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ISOTOPIC AND GEOCHEMICAL STUDY OF GROUNDWATER IN THE EASTERN PROVINCE OF KENYA

BY

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FACULTY OF GRADUATE STUDIES AND RESEARCH
UNIVERSITY OF WINDSOR
1988

ISOTOPIC AND GEOCHEMICAL STUDY OF GROUNDWATER IN THE EASTERN PROVINCE OF KENYA

by

Martin Peter Mwangi

A Thesis
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and approved by:

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ABSTRACT

The Eastern Province of Kenya has both arid and semi-arid climatic conditions and drought-related problems are common. The isotopic and geochemical compositions of surface water and groundwater of the province were surveyed in an attempt to identify the sources and nature of groundwater recharge and groundwater flow directions.

The isotopic data is characterized by a large scatter in $\delta^{18}O$, δD, and tritium levels. The variations are due to differences in altitude and climate (temperature and rainfall) of the recharge areas.

Differences in groundwater chemistry are also evident and as in the case of isotopic composition, are the result of differences in altitude and climate. Geology is equally important in controlling the chemical composition of groundwater. Volcanic terrains have groundwater that is either magnesium or sodium-magnesium bicarbonate. Sodium chloride or sodium bicarbonate groundwaters are found in sediments. Groundwaters of variable chemical composition occur in the metamorphic rocks of the Basement System.

The isotopic and geochemical results show that the high elevation and high rainfall areas are the recharge zones for the groundwater in the low-lying arid areas. Groundwater recharge also occurs along seasonal stream valleys after heavy rains. Local groundwater recharge from precipitation on the low-lying areas is sporadic owing to aridity, and occurs only after exceptionally high rains. Evaporation of precipitation and surface-water occurs before and during the recharge processes.

Three groundwater systems are identified : the Chalbi-Kaisut Deserts; the Ewaso Nyiro-Lorian Swamp; and East Lake Turkana. Within each of these systems, different and unconnected aquifers and/or fracture zones occur.

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Lastly, but not the least, I would like to thank my wife, L. Njoki, children, and parents, without whose patience my studies in Canada would have been impossible.

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NOMENCLATURE

a - years

°C - degree Celsius

cm - centimetre

D - deuterium

EC - electrical conductivity

kg - kilogram

km - kilometre

km^2 - square kilometre

km^3 - cubic kilometre

L - litre

m - metre

m^3 - cubic metre

meq/L - milliequivalents per litre

mg/L - milligrams per litre

mm - millimetre

^{18}O - oxygen-18

s - second

TDS - total dissolved solids

TU - tritium units

μS/cm - microsiemens per centimetre

δ - delta unit in per mil (‰)

1.0 INTRODUCTION

1.1 Structure of Thesis

The thesis is divided into six chapters. Chapter one discusses the objectives, scope and limitations pertaining to this study.

In chapter two, background information concerning the location, access, population distribution, physiography, climate and vegetation, geology, surface drainage, and hydrogeology of the study area, are discussed.

Theoretical information on isotopic and geochemical parameters are presented in chapter three. Their occurrences in the hydrosphere, methods of analysis, and uses in groundwater studies are discussed.

In chapter four, the methods used during field sampling are explained. The results of the isotopic and geochemical analyses of the samples, and isotopic data for precipitation water from three East Africa stations, are discussed in chapter five.

The last chapter gives an outline of the conclusions and recommendations reached from this study.

1.2 Objectives and Scope

Like much of Eastern Africa, the Eastern Province of Kenya has both arid and semi-arid climatic conditions and, therefore, drought problems are common. Most of the rivers are seasonal, flowing only after heavy rains, and as such, groundwater is a vital resource in dictating the movement and the settlement of human communities of this area. About 40% of the population relies on groundwater for domestic and livestock water supplies (Government of Kenya, 1986).

Prudent development of groundwater resources of any region requires a knowledge of the hydrogeological parameters pertaining to recharge, flow and discharge. The objectives of this study, therefore, are to:

(i) identify the sources of groundwater recharge,
(ii) identify the nature of groundwater recharge,
(iii) identify groundwater flow directions, and
(iv) predict the consequences of over-exploitation of groundwater.

The solutions to these problems will aid in the investigation, development and management of groundwater resources for this arid region of Kenya.

The main tools in achieving these objectives are the determination and interpretation of naturally occurring isotopic and geochemical parameter concentrations in surface-water and groundwater resources for this region. This study was confined and, therefore, limited to the few boreholes, springs and streams of the area. Other limitations and problems encountered during this study are:

(i) Pumping-test data and geo-logs for most boreholes do not exist and the few that are available are unreliable.

(ii) Some production boreholes were not operational during the sampling programme owing to some mechanical problems and, therefore, groundwater samples were not collected from them.

(iii) Some sites that could have been sampled were inaccessible, because some sections of the unpaved roads had been washed away by previous rains.

(iv) Financial constraints did not allow drilling of new boreholes for sampling and pumping-test activities.

2.0 THE STUDY AREA

2.1 Location

The study area is the Eastern Province of Kenya which lies approximately between longitudes 36° 5' and 39° 20' E and latitudes 00° 00' (Equator) and 4° 25' N (Figure 2.1). The area covers the entire Marsabit and Isiolo districts and the northern part of Meru district. The total area covered in this study is approximately 103,000 km^2.

The main towns in the study area are Meru, Isiolo and Marsabit, which are the administrative headquarters for Meru, Isiolo and Marsabit districts respectively. Other important trading centres include Maua, Garba Tula, Mado Gashi, Archer's Post, Laisamis, Moyale, North Horr, Loiyangalani, and South Horr (Figure 2.2).

2.2 Access

The road from Meru is paved as far as Isiolo, where it branches into three unpaved roads. One road runs to Ethiopia through Marsabit and Moyale, another to the North Eastern Province via Mado Gashi and Habaswein, and the third road runs to Rift Valley Province. Although unpaved, the roads are fairly well maintained all-weather roads. These roads, however, may sometimes be unmotorable for a few days or weeks during periods of exceptionally high rains when sections of the roads may be washed away.

Other roads (tracks) are only used during the dry

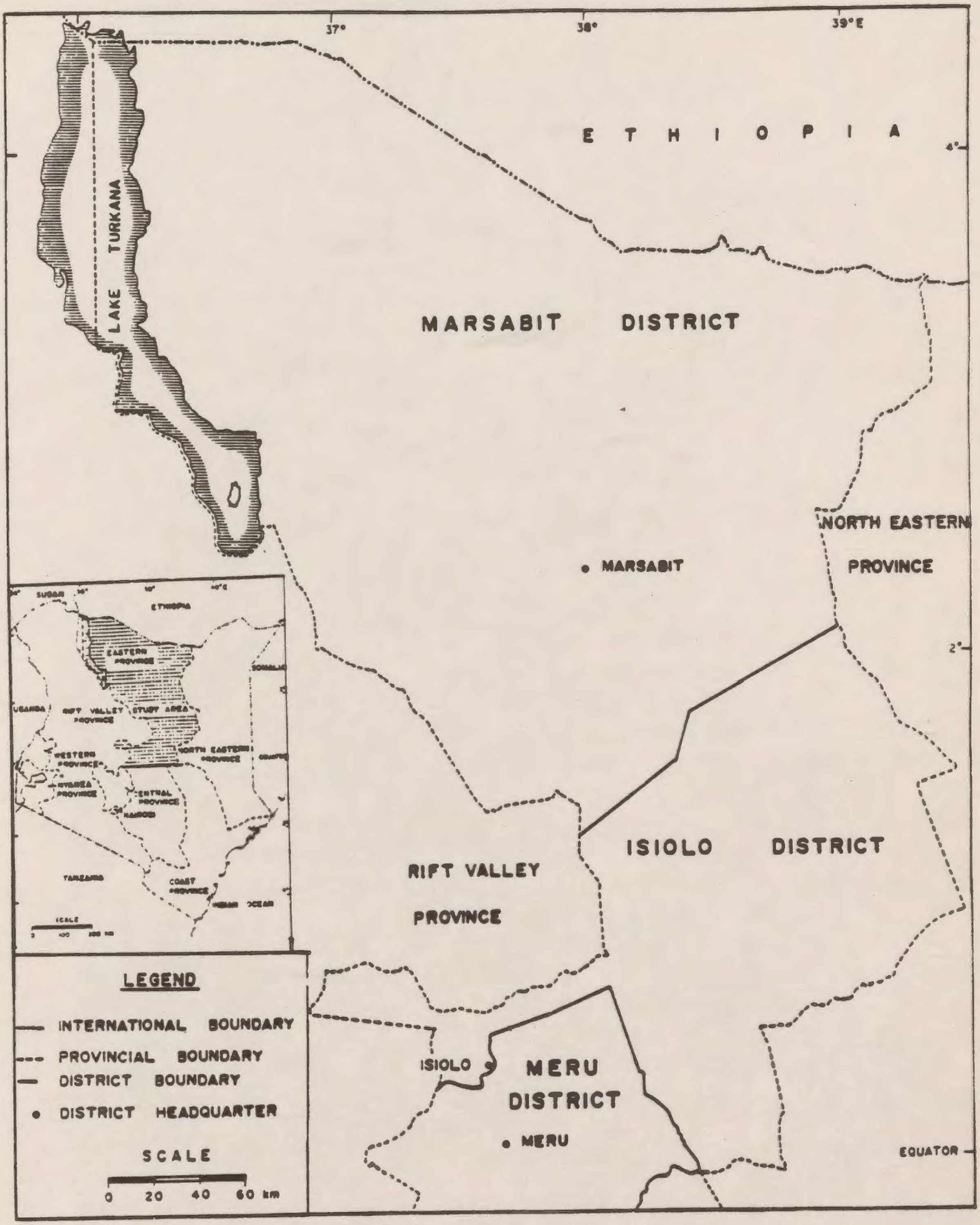

Figure 2.1 Location map.

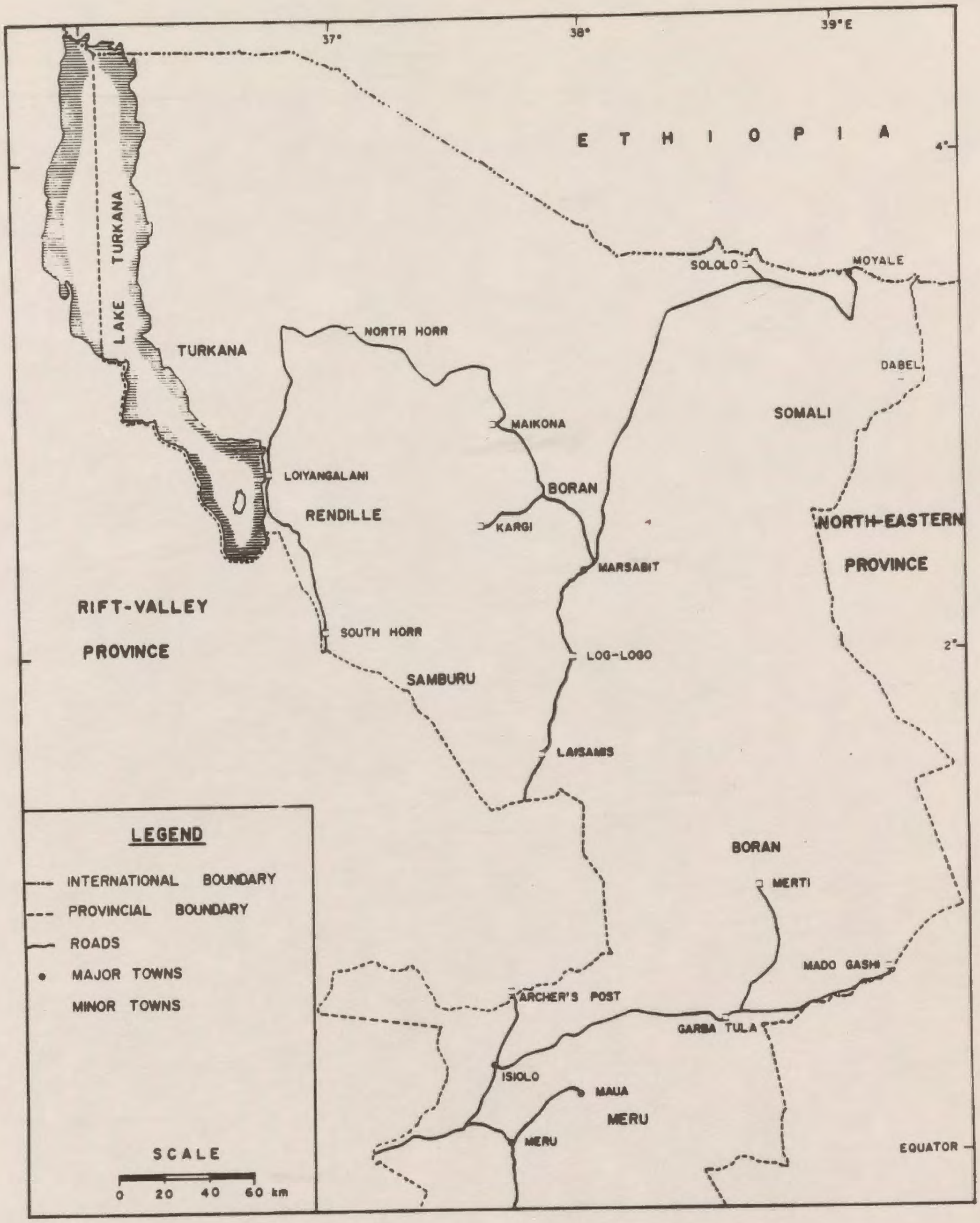

Figure 2.2 Distribution of population centres and roads.

seasons. To overcome the problem of accessibility during wet seasons, most of the centres have been equipped with airstrips that accommodate small aircraft.

