2	A16	26-10-99	83	54.95	42	1
		A10	29-10-99	50	26	18	13.66
2000-10	Nanyuki C. Home	**C11934**	06-2003	102	45-50 60-64 68-76 80	27.0	4.75#
	Kangaita	C14847	11-2005	200	46	33.30	26.6
	Nki Drt. Hospital	C16726	02-2006	188	44.0,	25.5	12.0
	Turaco (Ontulili)	C70145	10-2008	168	17,71,9 1,127,1 36	5.6	36.3

Region 3 : Narumoru- Lamuria							
Year	**Area**	**BH No.**	**Completion Date**	**T. Depth (M)**	**WSL (M)**	**WRL (M)**	**Yield (M^3/Hr)**
1930-40							
1940-50		C308	28.04.44	51			Dry
	Lamuria	C309	07-1946	134	68,72,110	17	3.54
		C555	JUN 1947	76	26,70	16	3.60
		C522	10.04.49	46	38	25	8.58
	Lamuria	C861	13/05/1949	91	85	32	6.36#
		C887	26.05.49	126	64	49	0.95
		C884	14.06.49	85	55,67	59	0.55
		C957	09-1949	156	34,154	2	8.22
	Tharu farm	C1015	11-1949	140	60,102,133	49	4.62
	Lamuria	C1015	09.11.49	140	133	49	4.62
1950-60		C1168	01-1950	126	85,127	84	5.45
		C1140	07-50	122	98,119	52	6.78
	Naromoru	C1562	09-1951	121	67,111	50	8.52
		C2349	01-1955	107	24,59	17	6.37
		C2369	01-1955	157	79,120,133	53	5.68
		C2345	01-1955	114	76	73	10.91
1960-70							
1970-80							
1980-90							
1990-2000		A13	28.8.99	53	47	9.2	13.66
		A12	29/8/1999	46.1	38	7	13.66
		A9	30.08.99	92	80	12.7	0.40
	Lamuria DO office	C12457	09-1999	60.9	55	28.2	0.42
		A8	23.09.99	47	40	13.5	1.00
		11A	24.09.99	154	150	25	1.65
		A20	21.10.99	92	81	18.25	13.66
2000-10	Naromoru	C12826	01-2000	146	74	54.3	15.03#
		C1124	06-2005	104	92	82	4.50
	Naromoru R. Lodge	C15221	04-2006	115	80	72.2	18
	Lamuria session	C17107	11- 2007	160.0	38.25	20.0	14.8
	Naromoru	GW1266	01-2008	145.0	25	14.08	23.8

Region 4; Suguroi-Opejata

Opejata Area

YEAR RANGE	Area	Bhs after1985	Completion Date	T. Depth (M)	WSL (M)	WRL (M)	Yield (M^3/Hr)
1930-40		C42	12-38	85	75	34	4.86
1940-50		C244	11-43	131	7	0.54	
		C382	11-45	152	40,97,147	66	4.80
		C555	JUN 1947	76	26,70	16	3.60
		C593	07-47	122	41,119	35	2.76
		C954	08-49	102	66,93	49	8.64
	Ol Pejeta	C954	08-1949	102	66,93	49	8.64
1950-60		C2027	03-1953	167	56	24.3	0.36
		C2003	08-53	183	46,99,157, 177	24	3.18
		C2023	SEP 1953	55	50	43	6.48
		C2036	SEP 1953	61	28,116	19	0.60
		C2363	02-1955	164	128	64	0.84
		C2414	08-1955	317*[4]	74,184	72	0.12
		C2479	FEB 1956	142	55	23	0.30
1960-70							
1970-80		C4683	09-1979	213	199	37	5.4
		C4737	03-1980	230	184	87.3	3.60
1980-90		**C7426**	20/08/1988	89	36	14	10.8#
1990-2000							
2000-10							

C* - Un registered

Region 5; Mutara ADC –Mpala area

YEAR RANGE	Area		Completion date	T. Depth (M)	WSL (M)	WRL (M)	Yield M^3/Hr
1930-40	Contact	P141	05-1931	67	62	14	11.36
	Basement	P175	04- 1932	66	39	32	3.03
		P171	11.06.32	121	191	64	0.46
1940-50		C296	04-44	66	66	18	5.22
		C296	04-1944	66	64	18	5.22
		C297	09-44	308	59,244	50	1.14
	Segera	C515	03 1947	105	30,98	34	4.32
	Mutara	C932	09-49	182.9	155	36.94	3.48#
1950-60		C1696	04-50	-	–	-	Dry
	Contact	C1702	5-1951	61	55	8	4.56
		C1702	05-51	61	55	8	4.56
		C1701	05-51	52	-	-	-Dry
		C1706	01-52	161	85,146	82	7.98
		C1791	06-52	176	36	29	2.34
		C2414	08-55	317	77	72	0.12
		C2561	06-1956	92	81	37	9.06
		C2562	09-56	213	52,146,202 ,204	45,62	13.62
		C2634	02-57	283	44,277	51	1.56
		C1703	08-58	172	85,98,151, 170	59	2.28
		C2858	02-59	107	17,41,50,1 05	12	9.00
		C2898	03-59	182	39	38	0.84
1960-70	Contact	C3563	04-1962	68	42,58,63,6 7	33	9.12
1970-80							
1980-90							
1990-2000							
2000-10	Basement	C17109	09- 2007	230	148,180, 204	51.6	7.5

Region 6: Naibor Area

YEAR RANGE	Area	Bhs before 1987	Completion date	T. Depth (M)	WSL (M)	WRL (M)	Yield M^3Hr
1930-40		P152	18-07-31	70	46,57	43	5.45
1940-50		C373	08-45	59	50	50	0.54
	Naibor	C395	Feb 1946	61	42	32	1.56
		C396	02-46	19	9	7	0.30
		C539	05-47	48	40	40	6.42
	Naibor	C715	May1948	63	44	41	0.48
	Naibor	C718	Jul 1948	132	69,119	50	0.90
1950-60		C2189	04-54	98	76	-	0.36
		C2375	01-55	128	69,72	61	1.68
		C2446	11-55	144	-	-	-Dry
	Naibor	C2803	May1958	92	58	32	1.3
1960-70							
1970-80							
1980-90		C4727	24-02-80	82	68,78	51.2	4.55
1990-2000	Drico Naibor 1	A30	03.10.99	75	65	35	0.2
	Naibor 2	A31	11.10.99	82	76	49	0.4