2.3 Population

The main ethnic groups comprising the population of the study area are the Turkana, Rendille, Boran, Samburu, Somali, and the Meru. The spatial distribution of these groups is shown in Figure 2.2.

The Meru ethnic group is settled on the slopes of Mt. Kenya and the Nyambeni Range and is mainly a farming group which, besides growing subsistence crops such as maize, potatoes and bananas, also grows cash crops such as tea and coffee. The other groups are found to the arid north and are predominantly nomadic pastoralists, whose livelihood is dependent almost exclusively on raising livestock. The settlement of these people depends on the availability of pastures and water for their livestock (cattle, goats, sheep, and camels).

The population of the study area is 740,000 with a population density of 1 person per km^2 (Government of Kenya, 1986).

2.4 Physiography

According to Ojany (1966), the study area can be divided into eight physiographic regions as shown on Figure

2.3. These regions are:

(i) Old Upland Massifs,
(ii) Tertiary to Recent Volcanic Highlands,
(iii) Intermediate Lava Slopes,
(iv Low foreland Plateau,
(v) Northern Plainlands,
(vi) High Lava Cones of North Kenya,
(vii) Lorian Swamp Low-belt, and
(viii) Chalbi Desert.

The Old Upland massifs include the oldest land surfaces in the area and consist of old, resistant Precambrian rocks. The region contains Oldoinyo Lenkiyio, Ndoto, and Nyiru Mountains whose heights are 2375, 2534 and 2806 m, respectively (Ojany, 1966). These mountains lie on the western side of the study area and form a long, continuous chain.

The Tertiary to Recent Volcanic Highlands lie in the southern region and include the most prominent highlands in Kenya. These highlands are Mt. Kenya and the Nyambeni Range. Mt. Kenya has a summit elevation of 5199 m (Ojany and Ogendo, 1973) and is ice-covered at high elevations during most of the year. The mountain is a composite volcano and has numerous parasitic cones and vents, especially on the northern flanks. They form prominent and distinctive features. The Nyambeni Range has an elevation of 2513 m (Ojany and Ogendo, 1973) and runs in a

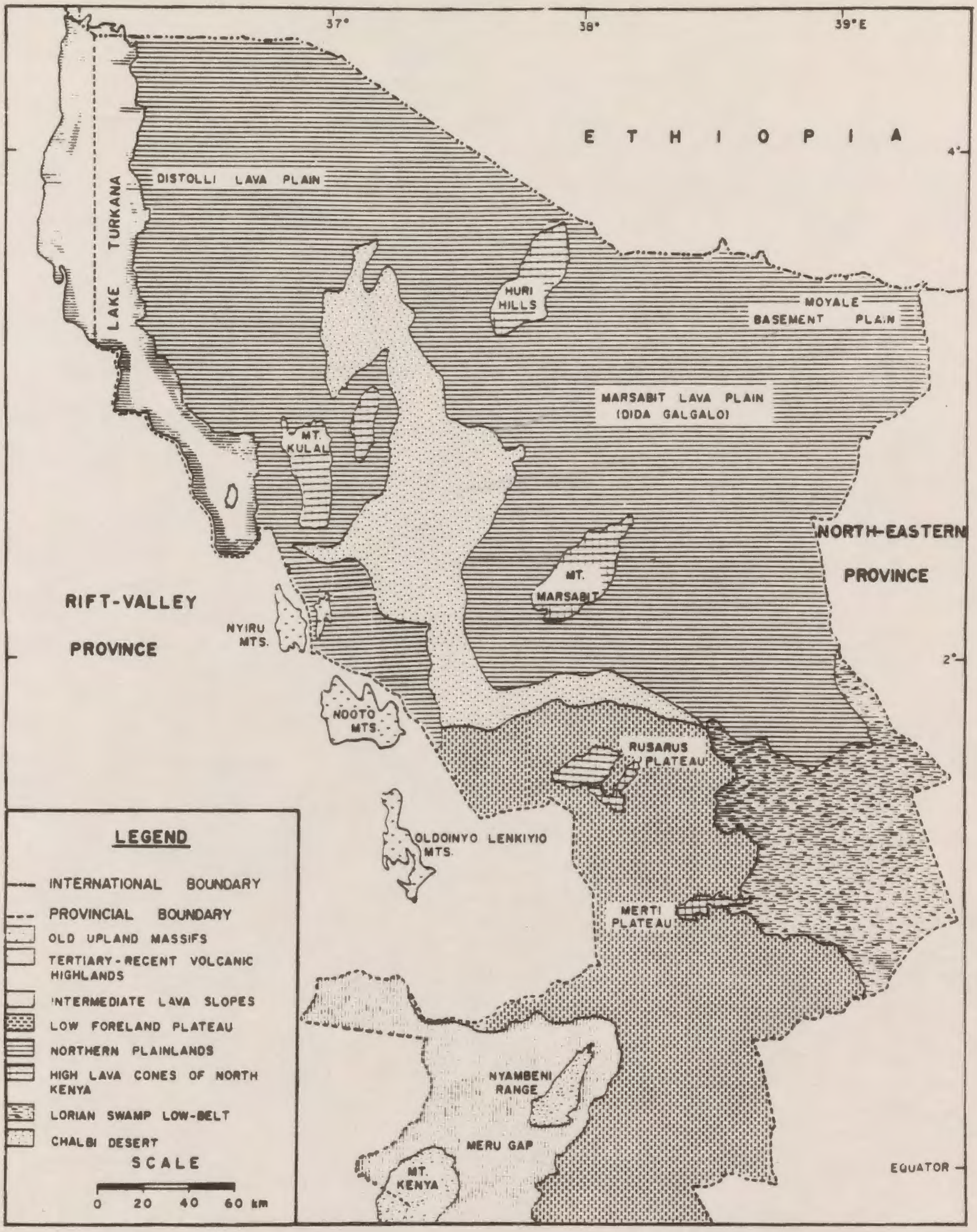

Figure 2.3 Physiographic regions of the Eastern Province. (Source: Ojany, 1966).

southwesterly to northeasterly trend from the foothills of Mt. Kenya. This is a fissure-eruption volcano, and like Mt. Kenya, has many parasitic cones and vents.

The Intermediate Lava Slopes are associated with the volcanic highlands of Mt. Kenya and the Nyambeni Range. The slopes of Mt. Kenya are separated into two sectors (Ojany, 1966) by the Nyeri corridor (not shown on the map), which is the col between the Aberdares Range and Mt. Kenya, and by the Meru gap, which is a low saddle between Mt. Kenya and the Nyambeni Range.

The Low Foreland Plateau includes the land between 300 m and 900 m (Ojany, 1966) and is characterised by flat topography and dryness. The Merti plateau is a distinctive example of landforms found in this physiographic region.

The Northern Plainlands and associated lava plains are dominated by low relief and aridity. These areas consist of extensive plains, averaging between 300 m and 760 m (Ojany, 1966) in elevation. Isolated volcanic cones rise to higher levels. Both the Moyale Basement and Marsabit Lava Plains, which resulted from the erosion of the Precambrian Basement rocks and fissure eruptions, respectively, lie in this physiographic region.

The High Lava Cones and Plateau of North Kenya are represented by Marsabit, Huri, and Kulal Hills with elevations of 1428, 1497 and 2292 m, respectively (Ojany and Ogendo, 1973). These lava cones, provide the only major break to the northern plainlands as they project above them.

The Lorian Swamp Low-belt lies below 300 m (Ojany, 1966) above the sea-level and occurs downstream of Merti on the lower reaches of the Ewaso Nyiro River. It is a shallow depression which, during the occasional rainy seasons, becomes swampy.

The Chalbi Desert, lying to the north of Nyiru and Ndoto Mountains is desertic environment composed mainly of aeolian sand dunes (Ojany and Ogendo, 1973). The desertic environment extends southwards to include the Kaisut Desert.

2.5 Climate and Vegetation

The climate of the study area is hot and dry. One salient characteristic of this climate is that the temperatures are high and the rainfall is unreliable, both in time and space. According to Ojany and Ogendo (1973), the main factors affecting the climate of a place are: latitude; altitude; nature of the prevailing winds; distance from an open water body; topography; vegetation cover; and pressure belts.

These factors interdependently affect the climate of the study area. There are two climatic seasons in the study area, the "long rains" and the "short rains" seasons.

The "long rains" season occurs between the months of

March and May when there is influence of moist Southeast Trade Winds originating from the Indian Ocean. The Inter-Tropical Convergence Zone (ITCZ), which is a zone of convergence of winds, is located in the northern hemisphere at this time of the year (Ojany and Ogendo, 1973). This zone causes upward movement of moist air, which cools and condenses as rain.

The "short rains" season occurs between the months of October and December. During this time, the ITCZ is located in the southern hemisphere and the Northeast Trade Winds, originating from the Arabian Peninsular, influence the rainfall pattern of the study area. These winds collect moisture only over a short stretch of the Indian Ocean and, as such, are not as moisture laden as the Southeast Trade Winds (Ojany and Ogendo, 1973). They do, however, cause limited precipitation in the study area.

The rainfall in the area is both unreliable and variable in the amount received annually. Altitude plays an important role in determining the amount of rainfall received in a location. Highest rainfall occurs around Mt. Kenya and the Nyambeni Range and decreases northeastwards. Exceptions to this trend occur where there are topographic highs projecting above the surrounding areas, such as Mt. Marsabit, Mt. Kulal, and the Huri Hills. Most of the area, especially on the plains, receive less than 500 mm (Ominde, 1968) while mountainous areas may receive up to or more than 1000 mm (Bake, 1984) mean annual precipitation. Figure 2.4 shows the mean annual rainfall distribution of the area.

Altitude also plays an important role in determining the temperatures of an area. The highlands are cool, while the plains are hot. In the plains, the mean annual temperatures range between 22 and 27 °C with a range of about 11 °C (Ojany and Ogendo, 1973).

Differences in altitude between the mountains and the plains cause differences in vegetation types. On the upper slopes of Mt. Kenya and the Nyambeni Range, where precipitation is high, dense forests occur. However, much of the original vegetation has been cleared to give way to human settlement. At lower levels of the slopes, where precipitation is more sporadic, scattered tree-grasslands and open grasslands occur (Ojany and Ogendo, 1973).

Bushland thicket and semi desert vegetation are the two types (Ominde, 1968) of vegetation found in the arid areas of the plains. The bushland thicket consists of open, dry bush formation with sparse desert grass. This grassland community has a wide variety of sparsely distributed deciduous schrubs and bushes varying in height from 3.0 to 4.6 m (Ojany and Ogendo, 1973). Much of the ground free of bushes is covered by dispersed bunches of permanent grass and lower schrubs. To the local population, this is the most important vegetation in terms of pastures for their

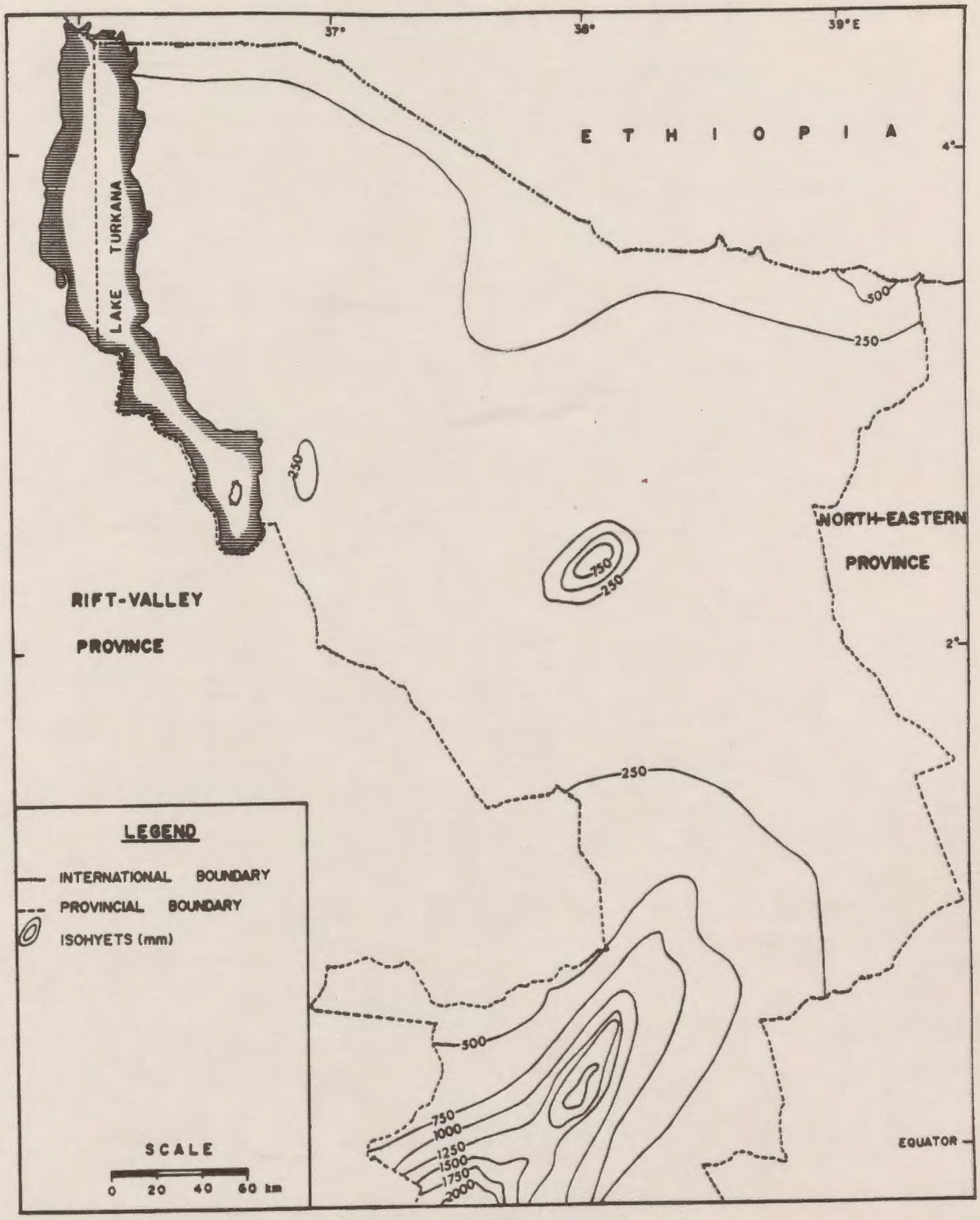

Figure 2.4 Mean annual rainfall distribution map of the Eastern Province. (Source: Government of Kenya, 1970).

livestock.

The semi-desert vegetation is mainly a desert schrub formation in which plant life is more restricted and much of the surface is bare. Widely scattered, dwarf trees ranging in height from 1.2 to 3.0 m also occur in these areas (Ojany and Ogendo, 1973). This vegetational area also includes sparse and annual grasses (Ominde, 1968). Some areas, especially the lava plains, may be bare and stony.

2.6 Geology

The details of the geology for most of the the study area are not fully known since the geological investigations and mapping have not been completed. In fact, except for the southern and the northeastern parts, most of the area has not been geologically mapped. Based on the available geological reports and other information, the rocks of the area can be divided into three groups (Figure 2.5): Basement System Rocks; Volcanics; and Sediments.

2.6.1 Basement System Rocks

These are high grade metamorphic rocks of the Late Proterozoic-Cambrian Mozambique Orogenic Belt (Key *et al*., 1987). They are the products of metamorphosed sedimentary rocks that had probably been deposited in a vast

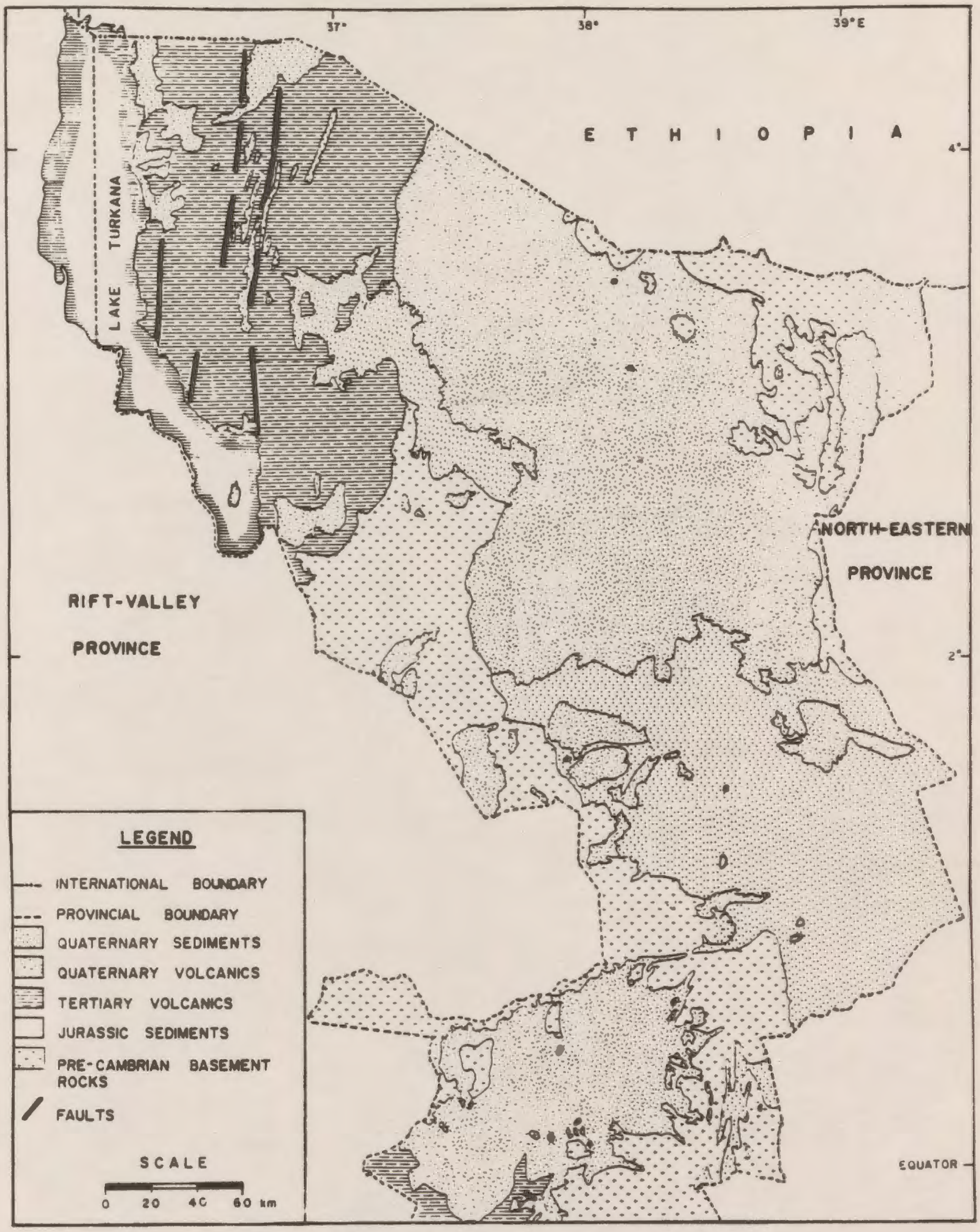

Figure 2.5 Geology of the Eastern Province. (Source: Government of Kenya, 1970).

geosyncline (Mozambique Geosyncline) or in a series of geosynclines which extended over much of Eastern Africa (Ojany and Ogendo, 1973). The original rocks, consisting mainly of sandstones, grits, shales, and limestones were metamorphosed to varying degrees by regional metamorphism and granitization to give quartzites, marbles, schists and gneisses of varying composition (Mason, 1955).

These rocks have been intruded by basic, ultrabasic and acidic igneous rocks which include amphibolites, pyroxenites, serpentinites, granites and quartz veins (Jennings, 1967; Rix, 1967; Walsh, 1972; Ndombi, 1983). These intrusives are more resistant to erosion than the surrounding basement rocks and form erosional remnant features represented mainly by scattered inselbergs which add diversity to the relief.

2.6.2 Volcanics

The volcanic rocks are mainly alkaline basalts dated as Upper Miocene-Recent (Mason, 1955; Brotzu *et al*., 1984). The most important and extensive volcanic activities are associated with Mt. Kenya, the Nyambeni Range and Mt. Marsabit. The Mt. Kenya and the Nyambeni volcanic rocks occur in the southern portion of the study area and they unconformably overlie the Basement System Rocks. Around Meru area, Mason (1955) divided the Mt. Kenya volcanic series into three groups: Basalts, Tuffs and Ashes of

Parasitic Cones, Upper and Lower Olivine Basalts.

The Nyambeni volcanics are mostly olivine basalts and at Kinna, Rix (1967) recognized two episodes of basaltic extrusion. The Lower Olivine Basalts along the northeasterly aligned fissures of the Nyambeni Range where lava was extruded quietly. The volcanism produced a parallel drainage pattern on the southeastern slopes of the range. The Upper Olivine Basalts which were extruded later exhibit a youthful topography and are typified by distinct flow-scarps and the development of narrow, steep-sided drainage channels. The Nyambeni Volcanic Series overlie the Mt. Kenya volcanic series and this indicates that they are comparatively young.

The Mt. Marsabit lava occurs in the north and is mainly basaltic in composition. It is associated with volcanic craters and vents through which lava was extruded. Other areas composed of basaltic lava are the Huri Hills and Mt. Kulal.

2.6.3 Sediments

Sediments, both consolidated and unconsolidated, dating from Jurassic-Recent (Rix, 1967; Matheson, 1970; Walsh, 1972) occur in the study area. Jurassic sandstones, outcrop to the northeast of Garba Tula area (Matheson, 1971). The Merti Beds, consisting of grits and conglomerates with a calcareous matrix are dated as Upper

Pliocene (Matheson, 1971). They are exposed on the flanks of the Merti Plateau where they have been preserved from erosion by a capping of olivine basalt. They also outcrop to the east of Garba Tula area.

Fossiliferous Plio-Pleistocene deposits (Bowen and Vondra, 1973) outcrop on the eastern area of the Lake Turkana Basin. These are lacustrine and fluvial deposits which are palaeontologically and archaeologically important. Other Pleistocene sediments occur to the east of the study area and are associated with lava flows (Rix, 1967). According to Rix (1967), these are fossiliferous lacustrine sediments deposited down in lagoons by the damming of drainage channels by the lava flows from the Pleistocene volcanicity.

Recent sediments, including soils and sands, depend on three factors (Mason, 1955): the distribution of rainfall; the type of underlying rock formation; and the nature of the drainage.

In well-watered, volcanic areas, such as the Mt. Kenya and the Nyambeni Range foot-hills, thick, brown, volcanic soils have developed. Small patches of secondary limestone (kunkar) occur in various parts of the study area and owe their origin to capillary action which draws lime-rich solution to the surface where by evaporation, a calcareous material is deposited (Matheson, 1971; Randel, 1970). Kunkar limestone is therefore a good indicator of areas deficient in rainfall. In areas of poor (impeded) drainage, black cotton soils (clays) have developed.

Reddish-brown soils are common and cover much of the north. These soils contain fragments of quartz, feldspar, hornblende and biotite, indicating that they were derived entirely from metamorphic rocks of the Basement System (Walsh, 1972). Pale-brown alluvium is found along both the perennial and ephemeral river valleys.

Fluvial deposits and wind-blown sands occurring as sand-dunes cover the entire Chalbi and Kaisut Deserts. In the Chalbi basin, these deposits overlie a sequence of Tertiary sediments that resulted from the weathering of the old land surface of the Basement System (Ndombi, 1983).

2.7 Surface Drainage

The following six catchment areas are recognizable in the study area and the immediately adjacent areas (Figure 2.6):

(i) Mt. Kenya,
(ii) Nyambeni Range,
(iii) Nyiru-Ndoto-Oldoinyo Lenkiyio Mountains,
(iv) Kulal-Asie Mountains,
(v) Mt. Marsabit, and
(vi) Huri Hills.