APPENDIX 5: Normalized Rainfall Data

Normalized Lolmarik Rainfall Data

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1965	-0.29984	-0.71416	-0.85492	-0.15482	-0.74472	-0.9262	-0.92887	-0.78426	-0.538131	0.891205	-0.15698	-0.23022
1966	-0.59991	3.47159	-0.85492	1.00777	-0.64103	1.065596	-0.52404	1.476109	1.68797	0.156979	0.10828	0.215367
1967	-0.36875	-0.71416	-0.85492	0.504173	2.50189	0.025282	1.401743	0.626323	-0.675081	1.015488	2.77544	-0.250214
1968	-0.59991	0.68533	-0.85492	2.68259	0.59012	1.007516	0.041046	-0.84149	-0.097744	0.053728	1.30741	-0.270209
1969	-0.1487	0.19763	-0.85492	-1.33612	-0.17534	-0.74513	-0.20917	-0.57253	-0.154135	-0.19101	0.50799	-0.304484
1970	-0.29318	-0.58694	-0.85492	-0.31885	-0.25452	-0.5931	-0.63649	-0.37797	1.252954	-0.70344	-0.79833	-0.775778
1971	-0.17982	-0.71416	-0.85492	0.128633	0.29035	0.119235	-0.74332	1.959657	0.197637	-0.24455	-0.18968	-0.667238
1972	-0.59991	1.74131	-0.85492	-1.19799	0.29977	0.455757	-0.74332	0.694993	-0.513963	1.260229	0.58249	-0.667238
1973	-0.4421	-0.28584	-0.85492	-0.69007	0.0773	-0.42911	0.622997	-0.06037	-0.274973	-0.26558	-0.39499	-0.587261
1974	-0.59991	-0.71416	-0.85492	-1.02101	-0.90498	-0.70072	2.292943	1.802289	-0.613319	-0.37839	-0.82376	0.055413
1975	-0.20649	-0.71416	-0.85492	-0.35482	0.63537	0.616331	1.893731	0.729328	0.146617	-0.1413	-0.36592	-0.59583
1976	-0.59991	-0.12468	-0.85492	-0.21669	-1.56863	-0.28562	0.131009	0.700715	-0.444146	-0.55621	-1.01635	0.520994
1977	-0.59991	-0.34097	-0.85492	1.568921	1.25377	-0.59481	1.640708	-0.25207	-0.041353	0.143595	0.50254	-0.341617
1978	0.10469	0.84224	-0.85492	-1.14475	-0.38462	-0.25828	2.031487	-1.25923	-0.272288	0.235373	-0.40407	0.281063
1979	1.24494	1.32146	-0.85492	0.151655	-0.11878	0.033823	-0.04048	-1.07897	0.135875	-0.36501	-0.26599	-0.364467
1980	-0.15092	-0.71416	-0.85492	-1.16777	-0.18665	-0.91937	0.206916	-0.47239	-0.218582	-0.99216	-0.28416	-0.775778
1981	-0.59991	-0.62087	-0.85492	1.225036	0.76546	-0.4889	-0.23166	0.855222	2.200859	-0.47591	-0.55305	0.055413
1982	-0.59991	0.6302	-0.85492	0.081151	0.42609	-0.58114	-0.7377	-0.30072	-0.613319	2.164627	1.03852	0.632391
1983	-0.59991	0.33333	-0.85492	-0.20518	1.8948	-0.48206	-0.40596	0.179971	0.001611	-0.43002	-0.13699	1.803485
1984	-0.59991	-0.71416	-0.85492	-0.97065	-1.40083	-0.66997	-0.47906	-1.25923	-0.033298	-0.31721	0.2282	-0.484433
1985	-0.41987	0.89313	-0.85492	-0.10158	0.75038	-0.58285	-0.27664	-0.45808	-0.441461	-0.89656	-0.27507	-0.267352
1986	-0.37319	-0.71416	-0.85492	1.491223	0.62217	1.361121	-0.5634	0.005436	-0.57841	0.221989	-0.31323	0.603827
1987	-0.40209	-0.71416	-0.85492	-1.26993	0.77677	2.175948	-1.06382	-0.60401	-0.71536	-0.85641	0.19186	-0.775778
1988	-0.59991	-0.71416	-0.85492	0.658129	-1.56863	0.341305	1.606972	0.071245	2.085392	0.805163	-0.20967	1.080834
1989	1.22272	1.23664	-0.85492	0.022158	-0.34314	-0.65289	-1.06382	-0.60114	0.090226	-0.1891	0.24455	-0.775778
1990	-0.59991	2	-0.85492	-0.38072	-1.34238	-0.96037	-1.06382	0.085551	0.761547	0.633078	-0.08249	0.938018
1991	-0.59991	-0.71416	-0.85492	-1.37353	-0.30543	-0.32832	1.016587	-0.05751	-0.71536	-0.60975	-1.22711	0.938018
1992	-0.59991	-0.29008	-0.85492	0.784748	-0.53167	-0.72122	0.622997	-0.91588	-0.71536	-0.57151	-0.15516	2.480434
1993	3.88998	1.27905	-0.85492	-1.37353	0.82579	-0.61872	0.060725	-0.68698	-0.71536	-0.70535	-0.95458	-0.775778
1994	-0.59991	-0.20526	-0.85492	1.496978	1.78733	-0.58456	-0.89514	-1.25923	-0.71536	-0.1891	0.80778	0.423879
1995	-0.59991	0.26124	-0.85492	-1.07137	0.71267	-0.96037	-1.06382	-1.25923	-0.71536	1.149331	0.02653	0.923736
1996	-0.14425	-0.60814	-0.85492	-1.48863	-1.02187	4.138709	0.847906	-1.25923	-0.71536	-0.76272	-1.33612	-0.775778
1997	-0.59991	-0.71416	-0.85492	1.446619	-0.45626	0.320806	0.932246	2.832332	-0.71536	3.176099	3.46039	1.423593
1998	3.75661	0.21883	-0.85492	-0.88432	-0.24887	1.021182	-0.50155	0.314449	0.170784	-0.38031	-1.33612	-0.775778
1999	-0.59991	-0.71416	-0.85492	-1.27281	-1.49321	-0.96037	0.707338	-0.68698	-0.393126	-0.99216	-0.46403	-0.775778
2000	-0.59991	-0.71416	-0.85492	-1.0354	-0.21116	-0.6358	-1.06382	0.171388	-0.71536	-0.8392	0.78961	-0.775778
2001	1.06713	-0.71416	-0.85492	0.122878	-0.49397	-0.96037	-0.07984	-0.60114	-0.070892	-0.72447	-0.33685	-0.775778
2002	0.87219	0.2659	-0.85492	0.284173	-0.84257	0.170994	-0.93365	-0.24549	-0.673738	-0.99197	-0.69241	1.203942
2003	0.572	-2.01993	-0.85492	0.532567	-1.37942	1.249573	-2.24852	-1.7877	-1.542159	-1.93423	-1.23997	-2.183091
2004	0.1097	-1.30153	-0.85492	0.915094	-2.20617	-0.96037	-1.06382	-0.46581	-2.0384	-1.69866	-2.08321	-2.183091
2005	-0.04423	-0.45971	-0.85492	-0.04978	1.1463	-0.46498	-0.13607	0.600572	2.292159	-0.62887	-0.48219	0.252499
2006	-0.24428	0.89737	-0.85492	0.597698	-0.56938	0.303724	-0.97948	1.630615	0.895811	1.856788	0.95313	2.451871
2007	0.68482	-0.14589	-0.85492	-0.29295	-0.43741	0.7137	-0.11358	0.895279	2.864125	-0.27132	-1.09084	-0.68152
2008	-0.20427	-0.71416	-0.85492	-0.79367	-0.23002	-0.93475	-0.45938	-1.25923	-0.258861	1.566157	0.13554	-0.775778

Normalized Narumoru Gate Station Rainfall Data

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1969	0.631579	2.693878	0.685117	-1.85645	0.77837	-0.90672	-0.739634	-1.14156	-0.03798	-0.08563	0.020841	-0.50361
1970	0.86373	-0.44133	2.111538	0.981584	-0.1811	-0.57205	-0.366763	-0.01034	-0.31421	-0.51292	-1.0212	-0.85129
1971	-0.64048	-1.19643	-0.75803	0.08437	0.94337	-0.1723	-0.308904	3.425339	-0.48685	-0.70589	-0.836148	0.556627
1972	-0.05692	0.915816	-0.30318	-1.3134	0.60521	3.12178	-0.858566	0.629606	-0.58513	0.713818	1.043119	-0.15594
1973	-0.21752	0.77551	-1.41856	-0.53738	0.02261	-0.49768	-0.026037	-0.66968	2.73758	-0.58873	0.211283	-0.89088
1974	-0.83129	0.114796	0.03796	0.306312	-0.6374	0.119	0.883639	1.473174	1.25286	-0.55944	-0.90981	-0.82031
1975	-0.83129	-0.625	-0.90351	-0.23516	0.59299	0.19027	3.120861	-0.11054	1.28738	0.047037	-1.136184	-0.91325
1976	-0.89649	0.625	-0.65936	0.328349	0.70911	0.83483	1.928319	0.076923	0.22762	-1.4123	-0.676249	-0.31256
1977	0.671331	-0.22449	-0.16773	1.478986	-0.37258	0.97738	1.738669	0.070459	-0.9251	-0.04945	2.088753	-0.03201
1978	0.528224	1.471939	2.113211	-1.1859	-1.95539	-0.84165	0.433623	-0.40142	1.8239	0.364059	-0.918793	4.023064
1979	2.577834	1.936224	-0.71455	-0.36109	0.35058	-0.27146	-0.578914	-0.78927	0.31262	-0.63525	-0.510959	-0.60861
1980	-1.08889	-0.31122	-0.42525	-0.25091	0.70299	-0.4326	-1.279653	0.396897	-0.65418	-1.16247	-0.492993	-1.15938
1981	-0.47035	-0.05612	1.399164	-0.42405	1.51375	-0.67121	2.085824	0.031674	0.55963	0.917126	0.020841	1.072978
1982	0.04325	-0.84184	-0.51221	0.964269	1.13689	-0.9656	-0.344262	-0.32062	-0.88792	1.51499	1.567733	-0.35215
1983	-0.93306	0.612245	-0.80987	0.567606	-0.46018	0.80694	-0.418194	0.506787	-0.2664	0.143522	-1.635645	0.038554
1984	-0.64684	-0.83673	-1.03227	-1.01432	-1.76798	-0.92532	-0.103182	-0.5404	1.58752	0.295141	0.976644	-0.1938
1985	-0.02035	-0.89031	0.745318	1.431765	1.2693	-0.6929	-0.312118	-1.41306	-0.25046	-0.68349	-1.270931	-0.01652
1986	-1.0062	-0.94898	-0.4587	1.51519	-0.53962	0.82244	-0.942141	-1.3969	-0.84542	-1.48122	-0.669062	-0.31084
1987	-0.6055	-0.47959	-0.59749	-0.83331	-0.26258	1.28416	1.102218	-0.67938	-1.29163	-1.80513	0.322673	-1.23339
1988	0.195898	-0.46939	-0.31321	1.743428	-1.38704	-0.445	-0.344262	0.76212	0.23825	0.105617	-0.735537	-0.35215
1989	-0.56416	2.033163	0.365719	-1.33228	-1.37075	-1.18252	-0.453552	-0.40789	0.40823	1.616644	1.264103	0.176248
1990	-0.42264	0.92602	3.196823	0.375571	-0.19536	-0.45429	-0.668917	-0.68908	-1.1429	0.208994	0.06396	1.272633
1991	-0.35904	-0.60459	-0.2714	-0.61136	0.03483	0.75116	-0.366763	-0.17518	-1.10305	-1.11251	-1.58534	-0.9253
1992	0.027349	-0.76786	-0.7413	0.096962	-0.22184	-0.25287	-0.675346	-0.87007	-0.46826	0.870606	0.565217	1.327711
1993	2.053109	2.079082	-1.25635	0.35196	0.54614	1.30896	-1.289296	-0.33678	-0.84807	-0.11837	0.193317	0.12117
1994	-0.71363	-0.68878	-0.35502	0.344089	1.33449	1.718	0.028608	-0.26244	-0.51607	0.606995	1.25512	-0.17315
1995	-0.91239	0.262755	1.063043	-0.19424	1.45468	0.24605	0.009322	-0.91855	0.91819	1.251378	-0.60618	0.739071
1996	0.366036	-0.8801	-0.20953	-2.51912	-1.02648	1.31825	-0.270331	1.709114	0.75618	-1.10217	-0.038448	-0.39346
1997	-0.45444	-1.29082	-0.05401	1.15473	-0.32165	-0.20328	1.009	0.875242	-1.35803	2.092178	0.563421	1.945611
1998	3.784703	0.237245	0.414214	1.022509	1.01059	0.42888	-0.289617	0.193277	-0.46295	-0.28032	-0.579231	-1.05783
1999	-0.35427	-0.64541	1.16505	0.29372	-1.24037	-1.07096	-0.926069	1.822237	-0.93307	-1.46399	1.661157	0.246816
2000	-0.84878	-1.18622	-1.26806	-1.93043	-1.20778	-1.10505	-0.482482	-0.50485	-0.44436	-0.80065	-1.639238	0.551463
2001	0.354905	0.408163	-0.0908	-0.87581	-1.22	-0.1506	0.144327	0.500323	-0.77636	0.355445	1.725835	-0.26437
2002	0.758785	-0.22704	1.051338	0.780104	0.0002	-0.55036	-0.791064	-1.05753	-1.28367	-0.21141	-0.324111	1.315663
2003	-0.08873	-0.33673	-0.29314	0.756493	1.46079	0.47536	-0.1964	0.849386	1.59814	2.547037	0.072943	0.75284
2004	0.704723	-0.48724	-0.12425	-0.22572	-1.17519	-0.78897	0.144327	-1.08985	-0.14954	-0.47674	0.577794	-0.64819
2005	-0.0442	-1.17347	-0.35836	0.255942	1.49949	-1.17013	-0.794278	-0.93471	1.80266	0.117677	-1.03198	-0.86506
2006	-0.62458	0.67602	-0.10418	0.331497	0.00224	-0.74558	-1.231437	0.480931	0.24622	0.553584	0.971254	-0.1525
2007	0.494832	0.329082	-0.92191	0.789548	0.72744	1.85745	0.999357	1.402069	0.24622	-0.34924	0.581387	-0.33838
2008	-0.42582	-0.48724	0.772074	-0.25563	-1.15278	-1.18872	1.433301	-0.48546	0.02576	1.273777	0.868847	-0.61377