Except for the Mt. Kenya and the Nyambeni Range, the catchment areas have mainly ephemeral streams. The

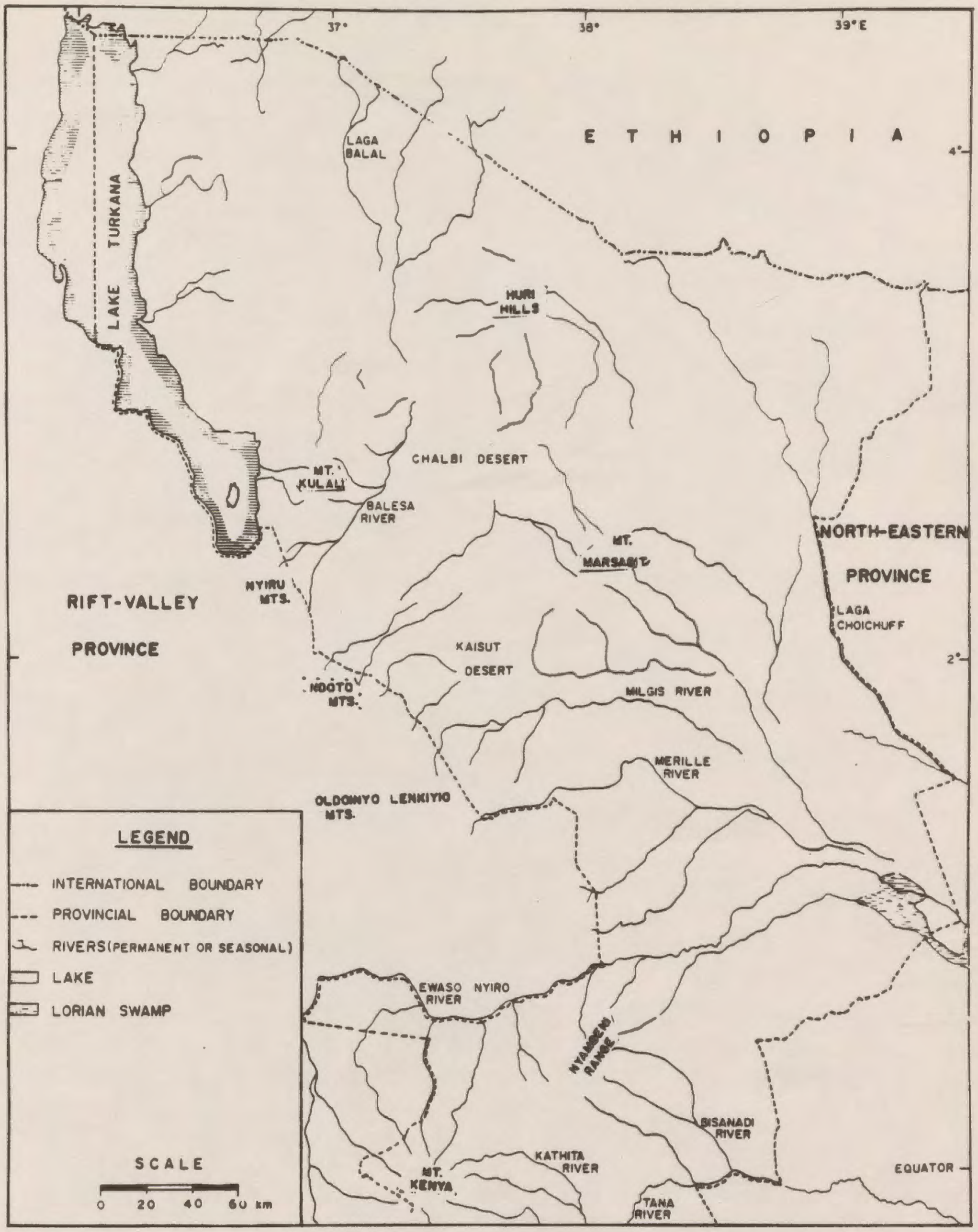

Figure 2.6 Surface drainage of the Eastern Province.

seasonality of these streams is, primarily, a meteorological phenomenon. However, one common characteristic of these catchment areas is that, more streams and of greater volumes, flow from the southeastern slopes. The southeastern slopes, being on the windward side of the rain-causing monsoon winds, have relatively higher rainfall than the northwestern slopes which lie on the lee-side of the mountains.

As in the rest of Kenya, earth movement forces which involved tectonic uplifts, downwarping, faulting, tilting and the consequential eruption of large quantities of lava, are responsible for the present drainage patterns (Ojany, 1971) in the area. The Tertiary to Quaternary volcanic activities had an effect on the pre-existing topography by burying a large part of Kenya and in the process altered the drainage patterns (Ojany,1971). This was also reported by Jennings (1967) who found that volcanic activities had altered the drainage channel of the Ewaso Nyiro River at the Archer's Post area.

On the volcanic mountains, radial drainage patterns have developed. On the slopes of Mt. Kenya and the Nyambeni Range, the streams are in their youthful stage and down-cutting of their channels strongly predominates over lateral erosion (Mason, 1955; Rix, 1967) resulting in steep-sided and comparatively deep channels in their upper reaches. These two volcanic masses are the main sources of the Tana River, which is the longest and the most important river in Kenya. Since the Tana River flows outside the study area, it will not be discussed here.

The Ewaso Nyiro River, originating in the high rainfall regions of Mt. Kenya and the Aberdare Range (outside the map), is the only perennial river of importance in the study area. However, it is only perennial as far as downstream of Merti where it becomes the Lorian Swamp (Williams, 1966; Matheson, 1971). Out of a total length of about 532 km and a drainage basin of approximately 57,000 km^2, only 270 km is the river perennial (Ojany, 1971). The main drainage direction is southeast.

At Archer's Post, the Ewaso Nyiro River's flow has been measured since 1949. The flow averaged 707.8 million m^3 annually (Swarzenski and Mundorff, 1977) between 1949 and 1972. During most of the year, however, monthly discharge is less than 50 million m^3 and may decrease to as low as 2 or 3 million m^3 in February or March (Swarzenski and Mundorff, 1977). November is the month with the maximum flow (Figure 2.7) and during 1949-72, averaged 148.4 million m^3 (Swarzenski and Mundorff, 1977).

Other rivers in the study area are seasonal with flows only after heavy rainfall. One common characteristic of these seasonal rivers is that they have thick accumulations of sand on their beds. Examples include Balesa, Merille and Milgis. Most of the seasonal rivers in the west drain

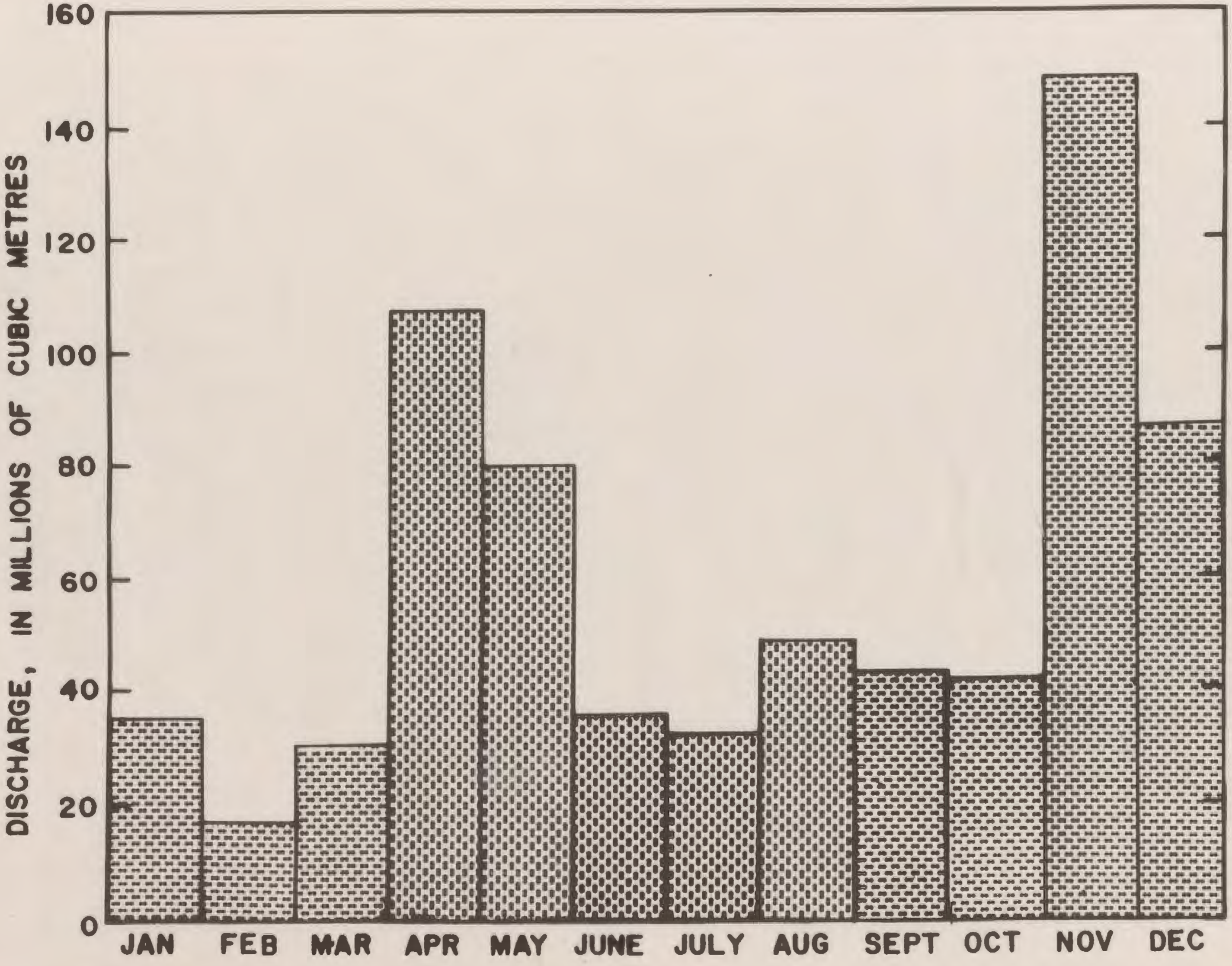

Figure 2.7 Average monthly discharge of the Ewaso Nyiro River at Archer's Post, between 1949 and 1972. (Source: Swarzenski and Mundorff, 1977).

into the Chalbi Desert which becomes impassable and water-logged during the wet seasons. Other rivers drain into Lake Turkana. Those in the east drain towards North-Eastern Province or disappear in swamps.

Lakes Turkana and Paradise are the only two lakes in the area. Lake Turkana, which has a total area of about 6,405 km^2 (Ojany and Ogendo, 1973), is the largest lake in Kenya resulting from tectonic activities associated with the formation of the Rift Valley. The principal influent river is the Omo River, which originates from the Ethiopian Highlands and provides 80-90% (Yuretich and Cerling, 1983) of water input to the lake. Other influents to the lake are the Turkwel and Kerio Rivers which flow from the Rift Valley Province. Lake Turkana has no outflows and is of moderate salinity (Yuretich and Cerling, 1983).

Lake Paradise is a crater lake (Ojany and Ogendo, 1973) on Mt. Marsabit. Inflow into Lake Paradise is from springs and surface runoff from Mt. Marsabit.

2.8 Hydrogeology

All the water resources in Kenya are vested in the Government and administered by the Ministry of Water Development which was established in 1974. The Ministry of Water Development was formerly in the Ministry of Natural Resources and lately in the Ministry of Agriculture. One of the main objectives of the ministry is to investigate, develop and manage the groundwater resources of the country.

Groundwater is the most important water resource in arid and semi-arid regions, where surface water resources are lacking or insufficient. Groundwater investigations to locate new borehole sites for either individuals or institutions, are mainly carried out by the Ministry's geologists using geophysical methods. The drilling of boreholes is done by using either rotary or percusion drill rigs. Drilling is done by Ministry or private contractors. Besides drilling, the wells are installed with casings, screens and pumping equipment.

So far, more than 6,000 boreholes (Ministry of Water Development, 1985) have been developed in different parts of the country but, unfortunately, not all are operational. Some were abandoned immediately after drilling either due to very low yields (dry) or non-potable groundwater. Non-potable waters are highly mineralized from leaching of inorganic ions in the upper portions of the soil(s), and rock(s) or in the subsurface flow.

Groundwater has been struck in both confined and unconfined aquifers, and at different levels within the study area. Table 2.1 shows borehole data for some of the production boreholes in the area. The distribution of some production boreholes and wells is shown on Figure 2.8.

The water infiltration rates in the unconsolidated

TABLE 2.1: DATA FOR SELECTED PRODUCTION BOREHOLES

B/H NO.	LOCALITY	T.D.*	S.L.**	R.L.***	T.Y.****
C-1758	Log-Logo	85	70	61	8.04
C-2324	Kula Mawe	52	41	36	5.46
C-3008	Bubisa	217	107	81	5.64
C-3681	Log-Logo	123	N.A	88	2.80
C-3691	Sololo	46	38	32	4.00
C-3782	Sololo	97	53;59	43	1.60
C-3819	Gudas	126	106	86	8.20
C-3840	Dabel	41	14	10	5.50
C-3896	Walda	61	40;46	31	27.30
C-3959	Oda	76	39	1	2.18
C-3960	Kargi	96	18;72	13	10.90
C-3966	Golole	77	53;74	49	10.00
C-4181	Bori	59	47	39	4.50
C-4514	Merti	106	34	31	0.70
C-4543	Merti	50	38-46	14	3.00
C-4582	Sagante	250	155	114	N.A
C-4643	Yamicha	180	75	73	3.50
C-4825	Kalacha	64	32;62	artesian	218.20
C-5001	Sabarei	26	3;21	2	32.70
C-5047	Ileret	100	8;62	7	3.65
C-5565	Ruiri	120	28;67	25	3.96
C-5881	Njuruta	150	38;119	42	2.00
C-5901	Godoma	100	19;34	19	2.20
C-6000	Muramba	120	40;106	68	2.25
C-6063	Sololo	60	45;49	44	2.30
C-6357	Dukana	100	18;88	87	6.00

* - Total drilled depth in metres
** - Water struck level in metres
*** - Water rest level in metres
**** - Tested yield in m/hr
N.A - Data not available
Source: Ministry of Water Development, 1985.

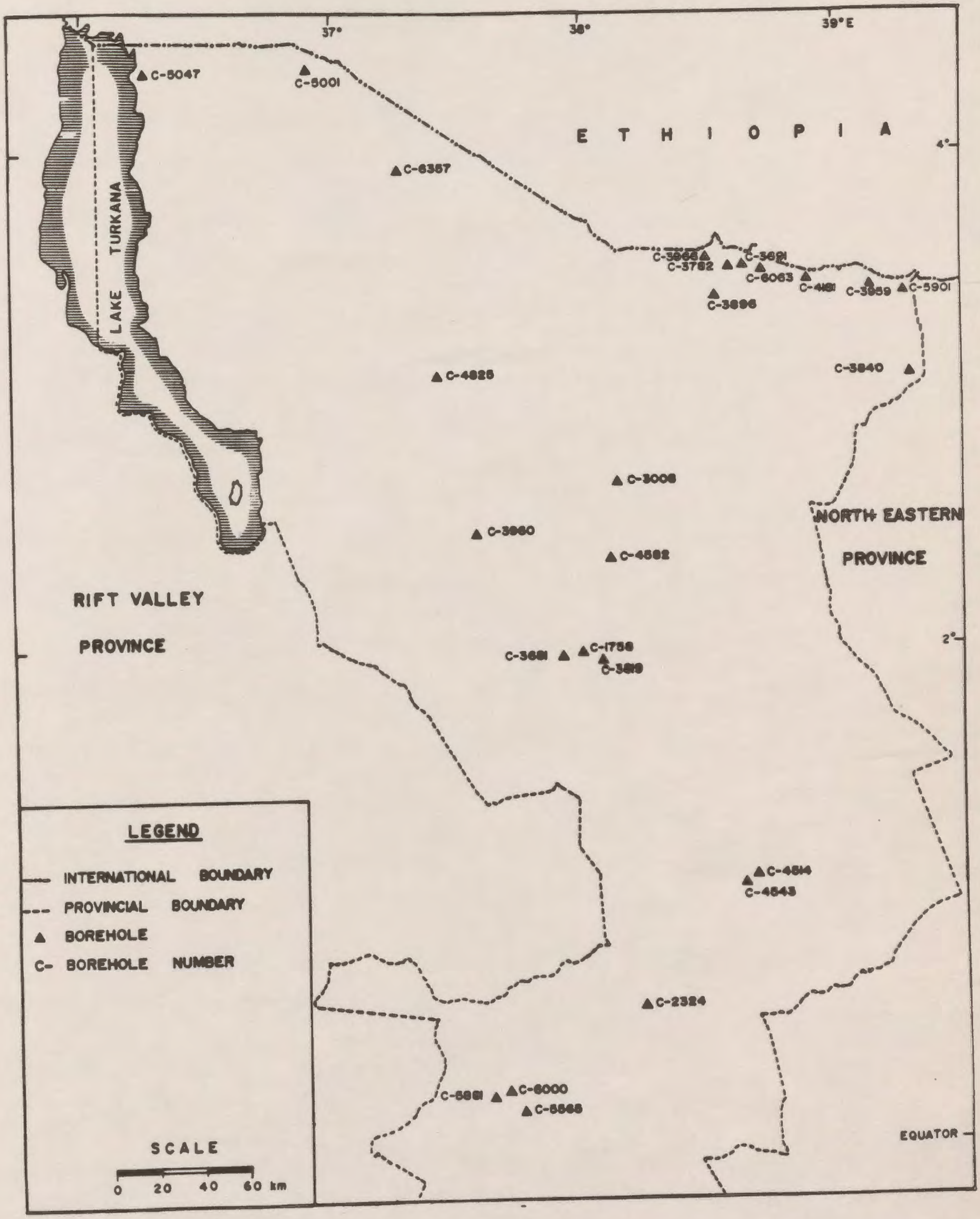

Figure 2.8 Distribution of selected production boreholes in the Eastern Province.

sediments are high because individual particles are not cemented together. The infiltration rates increase with increase in grain size and uniformity. However, these sediments are good aquifers only if underlain by impermeable layers, such as clay. Cementation in consolidated materials reduces infiltration rates (Bake, 1984).

The igneous and metamorphic rocks of the Basement System have very poor water-supply potential, because they are almost completely impermeable. Groundwater can only be found in fractured and weathered zones. The groundwater storage capacity in these zones is limited (Bake, 1984) and depending on the nature of the recharge, boreholes drilled in such sites may yield low to substantial quantities of groundwater. Nevertheless, where unweathered rocks underlie permeable sediments, boreholes usually yield substantial amounts of groundwater.

In areas where boreholes and other supplies of water are lacking, hand-dug wells are a common feature. Generally, hand-dug wells are dug by the local communities in areas along or in sandy river beds, at points where subsurface water is retained by clay or natural rock bars (Matheson, 1971; Rix, 1973). These units may reach thicknesses of 10 m or more. The walls of most of the wells are tortuous and far from plumb. To draw water from such a well, a chain of men, whose number depends on the depth of the well, stand one below the other on rock platforms or tree roots in the in the well, and pass skin buckets of water up the surface. The men empty these buckets to troughs for the waiting livestock and return them back down the well quickly.

In some favourable points along the sandy river beds, wells may give permanent water supplies, although the levels may drop considerably in dry seasons. There is also the problem of collapsing walls. Wells have to be re-dug after every surface flow in the sandy river beds following heavy rains. To overcome these problems, wells are dug and installed with concrete linings which extend above the ground surface. In these wells, water is drawn by using hand pumps. Vandalism and poor maintenance of hand pumps have rendered some of them inoperable.

Perennial springs occur in the volcanic mountains, and are generally fault-controlled. The springs are used by the local communities for their domestic and livestock water-supplies. The Bakuli spring on Mt. Marsabit is the main source of domestic water-supplies for the Marsabit town's population. Although the springs on Mt. Kulal are hot, they are used for domestic water supplies by the population around and in Loiyangalani trading center. This shows how acute is the problem of water availability and of potable standards in the arid and semi-arid areas of the Eastern Province.

Groundwater recharge is thought to be from the high-rainfall mountain regions (Rix, 1967; Bake, 1984) both within and outside the study area and from local precipitation.

3.0 THEORETICAL CONSIDERATIONS

3.1 Isotopes

Isotopes may be defined as atoms whose nuclei contain the same number of protons, but a different number of neutrons (Hoefs, 1973). Isotopes have, therefore, the same atomic number, which is equal to the number of protons, and a different mass numbers, which is the sum of protons and neutrons in the nucleus. An isotope of element could either be stable or radioactive depending on whether the nucleus is subject to radioactive disintegration.

Environmental isotopes are those isotopes whose natural abundance variations may be used for hydrogeological studies. These studies are conducted to gain a better understanding of the groundwater systems which facilitates the development and management of the groundwater resources, and the evaluation of environmental problems. According to Fontes (1980), most environmental studies have been based on isotopes of the elements having low atomic numbers. These elements and their isotopes include hydrogen (protium, deuterium and tritium), carbon (carbon-12, carbon-13 and carbon-14), nitrogen (nitrogen-14 and nitrogen-15), oxygen (oxygen-16 and oxygen-18)and sulphur (sulphur-32 and sulphur-34).

Oxygen and hydrogen isotopes are more commonly used in groundwater studies than the other isotopes because they are primary constituents of some water molecules. Table

3.1 shows the approximate terrestrial abundance of oxygen and hydrogen isotopes. These isotopes are conservative in the hydrologic cycle.

3.1.1 Oxygen-18 and Deuterium

Oxygen has three stable isotopes and hydrogen has two stable and one radioactive isotopes. The existence of these isotopes has made it possible for water molecules to have nine (Faure, 1977) different isotopic configurations whose mass numbers range from 18 to 22. Since molecules of water containing different isotopes of oxygen and/or hydrogen have different masses, their vapour pressures are different (vapour pressure is inversely proportional to the molecular mass).

Isotopic ratios are used in expressing the concentration of oxygen-18 and deuterium in the hydrologic cycle. Mass spectrometers are used to make rapid and accurate measurements of the isotopic ratios. The isotopic ratios used are those for the heavier to the lighter isotopes (oxygen-18/oxygen-16 and deuteriun/protium). The oxygen isotopic ratio is determined on a McKinney-Nier type spectrometer (Craig, 1961b). The water sample to be analyzed is converted into carbon dioxide gas and the analysis made by comparing its oxygen isotopic ratio to that of a standard gas (Faure, 1977) after allowing the water sample to equilibrate with carbon dioxide gas at

TABLE 3.1: APPROXIMATE TERRESTRIAL ABUNDANCE OF OXYGEN AND HYDROGEN ISOTOPES

Element	Isotopes	Abundance (%)
Hydrogen.	Protium	99.984
	Deuterium	0.015
	Tritium	Radioactive (Half-life = 12.35 a)
Oxygen.	Oxygen-16	99.76
	Oxygen-17	0.037
	Oxygen-18	0.1

(Source: Fritz and Fontes, 1980).

25 °C.

The determination of hydrogen isotopic ratio is carried out using hydrogen gas. Water is converted to hydrogen gas by being passed over hot metallic uranium or zinc (Hoefs, 1973).

The isotopic ratios are expressed in delta (δ) units, as per mil difference relative to the international standard, SMOW (Standard Mean Ocean Water). The δ values are determined by:

$$\delta \text{(per mil)} = [Rx-Rs/Rs]x1000 \qquad \text{(Craig, 1961a)}$$

where, R is the isotopic ratio of either oxygen or hydrogen isotopes, x is the sample and s is the standard. The accuracy of measurements is usually better than +/-0.2 and +/-2% for oxygen-18 and deuterium, respectively (Payne, 1972). The stable isotope data is often presented on a δ diagram, which is obtained by plotting deuterium versus oxygen-18 concentration (Gat, 1971).

The deuterium and oxygen-18 δ values for meteoric waters frequently satisfy the linear relationship:

$$\delta D = a\delta^{18}O + d \qquad \text{(Gat, 1971)}$$

where,

a = slope of the line

d = deuterium excess parameter.

Craig (1961b) showed that globally, this relationship in precipitation is

$$\delta D = 8\delta^{18}O + 10$$

This is the "meteoric water line" and holds only for water that has not been subjected to evaporation.

When water evaporates or condenses, isotopic fractionation occurs. Fractionation is a process that seperates the isotopes of an element (Toran, 1982). Isotopic fractionation occurs during several chemical and physical processes and according to Faure (1977), fractionation may occur during:

(i) isotopic exchange reactions, where the isotopes of an element are distributed among different molecules containing that element;

(ii) undirectional reactions, in which reaction rates depend on isotopic composition of the reactants and products; and

(iii) physical processes, such as evaporation and condensation, melting and crystallization, adsorption and desorption, and diffusion of ions or molecules due to concentration or temperature gradient.

The fractionation factor, x, which indicates the isotopic fractionation is defined as:

$$x = RA/RB \qquad \text{(Faure, 1977)}$$

where,

RA = isotopic ratio in molecule or phase A

RB = the same in molecule or phase B

The fractionation factor for any chemical reaction or physical process is temperature dependent and approaches unity at increasing temperatures (Faure, 1977). The fractionation factor also depends on the rate of the reaction. If the reactions proceed slowly, equilibrium conditions are achieved. But, if the reactions are fast, non-equilibrium conditions are realized (Dansgaard, 1964).

When water evaporates from the surface of the ocean, the water vapour is enriched in light isotopes of water (oxygen-16 and protium) because the water molecule of these isotopes has a higher vapour pressure than water molecule containing oxygen-18 and/or deuterium. As a result, the values for oxygen-18 and deuterium of water vapour in the atmosphere above the oceans are both negative. When the condensation of water vapour occurs, the first raindrops formed are enriched in oxygen-18 and deuterium relative to the remaining water vapour. As the moist airmass moves further inland, and as the condensation and precipitation process is repeated many times, the remaining airmass becomes progressively depleted in oxygen-18 and deuterium and, therefore, becomes progressively lighter.

When a moist airmass moves from lower to higher latitudes, it becomes more depleted in oxygen-18 and deuterium because of a combination of factors, which include (Faure, 1977):

(i) isotopic fractionation, due to differences in vapour pressure of isotopic water molecules at a given temperature;

(ii) decrease of temperature in the airmass increases the fractionation factor; and

(iii) re-evaporation of water from raindrops and from surface water in the ground both of which enrich the vapour phase in the light isotopes.

Generally, the stable isotopic composition of precipitation at any site is determined by the following four factors (Thatcher, 1967):

(i) Distance from the ocean

The water vapour leaves the ocean with a slightly negative δ value for both oxygen-18 and deuterium, determined by the isotopic composition of the surface ocean water in the source area. The precipitation becomes progressively lighter as the water vapour moves inland because of preferential precipitation of the heavy isotopes.

(ii) Temperature

The isotopic fractionation factor increases with decreasing temperatures. Dansgaard (1964) demonstrated a linear relationship between $\delta^{18}O$ values of average annual precipitation and the average annual air temperature. The relationship is

$$\delta^{18}Om = 0.695t - 13.6$$

where,

$\delta^{18}Om$ = annual mean oxygen-18 delta value of precipitation

t = average annual surface temperature (°C).

(iii) Exchange

When precipitation falls, it is exposed to the prevailing isotope ratio in the humidity already present in the atmosphere. The raindrops exchange with atmospheric vapour to reach an equilibrium concentration. The effect is a function of drop size, duration of rainfall and temperature. With heavy rains, the effect is not significant because the first fall of rain sweeps out the prevailing atmospheric vapour and provides a new vapour phase.