Normalized Ol Donyo Rainfall Data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1955	-0.40669	-0.1835	-1.01552	-0.0978	0.04976	-0.2878	-1.38	0.60201	1.77058	-0.47494	0.4992715	0.879591
1956	0.274404	-0.8182	-1.1239	1.02449	-0.7591	-0.0097	-1.38	-1.09313	0.6802	-0.719527	-0.405699	-0.71571
1957	0.601426	-0.8182	-0.44435	-0.6504	0.91416	-0.2942	-1.38	0.98727	0.06915	0.088412	0.6012627	0.325364
1958	-0.41898	1.86621	-0.40627	-0.2304	-0.5728	1.25997	-1.34	0.303853	0.41676	-1.002205	-0.438077	-0.2832
1959	-0.1313	-0.4666	-0.77827	-0.6555	-0.1703	-0.8353	-1.40	-0.29916	-0.61873	-0.73757	0.3762344	0.23408
1960	0.099828	-0.8182	2.206503	-0.6487	-0.656	0.0097	-1.37	-0.23216	-0.66996	0.052326	-0.609681	0.088459
1961	-0.49275	-0.6467	-0.2188	0.6725	-0.1981	0.02048	-1.37	0.427806	1.33882	4.667402	4.468836	-0.09628
1962	0.950578	-0.3293	-0.68161	-0.8885	0.14889	-0.9388	-1.40	0.360804	-0.9517	0.577586	-1.006314	0.340578
1963	0.40718	0.09091	0.809315	0.61979	3.08505	-0.6391	-1.39	-0.29246	-1.10172	-1.068364	0.6870649	2.364051
1964	-0.52225	-0.6038	-0.99795	0.84935	-1.3123	0.14335	-1.37	0.705863	-1.10172	-1.194667	-1.077546	0.718757
1965	0.161298	-0.8182	-1.1239	-0.1097	-0.8741	-0.7534	-1.40	-1.29079	-0.93707	0.856255	-0.135341	-0.47229
1966	-0.61569	1.42024	1.770064	0.93436	-0.4518	1.45613	-1.33	2.012395	0.59239	0.776063	-0.213048	-0.50706
1967	-0.44357	-0.8182	0.516403	0.52797	2.9998	0.19077	-1.37	0.2	-0.64069	1.369487	1.9886676	-0.70919
1968	-0.61569	3.12693	1.954599	2.45621	0.09933	1.82475	-1.32	-1.7196	-0.24186	0.146552	0.6595435	-0.68746
1969	0.008852	0.14666	1.81693	-1.4496	0.88838	-0.9431	-1.40	-0.58392	0.18258	0.256816	0.4345151	-0.31797
1970	-0.61569	-0.8182	0.484183	-0.528	-0.664	-0.4257	-1.39	-0.03451	1.78888	-0.597233	-1.069451	-0.85047
1971	-0.24932	-0.8182	-0.86321	0.84254	-0.5648	0.04419	-1.37	2.179899	0.74607	-0.348637	-0.256759	-0.83743
1972	-0.53455	1.43739	-0.4297	-1.2506	0.60091	0.16059	-1.37	0.843216	0.26308	1.01263	0.3163348	-0.81352
1973	-0.46324	-0.235	-0.94815	-0.8306	-0.4261	0.10239	-1.37	0.2	-0.33333	-0.270449	-0.520641	-0.93958
1974	-0.51733	-0.8182	0.961629	-0.7337	-0.3448	-0.6499	-1.40	1.727638	-1.10172	-0.392743	-0.846042	-0.05064
1975	-0.56159	-0.7539	-0.47657	-0.0145	0.1588	0.96249	-1.35	1.308878	-0.46506	-0.240377	-0.470455	-0.7331
1976	-0.56159	-0.2564	-0.86614	-0.6793	0.33525	-0.152	-1.38	1.292127	-0.84559	-0.551123	-1.028978	0.277548
1977	-0.61569	-0.6338	-0.23052	2.14844	1.52478	-0.2986	-1.38	0.655611	0.54482	-0.384723	1.6357455	-0.26146
1978	0.003934	1.57461	2.253368	-0.8153	-0.1584	-0.277	-1.38	-1.21039	-0.36626	0.517442	-0.667962	-0.05064
1979	1.316941	0.57118	-0.07528	0.41064	0.62867	-0.346	-1.39	-1.22714	0.14965	-0.617281	-0.637203	-0.47229
1980	-0.12638	-0.8182	-0.2481	-1.2999	0.66039	-0.9431	-1.40	-0.99263	-0.70655	-0.907979	-0.559495	-0.95045
1981	-0.61569	-0.205	2.891916	1.04149	0.61281	-0.4473	-1.39	0.424456	1.88767	-0.458901	-0.839566	-0.13106
1982	-0.61569	-0.4494	-0.74605	0.37834	0.95182	-0.4732	-1.39	-0.56717	-0.75412	1.307338	0.8602882	-0.0702
1983	-0.61569	0.3482	-1.1239	-0.3528	1.1818	0.06359	-1.37	-0.59732	-0.61873	-0.400762	0.0071232	0.51228
1984	-0.61569	-0.8182	-1.1239	-1.1265	-1.3519	-0.4883	-1.39	-1.7196	0.24479	-0.184242	-0.145054	-0.44186
1985	-0.29112	0.62264	0.396309	-0.1012	1.04897	-0.665	-1.40	-0.47672	-0.29308	-0.930032	-0.271329	-0.51358
1986	-0.32309	-0.8182	-0.70797	1.66723	-0.1505	2.19983	-1.31	-0.52697	0.08379	-0.496993	-0.038206	0.192784
1987	0.667814	-0.8182	-0.35647	-1.3816	-0.1287	1.30739	-1.33	-0.60067	-0.58946	-1.194667	-0.1661	-0.90698
1988	-0.20261	-0.8182	1.491798	1.69614	-1.5502	0.67364	-1.35	0.387605	3.23052	1.832598	-0.342561	1.042599
1989	0.88419	0.93568	-0.05185	0.68781	0.15484	-0.8353	-1.40	-1.01608	-0.12477	-0.216319	-0.099725	-0.51793
1990	-0.30834	2.49657	0.545694	-0.0995	-1.5502	-0.9431	-1.40	-0.69782	0.32894	0.856255	-0.62587	0.625299
1991	-0.57143	-0.8182	0.463679	-1.3714	0.28569	-0.1412	-1.38	-0.91223	-0.58946	-0.174218	-1.092116	0.223212
1992	-0.44603	-0.5094	-0.84856	0.13348	-0.547	-0.6801	-1.40	-0.63082	-0.99927	-0.659383	-0.274567	0.925234
1993	3.556922	1.49743	-0.95694	-1.1877	0.7278	-0.2986	-1.38	-0.50352	-0.7285	-0.777666	-0.905941	-0.62443
1994	-0.61569	-0.0463	-0.50586	1.5176	1.14215	-0.4171	-1.39	1.024121	-1.10172	0.337009	1.3702445	-0.20061
1995	-0.60831	0.29245	0.340656	-0.3749	-0.0573	-0.4171	-1.39	0.447906	1.1266	1.110866	-0.187146	0.514453
1996	-0.09688	-0.6509	0.156122	-1.6417	-1.2072	4.68528	-1.23	-1.03953	-0.47237	-0.009824	-0.935082	-0.69398
1997	-0.61569	-0.8182	-0.64938	1.78626	-0.436	0.75124	-1.35	0.273702	-1.10172	-1.170609	2.2217905	4.924364
1998	4.705188	1.49314	-0.20709	-0.4089	1.1481	1.62643	-1.33	0.59866	-0.04427	0.250802	-0.923749	-0.49185
1999	-0.61569	-0.6424	0.75952	-1.101	-1.6651	-0.5486	-1.39	-1.14003	-0.60776	-0.659383	-0.179051	-0.69181
2000	-0.57881	-0.8182	-0.72847	-0.9599	0.10329	-0.4775	-1.39	0.535008	-0.6846	-0.256415	0.3681399	-0.35492
2001	2.020162	1.45026	1.084651	0.37154	-0.7076	-0.4473	-1.39	-0.89548	-0.08086	-0.879912	-0.101344	-0.32015
2002	-0.26654	-0.5695	-0.31254	0.78983	-0.3765	-0.1218	-1.38	-0.43652	-0.83095	-0.224338	0.7728671	1.516409
2003	-0.44357	1.62607	0.120972	0.6708	-1.2052	0.09161	-1.37	2.886767	-0.95536	0.298917	-0.279424	-0.0376
2004	-0.08704	0.06089	0.150264	0.6538	-1.2647	-0.7706	-1.40	0.709213	-0.27845	0.439254	0.8376234	-0.16801
2005	0.158839	-0.5823	-0.74312	-0.1522	0.75753	-0.4257	-1.39	0.156449	2.7146	-0.873897	-0.78938	-0.14627
2006	-0.22719	0.08233	-0.18658	0.53987	-0.5946	-0.9215	-1.40	0.18325	0.59239	1.17101	0.9833252	2.092371
2007	0.982542	0.53259	-1.1239	-0.3239	-0.7988	0.68441	-1.35	0.575209	1.58763	-0.412791	-0.975554	-0.80917
2008	-0.14851	-0.8182	0.120972	-0.9531	0.53945	-0.9431	-1.40	-1.26734	0.59971	1.561949	0.028169	-0.93958

Normalized Shatima Rainfall Data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1973	-0.35727	0.43556	-0.276014	-0.320856	-0.40045	0.05455	-0.1995	0.07352	1.97977	-0.42863	-0.31027	-1.42945
1974	-0.74518	-0.45724	-0.287553	-0.110353	-0.50498	0.05455	-0.0012	0.4508	-0.711	-0.5656	-0.31586	-1.11689
1975	-1.11717	-0.7564	-0.341619	-0.241918	-0.20966	0.08337	-0.0996	0.42407	0.95024	-0.29688	-0.57545	-0.99269
1976	-0.86055	-0.36999	-0.349202	-0.332551	-0.255	0.07112	-0.024	0.13913	-0.1572	-0.55815	-0.87692	0.185122
1977	0.11219	0.04447	-0.283267	-0.040916	-0.20525	0.10714	0.01487	0.2412	-0.9119	-0.17256	-0.01997	-0.85607
1978	-0.18222	1.38913	-0.065682	-0.221817	-0.37212	0.15108	-0.2133	0.14946	0.65902	-0.13981	-0.53637	0.924099
1979	1.81301	0.99492	-0.221947	-0.16773	0.052288	0.33405	-0.3788	0.05226	-0.6125	0.14975	0.26125	-0.4959
1980	-1.0734	-0.13939	-0.382828	-0.291985	0.162483	0.17125	-0.436	0.02613	-0.674	-0.33409	-0.51893	-0.46485
1981	-0.24985	0.22365	-0.197552	-0.387369	0.36587	0.1093	-0.021	0.2412	2.09052	-0.25519	-0.39471	0.727452
1982	-0.65765	-0.86235	-0.427005	-0.149091	-0.1618	0.04375	-0.3803	0.29831	-1.0391	0.56809	0.2159	-0.5787
1983	-0.45474	-0.34973	-0.319531	-0.120586	-0.43824	0.33765	-0.0401	0.4751	-0.1941	-0.13535	-0.60546	0.597045
1984	-1.02964	-0.79068	-0.274366	-0.422453	-0.4968	0.03654	-0.4093	0.01884	0.22014	-0.15619	-0.27678	-0.63044
1985	-0.22996	-0.06927	0.067836	-0.215605	-0.30222	0.08769	-0.256	0.01884	0.43342	-0.05793	-0.4938	-0.15435
1986	-1.06943	-0.86391	-0.364037	-0.019354	-0.38345	0.24113	-0.1316	0.07595	-0.5961	-0.2403	1.19566	0.770922
1987	0.0187	-0.48062	-0.412829	-0.226934	-0.18258	0.42626	-0.3529	0.07291	-1.0145	-0.51721	0.35965	-0.11502
1988	0.01273	-0.51334	-0.027769	-0.186003	-0.32678	0.52279	-0.1064	0.18834	0.21193	-0.08324	-0.28655	-0.23922
1989	-0.0191	0.39037	-0.234145	-0.28358	-0.40045	0.09345	-0.2743	0.15918	1.0938	0.19814	-0.05556	0.578415
1990	-0.53431	0.65837	-0.036011	-0.182348	-0.2084	0.03654	-0.1942	0.17012	-1.1088	-0.33409	-0.31167	0.28241
1991	-0.05093	-0.23132	-0.144474	-0.362884	-0.10261	0.50406	-0.3956	0.39855	-0.711	-0.50679	-0.52032	-0.61802
1992	1.38731	-0.9091	-0.385795	-0.071249	-0.40423	0.05671	-0.3895	0.05104	-0.2721	-0.36313	0.17891	0.435587
1994	-0.23195	-0.65512	-0.405246	-0.288696	-0.25059	0.2793	-0.2674	0.13792	-1.1909	0.11477	0.14192	-0.76499
1995	-0.46668	0.05226	-0.063704	-0.168826	0.062363	0.1518	0.19569	0.07777	0.79848	-0.13683	-0.40658	-0.37791
1996	-0.60326	0.80302	0.9011331	0.819764	0.988766	-0.82745	1.1054	-0.89432	0.31489	0.81898	0.55878	0.255749
1997	-1.73467	4.4217	5.5516473	5.58477	5.454026	-5.54746	5.49021	-5.57979	-2.016	5.426	5.21182	3.309978
1998	2.70818	0.61786	-0.085792	-0.220356	0.129739	0.23824	-0.3407	0.31532	-1.1293	-0.17182	-0.67036	-1.10033
1999	0.0923	-0.78756	-0.253926	-0.362153	-0.47791	0.05095	-0.3155	0.19685	-1.1909	-0.61473	-0.38215	-0.60147
2000	-0.48856	-0.94338	-0.429312	-0.484581	-0.39479	0.04231	-0.3651	0.11301	-0.432	-0.56411	-0.42611	-0.73187
2001	-0.02705	-0.46503	-0.173156	-0.349362	-0.49239	0.31028	-0.2606	0.12212	0.86	-0.2202	0.08331	-0.47313
2002	-0.12851	-0.92468	-0.113485	-0.142148	0.145481	0.09345	-0.4139	0.0401	-0.8422	-0.09887	-0.29143	1.936312
2003	-0.56813	-0.67694	-0.079528	-0.085136	-0.10072	0.1554	-0.4063	0.61605	1.65164	-0.27008	-0.35773	0.489406
2004	3.00656	-0.21729	-0.297443	-0.21597	-0.27137	0.48677	-0.2445	0.08142	-0.2352	-0.38174	-0.41565	-0.98855
2005	0.00875	-0.58345	-0.154035	-0.114739	-0.00753	0.07112	-0.3933	0.35481	1.04458	-0.56857	-0.47706	-0.40482
2006	0.58166	0.90611	0.1034408	-0.259094	-0.33119	0.04879	-0.4009	0.43439	-1.0555	-0.41374	-0.09185	1.677566
2007	0.93177	-0.04902	-0.425356	-0.229857	-0.18447	0.94491	0.14915	0.14278	0.56468	-0.16959	-0.34098	-0.94715
2008	-0.11458	-0.73771	-0.084144	-0.360326	-0.50498	0.05167	-0.1156	0.15432	0.8395	-0.0624	-0.28724	-1.31146

Normalized Sirimon Rainfall Data

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1983	-0.26932	0.72113	-1.10745	-0.0032	2.10391	-0.4239	-1.09102	0.960968	1.3854256	0.66443	-0.10875	1.30367
1984	-0.62998	-0.8186	-0.53838	-1.0806	-0.63005	0.13825	0.39729	-0.441582	0.3720467	0.03042	-0.63272	-1.0681
1985	-0.19438	-0.083	1.33733	0.72498	2.04453	-0.4898	0.67712	-0.649753	0.3578138	0.18448	0.196078	-1.1773
1986	-0.33255	-0.1942	-0.69188	1.10073	1.11385	1.50064	0.36962	-0.0981	0.793339	-0.86233	-0.87164	0.14257
1987	0.01639	-0.16	-0.62074	-1.0965	1.93998	0.59788	-1.29397	1.915951	-1.441218	-1.02034	0.818916	-0.0106
1988	-0.48946	-0.4508	1.24373	2.14945	-0.98244	2.44003	2.29459	0.69555	3.0734415	0.03832	0.751359	0.44029
1989	0.95082	1.93584	1.14264	0.65174	-0.12018	-0.8103	0.22817	0.034608	0.0731568	1.62038	1.435162	-0.0658
1991	1.30913	-0.8443	1.9401	-0.7377	0.15219	-0.0266	1.4182	0.409316	0.3464276	-0.52064	-1.24567	-0.4959
1992	-0.59719	-0.8443	0.24036	0.0138	-1.21737	-0.6913	0.57872	-1.034869	-1.170794	-0.08809	-1.0463	2.1439
1993	0.30679	1.55518	-1.36204	-0.4469	0.0799	-0.1108	-1.66913	-0.805881	0.8844293	-0.95516	-0.12523	0.58253
1994	-0.62998	0.49444	-0.98016	0.46173	0.70079	0.25362	-0.16851	0.260994	-0.803587	0.95872	1.461526	-0.6844
1995	-0.38642	1.51668	0.82815	0.8757	0.14573	-0.0009	-0.26384	-0.314078	0.0930828	-0.37448	-0.07085	-0.0427
1996	-0.44262	-0.5577	0.70461	-1.3481	-0.84949	1.41091	0.80627	1.174343	-1.338742	-1.20798	-0.8288	-0.9524
1997	0.37237	-0.8443	-0.48222	2.12079	-0.61069	2.27889	1.60578	-0.909966	0.1642471	2.85483	2.417202	0.88025
1998	4.15222	1.82891	1.55073	-0.5689	0.83761	0.92749	0.05597	1.629716	-1.441218	1.85147	-0.49267	-0.2577
1999	-0.62998	-0.6133	0.81318	-0.9627	-1.23028	-0.7425	1.12915	0.250585	0.07885	-0.42386	0.070852	1.9388
2000	-0.62998	-0.8443	-1.36204	-0.5742	0.0244	-0.2243	-0.23309	0.489982	0.383433	-0.23622	-0.88812	-0.8035
2001	0.40984	2.03849	0.65593	-0.7579	-0.33445	-0.2115	-1.18327	-0.834504	-0.857672	0.23978	1.230845	0.64208
2002	-0.2178	-0.408	-0.08911	-0.4363	-0.64941	-0.8469	-0.82657	-0.686183	-0.644179	-0.23227	-1.07102	1.25405
2003	-0.37471	-0.6219	-0.58705	0.01061	-0.45837	-0.4148	-0.23001	-0.558678	-0.71819	-0.02884	-0.27352	0.18227
2004	-0.12412	0.12233	-0.47473	-0.2834	-1.25481	-0.8121	0.32349	-0.933385	-0.333903	-0.47719	0.232328	-1.2038
2005	-0.26698	-0.8443	-1.36204	-0.2632	0.72273	-0.8396	-1.07872	-1.06089	-0.177341	-1.35019	1.183061	-0.787
2006	-0.55269	-0.7203	0.50992	1.82783	-0.56938	-0.8194	-1.14945	2.150143	-0.003701	0.47482	0.186192	0.59907
2007	-0.1171	-0.5235	-0.75552	-0.7918	-0.3138	-0.9897	0.04059	0.076243	0.9299744	-1.0954	-1.46976	-1.1972
2008	-0.62998	-0.8443	-0.54961	-0.587	-0.64425	-1.0923	-0.73432	-1.721832	-0.003701	-0.04464	-0.86011	-1.3659