(iv) Evaporation

Evaporation causes the enrichment of oxygen-18 and deuterium in precipitation relative to the oceanic water. In arid and semi-arid regions, precipitation shows isotopic enrichment of heavy isotopes by evaporation from the falling raindrops. The enrichment of both oxygen-18 and deuterium in the raindrops proceeds along a line with a slope of less than 8 (Gat, 1971).

Despite these variable effects, the average isotopic composition of precipitation at any site is relatively consistent from year to year (Thatcher, 1967).

3.1.2 Tritium

Tritium is a radioisotope of hydrogen with a half-life of 12.35 years (Fritz and Fontes, 1980). The occurrence of tritium in the hydrologic cycle is from both natural and man-made sources.

Tritium is produced naturally in the atmosphere by the interaction of fast, cosmic-ray produced neutrons with stable nitrogen (nitrogen-14). After production, tritium combines with oxygen and is subsequently dispersed throughout the hydrosphere. The estimated atmospheric production of tritium is 0.25 atoms/cm^2/s (Payne, 1972) resulting in steady-state concentrations of between 5 and 20 tritium units (TU) in precipitation (Fontes, 1980). 1 TU corresponds to a concentration of one atom of tritium in 10^{18} atoms of hydrogen (Fontes, 1980).

The first major source of man-made tritium entered the atmosphere during the initial tests of thermonuclear devices in 1952 (Fontes, 1980) followed by further tests in 1954 and 1958. Highest concentrations of tritium followed the test series of 1961 and 1962 (Payne, 1972) after which there was moratorium on atmospheric testing. These tests introduced considerable quantities of tritium into the atmosphere and at its maximum level in the northern hemisphere in 1963, artificial tritium in precipitation reached 2 to 3 orders of magnitude (Fontes, 1980) above that of natural tritium. In the southern hemisphere, maximum concentation was observed between 1964 and 1965 (IAEA, 1968) and was not as high as in the northern hemisphere.

Prior to the thermonuclear bombs testing, only a few natural tritium measurements in precipitation had been made. According to Fontes (1980), pre-nuclear testing levels for tritium, when corrected for decay, are everywhere below 5 TU.

The atmospheric distribution of tritium shows two patterns (Thatcher, 1967; Payne, 1972). Firstly, the concentration of tritium increases with increase in latitude. However, tritium concentration in precipitation in the northern hemisphere is higher than in the southern hemisphere because most testing of thermonuclear devices was carried out in the northern hemisphere. Also, the ratio of oceanic area to landmass is greater in the southern hemisphere and hence there is more dilution of the atmospheric tritium by oceanic water vapour in the southern hemisphere. Secondly, at any given latitude, the concentrations of tritium in precipitation at stations near the coast are lower than those inland because of the influence of diluting effect of oceanic water vapour of low tritium content on the high tritium concentations injected into the troposphere from the stratosphere (Thatcher, 1967).

The usefulness of tritium in groundwater studies depends on the accuracy of its analyses. Samples with low tritium concentrations are electrolytically enriched in cells with nickel and steel electrodes and their tritium concentrations then determined by liquid scintillation and gas phase counting techniques (Hoffman, 1967). Direct counting technique is used when tritium concentrations in water samples are high.

3.1.3 Applications

Isotope analyses can be taken as an independent approach to solve hydrogeological problems, but studies including combined hydrogeological, hydrochemical and isotope data will yield more detailed and in some cases, safer conclusions (Fontes, 1980).

According to Fontes (1980), two general rules can be recognized for the distribution of environmental isotopes in groundwater. Firstly, the origin of groundwater can be deduced if the isotope content does not change within the aquifer. The origin of the groundwater will give information on the location, period, and process of recharge. Secondly, the history of groundwater will be reflected if the isotope content changes along groundwater flow paths. The history will give information on the mixing, salinization and discharge process.

Isotopic investigations of groundwater start with estimation of the concentration of isotopes in the recharge water. The recharge of oxygen-18, deuterium and, tritium is primarily controlled by the distribution of isotopes with time in the annual precipitation, the distribution of precipitation intensity throughout the year, and evaporation (Thatcher, 1967).

It is usually assumed (Gat, 1971) that during sub-surface flow, the stable isotopic content is a conservative property of the water mass, and that it is possible to relate to the stable isotopic composition of the groundwater to that of the average precipitation in the recharge area. If groundwater and precipitation have the same isotopic content, then direct local recharge occurs. However, according to Gat (1971), incongruous results could be observed owing to:

(i) geographic displacement by sub-surface or surface flow;

(ii) recharge from partially evaporated surface water bodies;

(iii) recharge that occurred in past periods of different climate when the isotope composition of precipitation was different from that at present;

(iv) mixing with non-meteoric water bodies, such as sub-surface brines, sea-water or juvenile waters;

(v) isotopic fractionation processes, resulting from differential water movement through the soil, or the aquifer; and

(vi) interactions with geologic formations, accompanied by an isotope exchange or fractionation between the chemical species.

It is important, therefore, to identify the occurrence and source of recharge in evaluating the groundwater resources of a region.

Recharge occurs when the amount of precipitation exceeds evaporation, evapotranspiration and runoff on the earth's surface during a precipitation event. Recharge is more pronounced in humid regions than in arid and semi-arid regions, where evaporation is more important due to high temperatures. Despite high temperatures in these regions, groundwater recharge does occur as has been shown by Mazor et al. (1974, 1977) and Mazor (1982) in their studies of the Kalahari area. Issar and Gat (1980) used environmental isotopes to study the regime of groundwater recharge and flow in Wadi Feiran basin, Southern Sinai.

The applications of oxygen and hydrogen isotopes in groundwater hydrology are summarized in Table 3.2. Oxygen-18 and deuterium are excellent indicators of the circulation of water, while tritium is used in the determination of the residence time, assuming no contamination of groundwater has occurred (Terwey, 1984).

TABLE 3.2: APPLICATIONS OF OXYGEN AND HYDROGEN ISOTOPES IN GROUNDWATER HYDROLOGY

Isotope	Deuterium	Tritium	Oxygen-18
Half-life	stable	12.3 a	stable
Recent recharge		X	
Origin	X		X
Movement	X		X
Precipitation data	X	X	X

(Source: Terwey, 1984).

3.2 Chemistry

The chemical characteristics of water determine its potability and other domestic uses, and its usefulness in industrial and agricultural activities. By examining the dissolved constituents in groundwater, hydrogeological problems, such as the origin, history, direction and velocity of groundwater flow may be solved (Sugisaki, 1962; Matthew and Upchurch, 1978). The chemical characteristics of water are the result of dissolved ions, whose sources are the soils and rocks, and the atmosphere (Gorham, 1961; Freeze and Cherry, 1979).

Ion supply by soil and rock weathering, involving solution, hydrolysis, and oxidation-reduction reactions (Gorham, 1961) is the main source of ions in groundwater. According to Freeze and Cherry (1979), the concentrations of ions in groundwater are controlled by the availability of the elements in the soil and rock through which the water has passed, geochemical constraints, rates of geochemical processes, and by the sequence in which the water has come into contact with the various minerals occuring in the geological materials along the flow path.

Atmospheric materials, whose sources are the sea, land surface, volcanoes, products of air pollution and organic debris (Boyce, 1951; Gorham, 1961; Yaalon, 1967) are transferred to surface water by rain or snow as a dry fallout, or in gaseous form. The surface water so charged with atmosphheric ions may eventually infiltrate into the groundwater zone.

The major ions: calcium, magnesium, sodium, potassium, chloride, sulphate and bicarbonate, account for more than 90% (Freeze and Cherry, 1979; Ollier, 1984) of the total dissolved ionic species in water. Other important chemical parameters included in the study of water quality are alkalinity, electrical conductivity, hardness, pH and total dissolved solids (TDS).

3.2.1 Alkalinity

The alkalinity of water is its quantitative capacity to neutralize a strong acid to a designated pH (APHA et al., 1976). The determination of alkalinity is a measure of the excess basic constituents over the amount necessary to balance the strong acid constituents and is primarily caused by the presence of carbonate and bicarbonate ions (Hem, 1970; Matthess, 1982).

Hydroxide, iron, silicate, borate, and phosphate ions may have some influence on alkalinity but are insignificant in comparison with carbonate and bicarbonate ions (Davis and DeWiest, 1966; APHA et al., 1976; Matthess, 1982). Alkalinity analyses are mostly reported in terms of carbonate and bicarbonate ions concentration in water.

Carbonate and bicarbonate ions are common constituents of most groundwater because of the abundance of carbonate rocks in nature and because carbon dioxide, which helps dissolve these rocks, is readily available (Rainwater and Thatcher, 1960). Carbon dioxide is derived from the atmosphere, soil, and diagenesis of organic compounds (Matthess, 1982).

Alkalinity is determined by titrating a water sample with a standard solution of strong acid, and the carbonate end-point is taken as pH 8.2 and the bicarbonate as pH 4.5 (Rainwater and Thatcher, 1960; APHA *et al*., 1976).

3.2.2 Electrical Conductivity

Electrical conductivity (specific conductance) is a numerical expression of water's ability to conduct an electric current (Water Quality Branch, 1983). This number depends on the total concentration of the ionized substances dissolved in water and the temperature at which the measurement is made (APHA *et al*., 1976). It is the reciprocal of specific resistance, which is the resistance in ohms, of a cube 1 cm on a side of an aqueous solution at a specified temperature (Rainwater and Thatcher, 1960; Hem, 1970; APHA *et al*., 1976). In water analyses, electrical conductivity is reported in microsiemens/centimetre (µS/cm).

Pure water has very low electrical conductivity, however, the presence of charged ionic species makes the solution conductive. The conductivity measurement of an aqueous solution may provide some information on the concentration of ions in the solution because concentration and conductivity are linearly correlated (Hem, 1970). An estimate of the total dissolved solids (TDS) in an aqueous solution can be found from:

$$TDS = AC \qquad \text{(Hem, 1970)}$$

where,

C = electrical conductivity (μS/cm)
A = conversion factor (between 0.55 and 0.75).

The temperature of a solution affects the ionic velocities and, consequently, the electrical conductivity. The response of electrical conductivity to temperature changes varies for different solutions, but in dilute solutions for most ions, an increase of 1 °C, increases the conductivity by about 2% (Rainwater and thatcher, 1960; Hem, 1970). The electrical conductivity readings are usually adjusted to 25 °C, so that variations are a function only of the concentrations and types of dissolved ions (Davis and DeWiest, 1966).

Electrical conductivity measurements may be taken in the field or in the laboratory by using a conductivity meter. Storage of water sample prior to conductivity measurements, however, may change its conductivity values, especially due to adsorption of atmospheric carbon dioxide (APHA *et al*., 1976; Water Quality Branch, 1983).

3.2.3 Hardness

Hardness of water is defined as its content of metallic ions which react with sodium soaps to produce solid soaps, or scummy residues, and which react with negative ions when water is evaporated in boilers to produce solid boiler scales (Freeze and Cherry, 1979). Hardness is a characteristic of water that represents the total concentration of calcium and magnesium ions expressed as calcium carbonate (APHA et al., 1976).

Hardness is an indication of the soap-consuming power of water. Soap will not cleanse or lather until the polyvalent cations have been either neutralized or precipitated as insoluble salts (Rainwater and Thatcher, 1960). Soap is precipitated chiefly by the calcium and magnesium ions commonly present in water, but may also be precipitated by ions of other polyvalent metals, such as manganese, strontium, and zinc, and by hydrogen ions.

Hardness may either be carbonate or non-carbonate hardness. The carbonate hardness, which is the amount of hardness equivalent to the total alkalinity, is the numerical sum of the carbonate alkalinity and the bicarbonate alkalinity. The amount of hardness in excess of this is non-carbonate (APHA et al., 1976).

Two methods, the calculation and the ethylenediamine tetraacetic acid (EDTA) titration methods (Rainwater and Thatcher, 1960) are used in the determination of hardness.

The determination of hardness by calculation is applicable to all waters and is considered to yield the higher accuracy of the two methods (APHA et al., 1976). Total hardness is computed from the results of the calcium and magnesium determinations as follows:

Total hardness = 2.5(Ca)+4.1(Mg) (Freeze and Cherry, 1979)

where,

Ca = concentration of calcium ions

Mg = concentration of magnesium ions

The EDTA titration method affords a means of rapid analysis.

Chemical softening or ion exchange is used to reduce hardness to acceptable levels (APHA et al., 1976).

3.2.4 pH

The pH of a solution refers to its hydrogen ion activity and is expressed as the logarithm of the reciprocal of the hydrogen ion activity in moles/L at a given temperature (APHA et al., 1976). The practical pH scale extends from 0, very acid, to 14, very alkaline, with 7 corresponding to exact neutrality at 25 °C.