Normalized Nanyuki Rainfall Data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1971	-0.6913	-1.0356	-0.3275	1.29714	2.093223	0.4191	-0.327267	2.16215	0.42009	-0.73448	-0.4158	1.1849761
1972	-0.7435	0.5816	-0.4462	-0.7178	0.47736	1.45309	-0.879395	-0.49695	-0.82605	0.660544	1.680977	-0.7082067
1973	0.475	0.2698	-0.9737	-0.5886	1.07813	-0.8375	0.26496	0.3285	0.10149	-0.31365	0.222249	-0.1697785
1974	-0.2862	1.2148	1.3578	-1.1915	-0.32169	-0.1506	1.523442	2.81537	0.54085	-0.6624	-0.84511	0.0820669
1975	-0.6129	-0.5095	-0.4462	0.61265	-0.34241	0.28028	0.693708	-0.1903	2.25206	0.279237	-0.81902	-0.851498
1976	-0.5149	0.4501	-0.5969	-0.5093	0.598698	0.02178	1.05768	1.24848	0.15288	-0.6066	1.280123	1.7537994
1977	0.4848	0.3575	0.7298	2.55054	1.169873	-0.8112	1.045342	-0.39193	-0.33273	-0.95536	1.918169	1.0156318
1978	0.4717	2.4228	1.6182	0.50159	-0.50518	-0.196	-0.388957	0.14787	1.74846	1.955592	-1.37405	-1.27703
1979	2.5822	1.8042	0.1247	-0.7087	-0.75377	-0.5311	-0.996607	-0.92964	0.90313	-0.20205	0.452324	-0.3564915
1980	-0.7043	-0.1198	-0.9281	-1.0397	-0.19444	-0.4641	-1.419186	-1.07456	-0.4869	-0.99953	-0.52728	-0.8428137
1981	-0.7468	-0.9917	3.4885	-0.7201	0.012726	0.75419	-0.077421	0.43772	0.09892	0.065334	-0.28771	-0.100304
1982	-0.0706	-0.9235	-0.1334	0.89143	-0.44599	-1.0314	-1.045959	0.06595	-0.64363	0.900023	0.561433	-0.7993921
1983	-0.6096	0.6887	-0.5604	-0.1738	-0.56437	-0.3061	-0.145281	0.8494	-0.82605	0.297838	-0.86172	1.3065567
1984	-0.6357	-0.9966	-0.8824	-1.493	-1.52027	-0.95	1.585133	-0.99265	-0.86716	-0.82051	0.336101	0.325228
1985	-0.5279	-0.7384	0.1201	-0.3076	0.20805	-0.0979	-0.870142	-1.19429	-0.5871	0.258312	-0.68857	-0.6951802
1986	-0.2306	-0.792	-0.2156	1.45807	0.782184	2.85807	0.049044	-0.00126	-0.38155	0.025808	-0.86172	1.1502388
1987	-0.1065	-0.7969	-0.8527	-0.26	-0.17668	2.53973	-0.475324	-0.52216	-0.99306	-1.22041	-1.15109	-1.0990013
1989	0.2039	0.1529	0.9651	0.08681	0.862089	-1.084	1.656076	-0.61248	0.95195	0.683794	-0.16912	-0.1437256
1990	-0.2372	0.6741	0.2297	1.16795	-0.40752	-0.8542	-0.456817	-0.2197	-0.56912	0.676819	0.189042	0.4511507
1991	-0.0608	-1.0356	-0.4074	0.85743	-1.0438	1.01508	-1.172424	0.21508	-0.41238	-0.67868	-0.33278	-0.8037343
1992	-0.0052	-0.9868	-0.5261	1.17928	-0.15596	-0.8686	0.332819	-1.05566	-0.62307	0.825622	0.791509	1.154581
1993	1.3701	1.0492	-0.9737	-0.575	0.039361	-0.2535	-1.428439	-1.08507	-0.13746	-1.5808	-0.19284	-1.064264
1994	-0.6325	-0.0614	-0.5787	0.22733	-0.4963	-0.196	-0.734423	-0.27851	-0.00642	0.265287	1.64777	-0.8297872
1995	-0.7599	0.075	1.4949	-0.9739	2.466114	-0.3348	-0.203886	-0.59357	0.21454	0.311788	-0.1288	0.1993053
1996	-0.3319	-0.8456	-0.4828	-0.9875	-1.23321	0.66563	-0.003393	1.73157	-0.22739	-0.68565	-0.29957	-0.0568823
1997	-0.7501	-1.0356	0.0425	1.23368	-0.56437	0.42389	0.946638	-0.02647	-0.43808	3.243664	2.409156	2.8002605
1998	3.6178	1.9113	-0.332	-0.0741	1.519088	0.41192	2.414867	0.8473	3.12564	0.218786	-0.57946	-1.0078159
1999	0.0078	0.2552	0.3919	-0.4549	-1.11187	-0.9596	-0.56169	-0.50956	-1.08556	-0.04162	-0.54388	-0.0264872
2000	0.047	-1.0356	-0.9007	-1.2913	-1.47292	-0.9141	-0.385873	-0.69649	-1.06757	-1.16694	-1.412	-0.5909683
2001	0.2403	0.6023	-0.3815	-1.4958	-0.97914	-0.354	-0.359223	-0.40218	-0.19699	-0.67473	-0.61596	0.181155
2002	0.2992	0.6142	-0.1996	-1.4896	-1.22104	-0.5903	-0.241425	-0.52743	-0.69882	-0.501	-0.72085	-0.0246635
2003	0.4506	0.8348	0.2445	-1.0951	-0.89021	-0.1544	-0.223569	-0.33024	-0.45983	-0.32235	-0.66426	0.3202753
2004	1240.2	1850.8	867.88	860.76	1125.656	911.769	1175.897	801.158	981.111	-0.5175	-0.73453	0.1823769
2005	0.5696	0.9906	0.2049	-1.1315	-0.83062	-0.0814	-0.132682	-0.28205	-0.29163	-0.39781	-0.69662	0.4134859
2006	831.23	1240.5	581.52	576.311	753.9556	610.907	787.8683	536.715	657.361	-0.52856	-0.7437	0.321094
2007	0.6493	1.095	0.1784	-1.1559	-0.7907	-0.0324	-0.071787	-0.24975	-0.17893	-0.44836	-0.7183	0.475937