When materials go into solutions, the pH is commonly altered because some of the ions so introduced combine with hydrogen and hydroxyl ions from the water molecules and shift the chemical equilibrium. Waters that contain only slightly dissociated acids and bases tend to have a marked constancy of pH. The reason given by Davis and DeWiest (1966) and Matthess (1982) is that when hydrogen or hydroxyl ions are introduced into these buffered solutions, the ions are first used in shifting the chemical equilibrium so that the acid or the base is transformed into a salt. Until this happens, the pH of the solution remains relatively constant. Most groundwaters have pH values of between 5.0 and 8.0 (Davis and DeWiest, 1966; Matthess,1982) and this is due to a buffered system formed by dissolved carbon dioxide gas and bicarbonate ions with carbonic acid.

The pH can be measured either colorimetrically or electrometrically in the field or in the labratory. However, field pH measurements are preferred because the pH values obtained in the laboratory may not be the same as that of the water at the time it was collected owing to hydrolysis and oxidation taking place within the sample bottle on storage (Rainwater and Thatcher, 1960). The pH may also change appreciably through loss of dissolved gases, the adsorption of fumes in the laboratory and from precipitation of salts.

According to Davis and DeWiest (1966), the differences between field and laboratory pH values are commonly as much as 0.5 or more. The following generalizations (Davis and DeWiest, 1966; Matthess, 1982) have been made about variations in pH:

(i) very high pH values (above 8.5) are associated with sodium-carbonate-bicarbonate water;

(ii) moderately high pH values are commonly associated with waters high in bicarbonate; and

(iii) very low pH values (below 4.0) are associated with waters containing free acids derived from oxidizing sulphide minerals, or from waters in contact with volcanic gases containing hydrogen fluoride, hydrochloric acid and other volatiles.

3.2.5 Total Dissolved Solids (TDS)

The total dissolved solids consist of dissociated and undissociated substances, excluding suspended materials, colloids and dissolved gases (Davis and DeWiest, 1966; Matthess, 1982). Theoretically, TDS is the anhydrous residue of the dissolved substances in water, and if all dissolved solids were determined accurately by chemical analyses, TDS would be the numerical sum of these constituents. The TDS can range from less than 10 mg/L in rain or snow water, to more than 300,000 mg/L in brines (Davis and DeWiest, 1966).

Two methods (Rainwater and Thatcher, 1960) are available for the determination of TDS. The residue-on-evaporation method is applicable to all waters regardless of concentration, provided the residue layer in the evaporating dish is kept sufficiently thin. The calculation method entails the analyses of all the dissolved solids, the sum of which is the TDS.

On the basis of TDS, water may be classified into four categories as shown in Table 3.3.

3.2.6 Calcium

Calcium is an essential constituent of many igneous-rock minerals, especially pyroxenes, amphiboles, and feldspars, and other silicates produced in metamorphism. In sedimentary rocks, calcium commonly occurs in carbonates such as calcite, aragonite and dolomite, and in sulphates, it occurs in gypsum and anhydrite (Hem, 1970). Because of its abundance in the earth's crust and high mobility in the hydrosphere, calcium is one of the common ions in groundwater.

The concentrations of calcium in normal potable groundwater generally range between 10 and 100 mg/L depending on the source (Davis and DeWiest, 1966). Calcium, in conjunction with other metallic ions, especially magnesium causes hardness in water. However, small concentrations of calcium carbonate combat corrosion of metallic pipes by laying down a protective coating (APHA et al., 1976).

In dissolved form, calcium occurs as a divalent cation. The solubility of calcium in most natural waters is influenced by the equilibria involving carbonates (Hem,

TABLE 3.3: CLASSIFICATION OF WATER BASED ON TOTAL DISSOLVED SOLIDS

Category	Total dissolved solids (mg/L)
Fresh water	0 - 1000
Brackish water	1000 - 10,000
Salty water	10,000 - 100,000
Brine water	more than 100,000

(Source: Davis and DeWiest, 1966).

1970). Calcium carbonate, for example, is easily soluble in water provided that there as an abundance of hydrogen ions. The dissociation of carbonic acid is one of the most important sources of hydrogen ions in groundwater systems.

The concentration of calcium in a water sample may be determined in the laboratory by using any of the three methods (APHA et al., 1976) available: atomic absorption, permanganate titration, and ethylenediamine tetraacetic acid (EDTA) titration. The atomic absorption method provides the best results in terms of accuracy, while simplicity and rapidity of titration makes EDTA titration the most common method for general use (APHA et al., 1976).

3.2.7 Magnesium

The magnesium ion, is normally the predominant form of magnesium in aqueous solutions and is one of the metallic ions imparting the property of hardness to water. In igneous rocks, magnesium is typically a constituent of the dark-coloured ferromagnesian minerals, such as olivine, pyroxenes, amphiboles, and dark-coloured micas (Hem, 1970). Chlorite, montmorillonite, and serpentine are altered minerals in which magnesium occurs. In sedimentary rocks, magnesium occurs mainly in carbonates, such as dolomite and magnesite. As in calcium compounds, carbon dioxide plays an important role in the solution of magnesium from both silicates and carbonate minerals

(Rainwater and Thatcher, 1960).

Magnesium salts, notably sulphates and chlorides, are very soluble in water. However, despite the high solubilities of its compounds, magnesium is generally found in lower concentrations in natural waters than is calcium. Davis and DeWiest (1966) gave two explanations for this phenomenon. Firstly, they attributed this to the abundances of the elements in the earth's crust, in which calcium is the more abundant of the two elements. This means that calcium is more available for solution in water than is magnesium (Hem, 1970). The second explanation given is that dolomite, which is a major source of magnesium in sedimentary environments has a slow dissolution in water.

The concentration of magnesium in water depends on the source of water and generally is below 10 mg/L (Matthess, 1982) except in sea water and brines, in which concentrations may exceed 100 mg/L (Davis and DeWiest, 1966). In sea water, however, magnesium is more abundant than calcium. This has been explained by the preferential abstraction of calcium by marine animals and plants (Davis and DeWiest, 1966). Also, calcium is more readily precipitated from solution than is magnesium (Hem,1970).

The atomic absorption spectrophotometric, gravimetric, or the calculation method may be used to determine the magnesium content in water (Rainwater and Thatcher, 1960).

3.2.8 Sodium

Sodium is not an essential constituent of many rock-forming minerals, however,the primary source of most sodium in natural water is from the release of soluble products during weathering of plagioclase feldspars (Davis and DeWiest, 1966). Other sodium sources include evaporite deposits (Hem, 1970). Sodium is generally present in fresh water as sodium ions but according to Matthess (1982), complex ions and ion pairs are possible in concentrated solutions.

Sodium salts are very soluble and most sodium leached from soils and rocks tends to remain in solution (Rainwater and Thatcher, 1960). The high solubility of sodium salts results in the concentration by evaporation of sodium salts in oceans and closed basins of arid regions (Davis and DeWiest, 1966). The sodium content of natural water may range from less than 1 mg/L in rainwater and dilute stream run-off in areas of high rainfall, to more than 100,000 mg/L in brines of closed basins in arid regions (Hem, 1970).

The two standard methods for the determination of sodium ion concentration in water are the flame photometric and the gravimetric methods (APHA et al., 1976).

3.2.9 Chloride

Although a minor constituent of the earth's crust, chloride in the form of the chloride ion is one of the major inorganic anions in natural water. The primary source of chloride ions are the dissolved products of weathering, emanations from volcanic eruptions, and discharge from deep thermal energy sources (Yaalon, 1967). Minor sources include chloride-containing fertilizers, salts for deicing highways, landfills, and atmospheric pollution by gaseous emissions from industries (Hem, 1970; Matthess, 1982).

According to Davis and DeWiest (1966), most chloride in groundwater comes from the following five sources: chloride from ancient sea water entrapped in sediments; solution of halite and related minerals in evaporite deposits; concentration by evaporation of chloride contributed by rain or snow; solution of fallout from the atmosphere particularly in arid regions; or volcanic water in hot spring systems.

More than three-quarters of the known chlorine content in the topmost 16 km of the earth's crust and in the hydrosphere is dissolved in the ocean as chloride (Matthess, 1982). The ocean is the largest reservoir of soluble salts, and according to Yaalon (1967), chloride constitutes about 56% of the total salts.

Together with other major ions in water, chloride ions may originate from the ocean surface as a spray and may be blown on shore by wind (Gorham, 1961; Yaalon, 1967).

Yaalon (1967) estimated that while ordinary sea winds may carry 1 to 10 kg of sea salt per km^3 of air, storm winds may carry as much as 100 kg of salt particles per km^3. Much of these particles may be precipitated on land as dry fallout or washed out from the atmosphere by rainfall. Rainwater in coastal regions usually contains a substantial concentration of chloride but the concentration generally decreases rapidly inland as terrestrial dust particles become more important nuclei of condensation. The ratio of chloride to other ions in the rain decreases accordingly (Davis and DeWiest, 1966).

Chloride concentrations found in natural water may range from about 0.1 mg/L in Arctic snow to more than 150,000 mg/L in brines (Davis and DeWiest, 1966). The same authors suggest that shallow groundwater in regions of heavy precipitation generally contains less than 30 mg/L chloride while concentrations of 100 mg/L or more are common in arid regions.

All chloride salts are highly soluble and chloride will only be removed from aqueous solution by freezing or evaporation. Chloride is also relatively free from the effects of ion exchange, adsorption, and biological activity (Davis and DeWiest, 1966). The circulation of chloride ions in the hydrologic cycle is largely through physical processes (Hem, 1970).

Three titration method or the gravimetric method may be used in the determination of chloride ion concentration in water (Rainwater and Thatcher, 1960; APHA et al., 1976). The titration methods are used for waters whose chloride concentrations are below 5000 mg/L, while the gravimetric method is recommended for water exceeding this concentration.

3.2.10 Sulphate

Sulphate is not a major constituent of the earth's crust, but is widely distributed in reduced form both in igneous and sedimentary rocks as metallic sulphides. On weathering in contact with water these sulphides yield sulphate ions which may be carried off in surface and/or groundwater (Hem, 1970). The most extensive occurrences of sulphate are in evaporite deposits, especially those in which gypsum or anhydrite are the common rock types. Other sources include the oxidation of sulphur dioxide from volcanic emissions, decomposition of organic materials, and from air pollution (Hem, 1970; Matthess, 1982).

Concentrations of sulphate, ranging between less than 0.2 mg/L and more than 100,000 mg/L (Davis and DeWiest, 1966) are found in natural water. The lowest concentrations are associated with rainwater and snow and the highest with magnesium sulphate brines. Groundwater in igneous and metamorphic terrains will generally contain less than 100 mg/L of sulphate (Davis and DeWiest, 1966).

In humid regions, the upper layers of soils and rocks are thoroughly leached and the soluble products formed by the weathering processes are removed in dilute solutions. This occurs because the amount of water available is large in relation to the supply of solutes. In arid and semi-arid regions, however, the rate and magnitude of leaching is limited because of low annual rainfall received. Ultimately, surface and groundwater in these regions tend to be comparatively higher in dissolved solids of which sulphate may be a predominant anion (Hem, 1970).

The standard methods for the determination of sulphate content of water are the gravimetric and the turbidimetric methods (APHA et al., 1976).

4.0 METHODS OF STUDY

4.1 Isotopes

The field sampling programme was carried out from July to September 1986 and from May to October 1987. The sampling involved collection of surface water and groundwater samples from existing water wells (drilled and hand-dug), springs, rivers, and reservoirs.

Duplicate water samples for deuterium, oxygen-18 and direct tritium analyses were collected using 125 mL rigid plastic bottles. At each site, two clean bottles were thoroughly rinsed with sample water prior to filling with sample water with as little head space as possible. The bottles were then quickly and carefully capped and the samples kept in a cool wooden container in the field vehicle before transferring and storing them in a cool room. A total of 37 pairs were collected with one of the two samples fom each site designated a back-up sample.

A similar procedure was followed when collecting samples for enriched tritium analyses. The samples were collected in 1 L rigid plastic bottles and no back-up samples were taken.

All the samples, excluding the back-up samples, were shipped to the Isotope Laboratory, Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada, where the deuterium, oxygen-18, tritium and enriched tritium contents of the water were determined using standard methods.

During sampling, storage and shipping, maximum care was taken to avoid evaporation and contamination of the samples.

4.2 Chemistry

Water samples for chemical analyses were collected at the same time as the samples for isotopic analyses. The samples were collected in 2 L rigid plastic bottles. After filling with sample water, the bottles were properly capped and kept in a wooden container before storing them in a cool room.

A total of 31 samples were collected and shipped to the Water Quality and Pollution Control Laboratory, Ministry of Water Development, Nairobi, Kenya, where the concentrations of the major ionic species were determined using standard methods.

Electrical conductivity is the only chemical parameter whose measurements were taken in the field. This was accompolished by the use of a pHOX Model 52 conductivity meter.

The types and locations of sampling sites are shown in Table 4.1 and Figure 4.1, respectively.