Normalized Ol Pajeta Rainfall data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1965	0.32569	-0.19347	-1.01804	0.071269	-1.30769	-0.5502	-0.43367	-1.15262	-1.0557	-0.59172	-0.3017	-0.4108
1966	-0.8578	0.86713	0.298597	-0.694878	-1.17618	-0.2766	-0.48724	1.797267	-0.87848	1.005917	-0.2553	-1.05634
1967	0.4633	-0.76224	-0.27054	1.594655	0.23573	0.15805	0.262755	-0.53531	-0.87089	0.307692	-0.1818	-0.72066
1969	0.36468	3.69697	1.875752	0.746102	0.56328	-1.2067	-0.06633	-1.27335	2.13418	0.801775	0.30754	-0.15023
1970	1.37615	-0.76224	0.931864	-0.091314	-0.09181	0.18541	-0.26786	-0.68337	1.08608	-0.98817	-0.3462	-0.87324
1971	0	-0.76224	-0.64729	0.44098	0.93052	0.71733	0.079082	1.908884	-0.32911	-1.23669	-0.6654	0.056338
1972	-0.91514	1.89044	-1.30862	-0.663697	0.26799	0.96049	-1.39286	-1.13895	-0.58228	-0.57396	0.38298	-0.73944
1973	0.16055	-0.39627	-0.71343	-0.405345	-0.57072	-0.7994	-1.03571	0.261959	2.60759	-1.38166	0.26886	-0.70657
1974	-0.55505	-0.19114	-0.57114	0.634744	-0.66998	0.07295	1.859694	1.14123	0.11646	-0.46154	-0.7157	-0.43897
1975	-0.49083	-0.44056	-0.55711	0.302895	1.66253	-0.4103	0.632653	0.646925	0.52152	-0.13018	-0.6596	-0.19953
1976	-0.67661	-0.09557	-1.39078	0.048998	0.1861	0.21884	0.880102	-0.19818	-0.42025	0.718935	-0.5803	0.41784
1977	0.31881	1.05594	0.202405	2.097996	0.09181	0.28267	2.545918	-0.24829	-0.67089	-1.18935	2.82785	0.673709
1978	0.5344	0.49883	2.162325	-0.761693	-1.02978	-0.6505	1.153061	-0.71071	2.52658	0.52071	-0.3269	0.41784
1979	4.05275	0.63636	1.911824	0.291759	-0.24814	-0.696	-0.54337	-0.00456	-0.51646	1.121302	-0.3752	0.474178
1980	-0.64679	-0.6014	0.346693	-1.331849	0.80397	0.24316	-1.26531	-1.27335	-0.95949	-0.34615	0.08704	-0.5939
1981	-0.75229	-0.58974	1.973948	0.485523	2.47643	0.48632	0.971939	0.102506	0.77468	-0.12722	-0.4565	0.079812
1982	-0.3211	-0.41259	-1.11623	-0.109131	0.72953	-0.1185	-1.20408	-0.53303	-0.88861	2.93787	1.00193	-0.46479
1983	-0.44954	0.44289	-0.53507	2.256125	-0.48883	1.44681	-0.24745	0.223235	-0.82532	-0.26036	0.05416	0.615023
1984	-0.78211	-0.45455	-1.25852	-0.596882	-1.30769	-1.1763	-0.1352	-1.22096	0.10127	1.639053	1.87041	-0.51878
1985	-0.43807	-0.03963	0.993988	-0.229399	-0.35484	-0.6049	1.382653	-1.18679	0.06329	-0.3432	-1.1025	-0.43192
1986	-0.68119	-0.76224	-0.54509	0.191537	-0.35484	1.44681	0.380102	-0.14351	0.53165	-0.51775	-0.8046	-0.41315
1987	-0.38073	-0.4662	-1.16232	-0.959911	-0.7469	0.87842	-1.39286	-0.4533	-0.71392	-0.9142	0.41393	-0.19249
1988	-0.21789	-0.73893	0.282565	1.356347	1.1464	3.44073	1.086735	0.961276	1.51139	-0.57988	-0.6402	0.100939
1989	0.55046	0.77622	0.148297	-0.547884	-0.12903	-1.2067	0.55102	-0.38269	0.66582	0.62426	1.75435	3.338028
1990	-0.24771	2.8042	-0.13828	-0.024499	0.52109	-0.6049	-0.67347	-0.84738	-1.0557	0.10355	-0.6712	-1.05634
1991	-0.91514	-0.76224	1.695391	-0.498886	-1.12655	0.66565	-1.39286	2.031891	-0.83544	-1.16568	0.17602	-0.92958
1992	-0.91514	-0.76224	-0.70341	0.095768	-1.18114	-0.2006	-0.67092	0	0.10127	0.860947	0.05609	0.2277
1995	-0.1789	0.95105	0.258517	0.741648	-0.12159	-0.386	-0.9949	-1.05467	0.97722	1.153846	-1.7698	0.42723
1996	-0.50688	-0.41259	0.456914	-1.737194	-0.48139	1.93921	0.232143	1.1959	-0.20759	-0.86686	-0.2398	-0.24413
1997	0.13761	-0.76224	-0.42886	1.567929	0.38213	-0.7295	-0.53827	0.892938	-0.00506	0.467456	2.88781	2.018779
1998	2.97248	-0.17483	-0.11222	-1.367483	1.12903	-0.1246	-0.08418	-0.11162	-0.6557	0.683432	-0.6731	-0.31925
1999	-0.58257	-0.70862	0.511022	-2.371938	-1.11166	-1.0091	-0.77551	-1.16401	-0.98987	-1.06509	-0.3114	-0.03521
2000	-0.77752	-0.76224	-1.21242	-0.888641	-1.25806	-0.8632	-0.97704	-0.1344	-0.9519	-0.79586	-0.4836	-0.60094
2001	0.48624	-0.20746	1.420842	-0.302895	-1.17618	1.94833	0.548469	0.09795	0.07848	-0.21598	1.11992	-0.46948
2002	-0.50459	-0.51282	0.865731	0.048998	1.86849	-0.8389	-0.92347	-0.67426	0.56709	-0.93491	-0.646	2.964789
2003	-0.18807	1.38881	0.400802	2.013363	2.07692	0.06687	-0.1301	2.728929	-0.63291	-0.26331	0.44101	1.023474
2004	1.3922	0.41725	-1.24649	0.36971	-0.22084	-0.9544	0.339286	0.323462	-0.4481	1.91716	0.11412	-0.96244
2005	-0.38761	-0.50816	-0.16433	0.142539	0.34491	-0.3222	-0.04082	-0.13895	-1.0557	-1.71598	-1.7698	-1.05634
2006	-0.73165	-0.56177	-0.08818	0.004454	-0.04218	0.11854	-0.76276	0.373576	-0.78734	-0.11538	0.95358	1.694836
2007	0.66743	-0.662	-0.86974	-0.122494	-0.57816	0.65046	1.885204	1.198178	0.53924	0.816568	-0.5899	-0.3615
2008	0.77523	-0.76224	0.278557	-0.766147	-1.10174	-0.9787	1.688776	-0.61276	1.45063	1.050296	-0.1818	-0.62441
2009	-0.47936	-0.24476	-0.97796	-1	1.49132	-1.2067	-1.39286	-1.27335	-1.0557	-1.71598	-1.7698	-1.05634

Normalized Ontulili Rainfall Data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1957	-0.6112	-0.219884	0.102338	-0.72082	-0.3998328	0.26756	-1.15209	-0.40287	-1.48527	-1.0023	0.14211	-0.67818
1958	0.64206	0.8871607	-1.21217	-0.57418	-1.2649763	0.64901	1.96145	-1.22751	-1.43285	-1.2659	-0.8214	-1.21412
1959	-0.77973	-0.823727	-0.9453	-0.20873	0.2688771	-1.1951	1.41106	1.531785	-0.9336	-0.7976	0.18275	-0.80701
1960	-0.39521	0.9878012	0.724305	0.03299	0.1950404	-0.3197	-0.96331	-0.31824	-0.05492	0.26318	-0.0519	0.67457
1961	-0.76074	-0.823727	1.116895	0.37897	0.353859	0.33068	-0.09918	-0.68038	-0.25711	3.72575	2.18589	0.25973
1962	1.928554	-0.823727	-0.82179	0.19223	-0.7230426	-0.4898	-0.61234	0.06357	-0.27958	-0.4199	-1.2842	-0.53646
1963	-0.64206	-0.552303	-0.93207	1.18662	-0.0696573	1.10456	-1.5908	0.510333	-0.57414	-0.3914	0.98637	2.06081
1964	-0.2789	-0.823727	-0.20644	0.31825	-1.1521315	-0.4267	-0.46078	0.404054	2.718422	-0.524	-0.8647	0.55347
1965	0.093757	-0.823727	-1.382	-0.3989	-1.0448593	-0.8823	-1.36214	-0.87916	0.21967	1.96173	1.22889	-0.30198
1966	0.124614	1.4605063	-0.36745	0.5004	-1.2092505	0.0343	0.08163	2.588664	-0.95357	0.23968	0.54719	-0.97191
1967	-0.7014	-0.436414	-0.05205	0.64589	1.3987183	0.97009	1.24355	-0.63905	-1.43535	0.40416	0.58128	-1.10848
1968	-0.77973	2.189387	0.719894	0.96437	1.5436055	2.53705	-0.2853	-1.3889	-1.15077	0.17925	0.45149	0.94769
1969	0.919772	0.8170174	0.832378	-1.6499	-0.4848147	-1.6699	0.30497	-0.57804	-0.95107	-0.138	0.37415	-0.07524
1970	0.646808	-0.671241	0.217027	-0.86631	-0.6450265	-0.4569	-0.91545	-0.35367	-0.52172	-0.4736	-0.9827	-1.08786
1971	-0.30501	-0.823727	-1.08425	-0.03689	0.7411535	1.8455	-1.2159	1.394017	1.802297	-0.8295	-0.8909	-0.36382
1972	0.017802	1.8356206	-0.12704	-1.54107	0.8135971	-1.6699	-1.28769	-0.4383	-0.76635	0.191	-0.2538	-0.73744
1973	-0.67529	0.9542543	-1.40847	-0.6475	-0.611591	-0.638	0.23318	2.033655	-0.35946	-0.3209	-1.2069	-1.17289
1974	-0.64206	-0.076548	1.185267	-0.96598	-0.2159376	0.20445	1.8285	1.055501	-0.95107	-0.8597	-0.8896	-0.29683
1975	-0.77973	-0.457762	-1.26511	-0.00481	1.2385065	0.54748	1.7966	-0.55442	1.110834	-0.1564	-0.7297	-0.72456
1977	-0.28127	-0.070448	-0.8637	1.79952	-0.0013931	-0.8905	1.42701	0.407991	-0.11982	1.18295	1.70608	-0.77609
1979	2.051982	1.9332113	-0.01897	-0.48826	0.1351351	-0.5722	-0.61765	-0.395	-0.00999	-0.9721	-0.5763	-0.63695
1980	-0.77973	-0.534004	-0.37627	-1.15615	-0.0877682	-0.7368	-1.22654	-0.33989	-0.58662	-1.0493	-0.8149	-1.19608
1981	-0.77973	-0.713937	3.216586	0.68828	-0.1894678	0.50906	0.87663	0.406022	-0.21967	-0.9084	-0.9775	-0.83535
1982	0.732257	-0.805428	-0.95412	0.65277	0.5697966	0.0096	-1.22654	0.90986	-0.51922	0.87412	1.01521	0.81628
1983	-0.5756	0.2558707	-1.11292	-0.04376	-0.1184174	1.00851	-0.62031	-0.50522	1.075886	0.90937	0.16308	1.8083
1984	-0.75125	-0.823727	-0.84605	-1.6648	0.0306492	-0.1605	0.52566	-1.07597	-1.01098	-0.0759	-0.4072	-0.89719
1985	0.164966	-0.186337	0.594177	0.93917	0.5210365	-0.9509	-0.83302	-1.40464	-0.36196	-0.9402	-1.0273	-0.37928
1986	-0.32874	-0.561452	-0.24173	1.76057	-0.5516857	1.6781	-0.76655	0.093092	0.881178	-1.3766	-0.5645	1.06364
1987	-0.44742	-0.823727	-1.22982	-1.47233	0.631095	0.83013	-0.45812	-0.10372	-1.62506	-0.8714	0.30073	-0.19376
1988	-0.56136	-0.823727	-0.05867	1.2817	-0.9877403	0.52003	0.38208	-0.31234	1.285572	-0.5827	0.37284	-0.29683
1989	3.16995	0.9207075	0.836789	0.77878	-0.4276957	-1.2143	0.77825	-0.18835	0.484274	0.19268	2.51494	2.01443
1990	-0.24567	2.4516621	1.897662	0.28388	-1.0546113	-1.5875	2.28051	-0.39697	-0.15976	1.37093	0.66125	0.42463
1991	-0.54712	-0.726136	2.314513	-0.79184	-0.2633045	-0.1578	-0.96863	-0.66463	-0.50175	-0.3981	-0.8936	0.17727
1992	-0.63494	-0.823727	0.344949	-0.93734	-0.9194762	-0.0864	0.43792	-0.82405	-1.31802	0.02148	-0.9643	1.09456
1995	-0.4949	0.1826776	0.894133	-0.25341	-0.6547785	-0.7259	0.16937	-1.06416	1.090864	-0.9822	-0.1607	1.25947
1996	-0.77973	-0.457762	0.223644	-1.68427	-0.6269156	2.67975	-0.03802	1.293643	1.642536	-0.1917	-0.7454	-0.62664
1997	-0.54949	-0.823727	-0.00573	1.84993	-1.2092505	0.44319	1.10263	-0.85751	-0.30205	2.08929	1.75983	1.90879
1998	3.656539	1.9027142	-0.34098	-1.20541	2.0702145	0.57492	-1.04839	0.957095	0.327009	-1.004	-0.672	-1.23989
1999	-0.03468	0.6985056	-0.14365	-1.16153	-1.5734188	-0.2605	-0.06062	-0.82712	-0.32596	-0.732	-0.9276	0.4839
2000	0.666653	0.9273053	-0.18114	-1.16987	-0.8811284	-0.1018	-0.2483	-0.48812	-0.2019	-0.7837	-0.879	0.15638
2001	-0.77973	-0.823727	1.132333	0.35262	-0.3218167	-0.1962	-1.32491	-1.07991	0.596605	0.97482	2.52543	0.0974
2002	-0.55661	-0.823727	0.181738	-0.02429	0.3817219	-0.9838	-0.4076	-1.00905	-1.2007	1.03693	-0.8214	2.20768
2003	-0.77973	-0.823727	-0.68505	0.99416	0.133742	0.08095	-0.12842	2.893722	-0.24713	-0.1598	-0.596	0.54316
2004	0.478282	1.1280878	-0.5064	2.08707	-1.3011981	-1.3076	0.20659	-0.0742	1.714928	-0.049	-0.4872	-1.23989
2005	0.739378	-0.823727	-1.32686	-0.36682	4.0122597	-1.0332	-0.80378	-0.95985	0.908637	-1.1803	-0.7598	-0.82505
2006	-0.51863	-0.823727	0.446405	-0.07928	-0.0264698	-0.3224	-0.7825	0.406022	-0.14229	0.24471	0.31647	0.38341
2007	-0.33824	-0.701738	-0.05646	-0.12739	0.507105	0.54748	0.19064	0.583153	0.336995	-0.5072	-0.9893	-0.95645
2008	0.525754	-0.823727	-1.0622	-1.07023	-0.0808025	-1.6699	0.84472	-0.8024	1.517723	0.64082	-0.0257	-1.23989

Normalized Shamata Rainfall Data

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	-0.4356	0.08	-1.1701	-1.1659	0.2174	-0.6485	-0.9781	-0.1842	-0.6891	-1.25781	-0.99305	-0.9723
1974	-0.6292	-0.4779	1.2978	-0.5844	-0.2327	0.54647	1.60183	0.51668	-0.2552	0.230112	-0.70831	-0.808
1975	-0.469	-0.7538	-0.4608	0.2879	-0.2202	1.40601	1.03975	1.11677	1.24236	0.347967	-0.99033	-0.8639
1976	-0.6813	-0.2756	-1.1307	-1.5119	-0.1135	0.23201	-0.5713	0.16914	0.04339	-1.92664	-1.17561	0.14784
1977	-0.0523	0.0126	-0.158	1.7251	0.0875	0.27626	0.52705	0.50741	0.25332	0.174131	0.58597	0.12403
1978	0.3816	0.5981	1.64828	-0.6362	-0.9264	-0.3107	0.19309	-0.1437	-0.2389	1.697407	-0.37861	0.4109
1979	1.3337	3.2529	-0.046	0.6589	-0.6097	-1.0538	-0.449	-0.6013	-0.4558	-1.67914	-0.83229	-0.927
1980	-0.4209	-0.5362	-0.523	-0.8952	1.1903	0.4137	-1.9118	-0.3371	-0.801	-1.83235	-0.26417	-0.9437
1981	-0.6412	-0.6925	2.98382	0.9681	-0.1473	0.84696	1.06562	1.02178	1.66923	0.059222	-0.24237	-0.4057
1982	-0.5384	-0.2848	-0.409	1.4661	0.4433	-1.2588	-1.6555	0.00116	0.13436	-0.19417	2.71267	1.21676
1984	-0.708	-0.9654	-0.4007	0.2445	2.5866	1.51083	-0.7665	-1.038	1.24236	-0.3297	-0.71376	0.7311
1985	-0.728	1.7201	-0.2721	0.2478	0.8328	-0.3876	1.03034	-0.9152	-0.0616	-1.0221	0.09687	0.74301
1987	-0.6065	-0.8458	-0.6889	-0.5777	0.5553	0.33916	-2.4175	-0.6962	-1.5405	-1.55834	0.60777	-0.7009
1988	0.0598	-0.8151	0.00373	1.5413	-0.9299	0.22269	0.33184	0.0892	1.69489	-0.06158	-0.25872	0.68587
1989	1.0239	0.4264	-1.0207	0.1542	0.0715	-0.9234	0.43297	-0.0301	-0.8593	0.663229	0.21948	-1.0425
1990	0.0211	1.1438	1.03857	0.7107	-0.1188	-1.3613	0.35536	-1.3855	-0.6284	0.333235	-0.89905	-0.3426
1991	-0.4583	-0.8397	-1.3339	-0.2351	-0.1811	0.53249	-0.1879	0.18767	-0.4185	0.029758	-1.28324	-0.1985
1992	-0.5784	-0.7324	-0.5396	0.064	-1.1861	0.02702	-0.3384	0.43559	-0.1362	-0.00854	-0.7124	1.57505
1993	2.2497	1.4994	-0.9979	-0.2284	-0.0477	0.28325	-0.917	-1.1133	0.40261	-0.91014	-0.28597	-0.4854
1994	-0.7227	0.1842	-0.6931	-0.1833	0.1978	0.58607	0.09666	-0.0382	-0.7101	-0.34738	1.17316	-0.1117
1995	-0.6332	0.5552	1.3372	-1.191	-0.1882	-0.2828	-0.3925	-1.345	2.06345	1.066883	0.1173	-0.458
1996	-0.9465	-0.7475	-0.2655	-1.9756	-1.2874	-1.6322	-1.992	-1.7372	-0.093	-0.98998	-0.91533	-0.951
1997	-0.5971	-1.0236	-0.3447	2.2198	-0.0815	0.71186	1.19732	-0.446	-1.5288	0.401002	1.74809	0.31925
1998	4.1645	0.5766	-0.7304	-0.9286	2.2807	-0.8884	-0.3079	-0.358	-0.1642	-0.1706	-0.72738	-0.8997
1999	0.0051	-0.6987	0.44753	-0.4624	-1.7695	-1.2844	-0.3502	-0.117	-1.2046	1.335003	-0.63202	-0.6259
2000	-0.5918	-1.0083	-1.1078	-1.5954	-1.1167	-1.2961	-0.3384	-0.3197	-0.8267	-0.5713	-0.61839	0.02881
2001	0.0545	-0.7538	-0.2825	-0.3788	-1.0402	0.51386	1.25376	-0.7576	-0.7474	-0.30318	-0.26417	-0.6675
2002	0.7154	-0.573	0.97843	0.0974	0.0537	-0.5274	0.17427	0.71942	-1.1439	1.850619	0.2876	2.96893
2003	-0.035	-1.0236	0.8229	0.6405	0.7652	0.88656	0.70814	4.03846	-1.3539	1.237773	1.48106	-0.1378
2004	0.192	0.0953	-0.297	1.3424	-1.0135	-0.8838	-0.0868	0.26993	0.02239	-0.7746	2.06553	2.80229
2005	-0.1925	-0.4718	-0.4629	-0.3153	2.0014	-0.5577	-1.084	0.15639	2.02379	0.560106	-0.72738	-0.6378
2006	-0.3555	0.6686	1.8287	-0.2385	-0.9779	-0.5623	-0.1832	0.97081	-0.3882	0.383324	1.15136	0.55255
2007	0.419	1.9194	-0.774	-0.312	-1.0313	3.12276	1.2961	0.08804	1.21204	-0.35327	-0.95218	-0.3402
2008	-0.3555	-0.1346	0.38739	-1.1726	0.0715	-0.8838	0.68462	-0.4449	0.51225	1.679729	0.73719	-0.8282

Normalized Tharua Rainfall data

Year	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
1943	-0.8059	-0.6694	-1.8186	-0.6698	-0.5221	-0.6738	0.84458	-0.2913	-0.103	-0.3835	-0.8774	0.64255
1947	-0.6439	-0.5966	0.06636	0.21013	0.2546	-0.4619	0.35622	-0.3111	-0.7996	-0.8821	-0.3042	2.0685
1948	-1.0302	-1.084	-1.2141	-0.9697	-1.07	-0.3403	0.41942	-0.9672	-0.3535	-0.8176	-0.6315	0.04631
1950	-0.5756	-1.084	0.145	0.39181	-0.2675	0.3403	-0.1005	0.47794	-0.9712	-0.5962	0.64843	-0.5673
1951	-0.8566	-0.3725	2.85082	2.05757	-0.2006	0.4411	2.11433	0.34219	0.1647	1.7817	0.93884	1.29088
1952	-0.2985	-0.6022	-0.5505	0.36774	-0.2701	-0.8995	-0.2471	-0.345	-0.1407	-0.4306	-0.8513	0.50748
1955	1.758	-0.717	-0.3785	-0.3743	-0.7639	-0.8127	-0.2298	1.56391	1.9288	-0.2911	-1.1601	0.18331
1956	1.2937	-0.6974	-0.1155	-0.5341	-0.126	-0.1736	1.23528	0.444	-0.1441	-0.0767	-0.8144	1.15581
1957	-0.3688	0.5322	-0.4841	0.95217	1.2037	-0.573	-0.9681	-0.4808	0.0892	-0.598	1.43823	1.26387
1958	0.1385	0.3865	-0.1106	-1.0879	1.5638	0.764	1.23528	-0.7834	-0.3604	-0.2615	-1.3691	1.48191
1959	-0.0839	-0.3781	-0.5652	-1.7621	1.3606	-0.2327	0.67222	-0.9276	-0.6795	-0.1168	-0.2551	-0.9899
1960	0.162	-0.703	1.23372	-0.1379	-0.8153	-0.7814	-0.7986	0.73812	-0.0892	0.2685	-1.2385	0.11192
1961	-0.3863	-0.2969	1.39592	0.86681	0.2392	-0.83	-0.994	1.13405	-0.6006	5.197	3.31592	0.23927
1962	1.6273	-0.451	-0.5333	-0.429	0.1569	0.4168	-0.5142	-0.5288	0.7859	1.1192	-0.3549	0.6329
1963	0.7102	0.3697	-0.5972	1.68764	1.9187	-0.639	-0.9365	0.33654	-0.9712	-0.7113	1.996	2.35022
1964	-0.9405	0.2381	1.31973	2.67703	-0.4733	0.5939	0.46538	0.87387	1.7091	-0.2319	-0.9803	0.56151
1965	0.8507	-0.8431	-0.8577	0.07442	-0.6301	0.5209	-0.27	-0.8117	-0.7241	-0.7026	-0.7806	-1.2639
1970	0.7083	-1.084	1.24109	0.79457	-0.1929	-0.1424	-0.5717	-0.7014	-0.5491	-0.9135	-0.0184	-1.3893
1974	-0.5815	0.0196	-0.3564	0.93685	-0.733	-0.8995	0.14076	1.03507	-0.906	-0.272	-0.1383	-1.2118
1975	-1.1141	-0.2493	-0.9339	0.0197	0.7613	-0.3299	1.05142	0.63631	1.4311	-0.1953	-0.6069	-1.1346
1976	-1.1278	1.5041	-1.16	-0.1707	0.409	-0.4654	0.86182	0.00566	-0.4084	-0.5771	-0.315	0.78534
1977	-0.2732	2.0167	-0.8528	0.82741	0.0617	0.2084	0.50847	-0.3535	-0.7241	-0.6939	0.59926	-0.2373
1978	-0.0917	4.0698	1.73753	-1.5826	-0.7973	-0.6286	-0.1896	-0.0622	1.4174	0.2284	-0.8159	2.2576
1979	1.9395	2.1287	-0.2851	-0.8887	-0.1363	-0.646	-0.6435	0.97285	0.556	-0.0349	0.44561	-1.4221
1980	-0.9346	-0.2633	0.49644	-0.7311	0.0977	-0.4098	-1.1175	-1.0945	-0.3466	0.3278	-0.5347	-0.9648
1981	-0.361	0.2773	-0.5972	-1.2367	2.1605	-0.8995	2.71761	-0.4383	0.2711	-0.3382	-0.9127	0.25856
1982	-0.4976	-0.6526	-0.9609	1.11415	-0.3241	0.0208	-1.1175	0.59106	-0.4324	1.5865	0.52704	-0.0617
1983	-1.0634	1.2772	-1.0125	-0.7946	-1.2449	0.6772	0.02585	0.7862	-0.4839	-0.3086	-1.5181	0.25084
1984	-0.841	-0.479	-0.1622	-1.3133	-1.2449	-0.8995	-0.9423	-1.0945	0.6109	1.1489	0.35187	-0.3724
1985	0.2654	1.028	1.30499	-0.7442	-0.9105	-0.8995	-0.0575	-1.0945	1.5135	1.046	-0.5747	-0.7255
1986	-0.5893	-0.8571	-0.5333	0.39619	-0.6996	0.7745	0.51422	-0.4893	-0.6143	-0.6015	1.28304	-0.2258
1987	-0.3785	-0.2045	-0.9191	0.18387	-0.1055	1.4031	-0.9796	-0.7353	-0.0446	-0.6328	0.39336	-0.2065
1988	-0.2985	0.5182	0.58	1.54099	-1.2449	1.9969	1.43062	0.44966	0.5285	0.4672	-0.1229	1.7424
1989	-0.5073	1.098	0.27279	1.10102	-1.2449	-0.8995	1.13186	-0.2178	0.3844	0.3295	0.20283	0.11192
1990	0.3395	1.4845	1.67117	0.14447	1.1497	-0.7397	-1.0026	-0.7014	-0.5525	-0.1656	-1.0157	0.67149
1991	-0.2712	0.0308	0.89948	0.22327	-0.5916	2.4832	-0.9423	1.89197	-0.9712	-0.9728	-1.0356	-0.0521
1992	0.0273	0.126	-1.423	0.14009	-0.9388	-0.8995	-0.2327	-1.0945	-0.9712	-0.3818	-0.2674	0.60589
1993	2.7141	0.3809	-0.87	-1.8693	-0.3807	1.4204	-1.0313	-0.8512	-0.9712	0.5858	-0.527	-0.631
1994	-1.1278	-0.7142	-0.0369	0.16417	-0.7407	0.5522	-0.3131	0.32523	-0.0995	-0.0192	2.12508	-1.3025
1995	-0.8449	0.0448	0.23593	-0.6413	0.7124	0.3959	-0.3103	-0.2913	0.7447	0.0227	-0.6884	0.42451
1996	-0.4332	0.1821	-1.0248	-0.7442	-1.0545	3.5563	-0.3878	0.93891	-0.8237	-0.0035	0.77597	-0.2894
1997	-0.3902	-1.084	0.32932	1.2236	-0.4475	-0.1771	2.0339	-1.0945	-0.9712	0.4446	1.73325	0.39749
1998	3.7288	0.6946	2.14058	-0.5407	1.178	0.5279	-1.1175	-1.0945	-0.9712	-1.2343	-1.9514	-1.7154
1999	-1.1278	-1.084	-1.9857	-2.2743	-1.2449	-0.8995	-1.1175	-1.0945	-0.9712	-0.9153	0.33805	-1.04
2000	-0.6595	-0.9999	-0.8552	-0.4794	-0.4604	-0.3091	-0.5573	-0.5147	-0.6452	-0.8246	-0.6899	-0.5557
2001	-1.1278	0.4454	-0.3514	-0.6545	-1.1548	0.6286	-0.9595	-0.8626	0.0927	-0.075	1.0295	-1.0439
2002	0.039	-1.028	0.94126	0.66543	3.0298	-0.6738	-1.0026	-1.0945	-0.7138	-0.5614	-1.9514	-0.0598
2003	-0.162	-0.7479	-0.1892	-2.2743	1.857	-0.257	-0.7297	4.18552	-0.9712	-0.0087	0.31961	-0.2798
2004	1.4517	-0.0924	0.20152	1.00252	1.2757	-0.83	0.158	-0.6222	-0.5388	0.0767	-0.9634	-1.2716
2005	0.3688	-1.084	0.89457	0.30426	0.8642	-0.5626	-1.1175	-0.3309	3.3015	-0.4498	0.40873	-1.069
2006	-0.0566	0.689	1.32219	-0.5056	0.6481	-0.6738	-1.1175	1.05486	-0.8134	-0.8577	0.72833	0.86445
2007	0.2868	0.2213	-0.9929	1.08788	-0.3832	2.57	2.42172	1.1595	2.7456	1.7259	0.53473	-1.4452
2008	0.2732	-0.8347	0.09339	-0.7574	-1.0031	-0.8127	0.0632	-0.8088	1.2904	-0.4515	0.21512	-1.0806
2009	-0.0741	-0.9439	-0.6095	-1.5366	0.2829	-0.8995	-1.1175	-1.0945	-0.9712	-1.2343	-1.9514	-1.7154

Appendix 6: Rainfall stations and their locations

No.	Station Name	Longitude	Latitude	Data period	Long term mean
	Forest Zone Upper Zone				
1	Ardencaple Farm	306006.83	9696.37	1948-2008	637.2
2	Embori Farm	316071.14	7766.90	1967-2008	681.4
3	Kisima Farm	323860.75	12663.72	1974-2008	877.6
4	Naromoru F S	292602.18	9976596.40	1965-2008	852.5
5	Naromoru Gate	293829.02	9981023.89	1968-2008	1069.2
6	Naromoru Met	301090.03	9981023.89	1978-2008	1500.0
7	Ndaragwa F S	224981.38	993021.68	1981-2008	901.0
8	Ontulili F S	296237.95	2954.15	1957-2008	887.2
9	Shamata Gate	224926.78	997750.21	1973-2008	1057.0
10	Sirimon Gate			1983-2008	806.1
11	Timau Marania	328143.95	9831.23	1939-2008	952.4
	Middle Zone				
12	Jacobsen	282214.51	9995527.14	1934-2008	695.3
13	Kalalu NRM	295548.95	9332.62	1986-2008	741.3
14	Loldaiga Farm	2900891.70	23732.17	1976-2008	661.0
15	Lolmarik Farm	307781.79	11497.23	1965-2008	739.2
16	Oldonyo Farm	309910.74	10674.96	1955-2008	626.4
17	Olpajeta	255941.57	7052.59	1965-2008	709.7
18	Satima	278424.83	9983931.80	1973-2008	669.3
19	Solio Ranch	263894.93	9972629.22	1967-2008	703.3
20	Suguroi Estate	237764.43	9997181.04	1962-1995	709.6
21	Tharua Farm	264679.85	9987996.10	1943-2008	729.3
22	Nanyuki KAF	280873.64	4724.15		929.94
	Lower Zone				
23	Loldoto Farm	279438.73	19340.94	1951-2008	643.1
24	Mpala Farm	266641.22	36040.93	1972-2008	518.9
25	Kamwaki Farm	295459.12	15008.10	1965-2008	613.6