TABLE 4.1: TYPES AND LOCATIONS OF SAMPLING SITES

Sample number	Location	Type of resource
MM-1	Moyale	surface water (resevoir)
MM-2	Oda	groundwater (borehole)
MM-3	Dabel	groundwater (borehole)
MM-4	Godoma	groundwater (borehole)
MM-5	Sololo Hospital	groundwater (borehole)
MM-6	Walda	groundwater (borehole)
MM-7	Bakuli	groundwater (spring)
MM-8	Sagante	groundwater (borehole)
MM-9	Ura Ura	groundwater (spring)
MM-10	Log-Logo	groundwater (borehole)
MM-11	Ewaso Nyiro	surface water (river)
MM-12	Merti W/Supply	groundwater (borehole)
MM-13	Merti Mission	groundwater (borehole)
MM-14	Garba Tula	groundwater (well)
MM-15	Bisanadi	surface water (river)
MM-16	Ruiri Mission	groundwater (borehole)
MM-17	Ramita's, Ruiri	groundwater (borehole)
MM-18	Njuruta	groundwater (borehole)
MM-19	Maikona School	groundwater (well)
MM-20	Maikona Market	groundwater (well)
MM-21	Kalacha	groundwater (borehole)
MM-22	Dukana	groundwater (borehole)
MM-23	L. Turkana	surface water (lake)
MM-24	Loiyangalani	groundwater (spring)
MM-25	Kargi	groundwater (borehole)
MM-26	Bubisa	groundwater (borehole)
MM-27	Sololo W/Supply	groundwater (borehole)
MM-28	Sololo Mission	groundwater (borehole)
MM-29	Log-Logo	groundwater (borehole)
MM-30	Isiolo	surface water (river)
MM-31	Kibirichia	surface water (stream)
MM-32	Rwarera	groundwater (spring)
MM-33	Muramba	groundwater (borehole)
MM-34	Ewaso Nyiro	surface water (river)
MM-35	Kula Mawe	groundwater (borehole)
MM-36	Kinna	groundwater (borehole)
MM-37	Boji	groundwater (well)

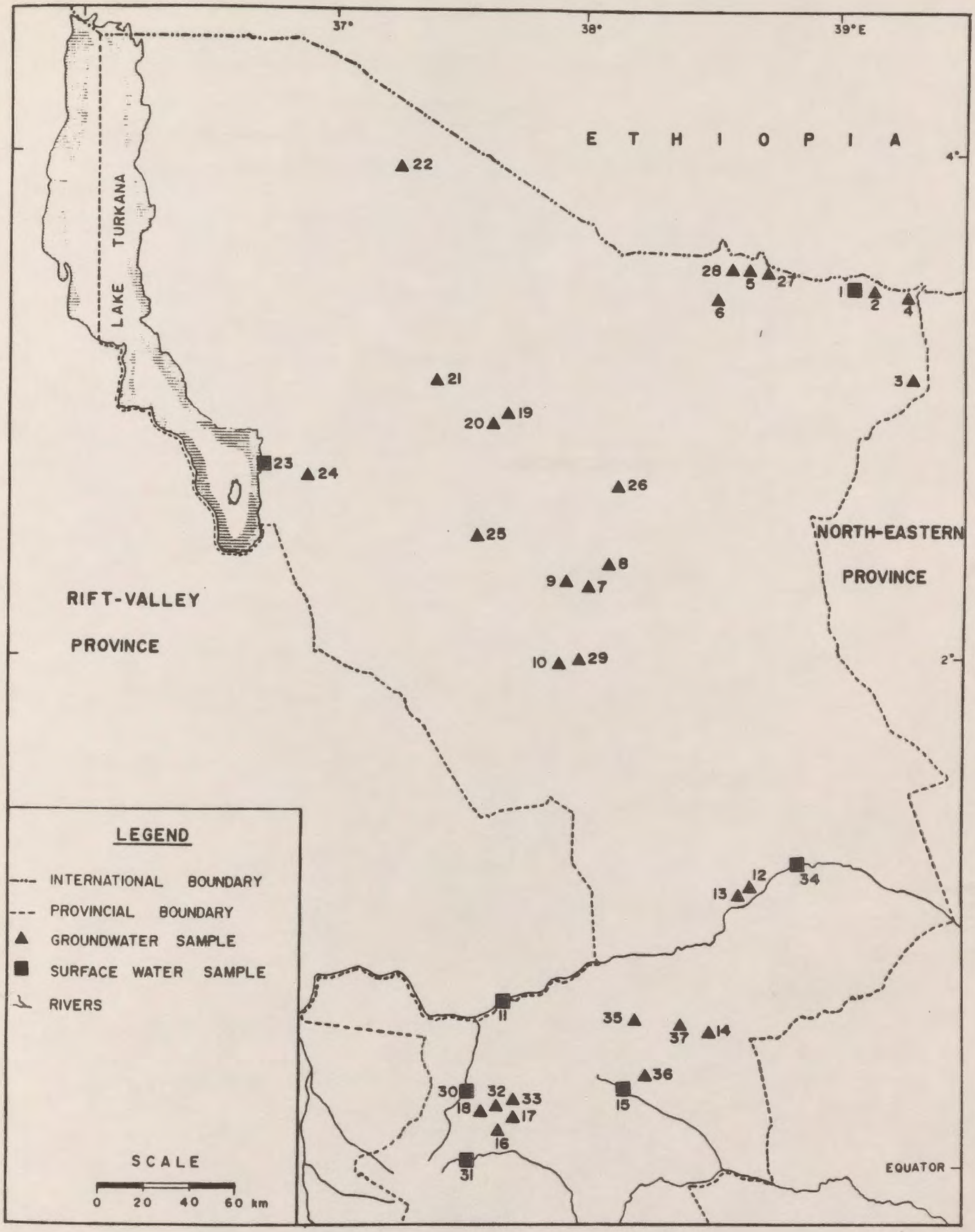

Figure 4.1 Location map of sampling sites.

5.0 RESULTS AND DISCUSSION

5.1.1 Oxygen-18 and Deuterium

The oxygen-18 and deuterium concentrations of the surface water and groundwater of the study area are shown in in Table 5.1. The table also shows the calculated deuterium excess parameter, d, for each sample. The stable isotopic compositions are given in delta (per mil) units relative to Standard Mean Ocean Water (SMOW). The results show that the isotopic composition for groundwater ranges from -4.21‰ to -1.93‰ for $\delta^{18}O$, and from -22.8‰ to -9.9‰ for δD.

Figures 5.1 and 5.2 are the areal distribution maps of $\delta^{18}O$ and δD for groundwater. The lowest δ values are found in the groundwaters from the higher elevation and higher rainfall areas in the south of the study area (Mt. Kenya and the Nyambeni Range) and other isolated mountainous areas in the north (Mt. Marsabit, Mt. Kulal and the Huri Hills).

The higher elevation and higher rainfall areas have groundwaters with more depleted δ values than the low-lying and drier areas to the east of the study area. This trend is demonstrated by comparing the $\delta^{18}O$ values from MM-18 and MM-24, high elevation sites (-4.09 and -4.21‰, respectively) with MM-12 and MM-13, low-lying sites in the Lorian Swamp physiographic region (-2.45 and -1.93‰, respectively). A similar trend is exhibited by the surface

TABLE 5.1: OXYGEN-18 AND DEUTERIUM CONTENT OF THE WATER

Sample number	Sampling date	$\delta^{18}O$ (‰)	δD (‰)	d (‰)
MM-1	23/8/86	+0.46	+2.5	-1.18
MM-2	23/8/86	-3.11	-17.4	+7.48
MM-3	22/8/86	-2.58	-15.6	+5.04
MM-4	22/8/86	-2.98	-16.7	+7.14
MM-5	23/8/86	-2.97	-17.0	+6.76
MM-6	23/8/86	-2.78	-15.8	+6.44
MM-7	20/8/86	-2.90	-16.7	+6.50
MM-8	20/8/86	-3.36	-18.4	+8.48
MM-9	20/8/86	-2.95	-18.0	+5.60
MM-10	26/8/86	-3.44	-20.1	+7.42
MM-11	26/8/86	-1.86	-8.4	+6.48
MM-12	28/8/86	-2.45	-14.5	+5.10
MM-13	28/8/86	-1.93	-9.9	+5.54
MM-14	28/8/86	-3.69	-22.5	+7.02
MM-15	28/8/86	-3.50	-18.8	+9.20
MM-16	29/7/86	-3.15	-19.4	+5.80
MM-17	29/7/86	-3.36	-19.5	+7.38
MM-18	29/7/86	-4.09	-22.6	+10.12
MM-19	10/9/87	-2.11	-15.3	+1.58
MM-20	10/9/87	-2.87	-18.9	+4.06
MM-21	10/9/87	-2.31	-16.8	+1.68
MM-22	11/9/87	-2.88	-15.8	+7.24
MM-23	13/9/87	+6.36	+38.2	-12.68
MM-24	13/9/87	-4.21	-22.3	+11.38
MM-25	13/9/87	-3.76	-21.4	+8.68
MM-26	16/9/87	-3.70	-22.8	+6.80
MM-27	17/9/87	-3.63	-18.5	+10.54
MM-28	18/9/87	-3.20	-17.4	+8.20
MM-29	19/9/87	-3.48	-21.2	+6.64
MM-30	19/9/87	-4.53	-25.4	+10.84
MM-31	2/10/87	-4.60	-24.6	+12.20
MM-32	2/10/87	-4.13	-21.3	+11.74
MM-33	2/10/87	-3.45	-22.4	+5.20
MM-34	27/5/87	-0.63	-7.4	+2.36
MM-35	28/5/87	-3.68	-20.2	+9.24
MM-36	18/6/87	-3.69	-19.8	+9.72
MM-37	18/6/87	-3.70	-21.1	+8.50

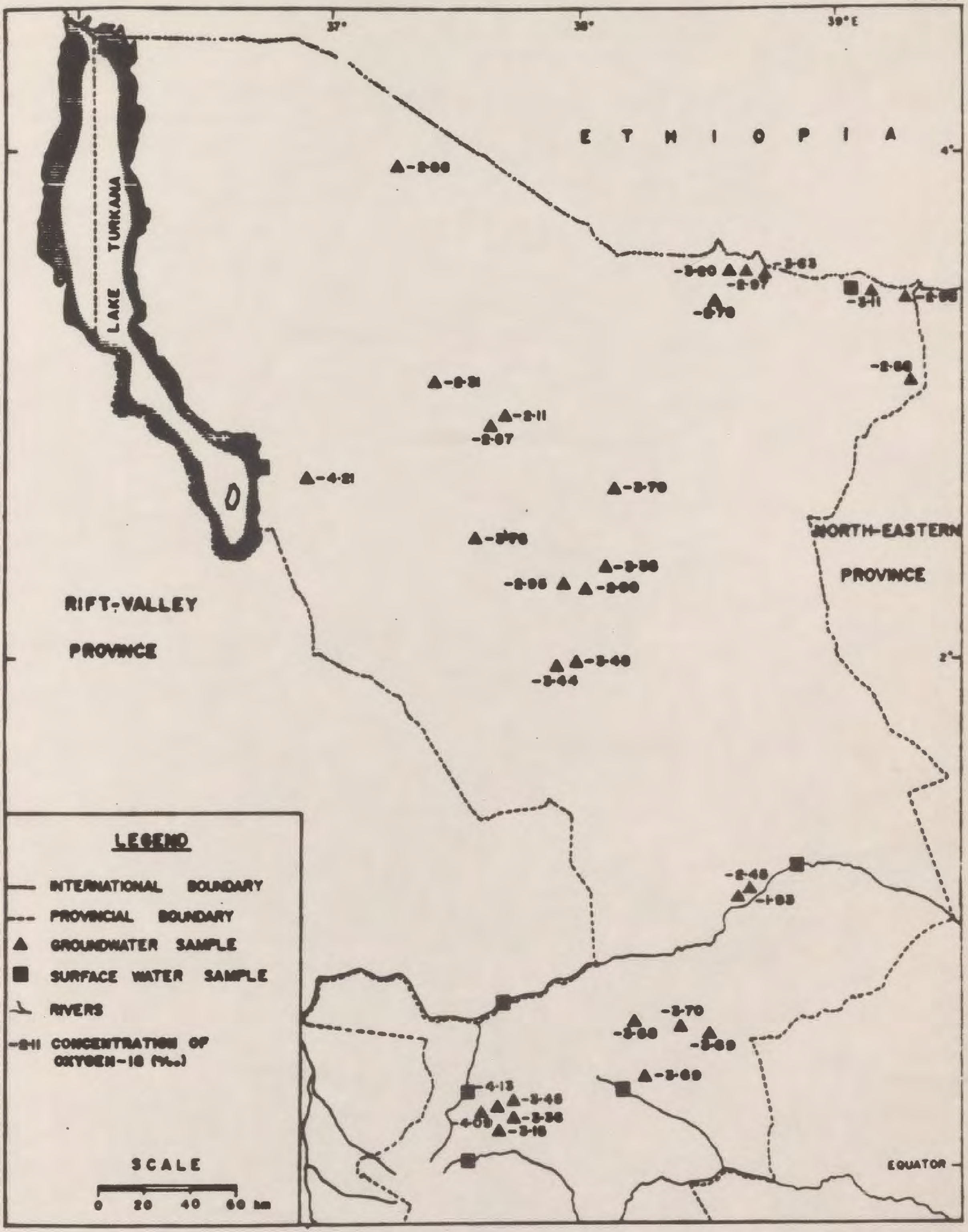

Figure 5.1 Areal distribution map of $\delta^{18}O$ in groundwater.

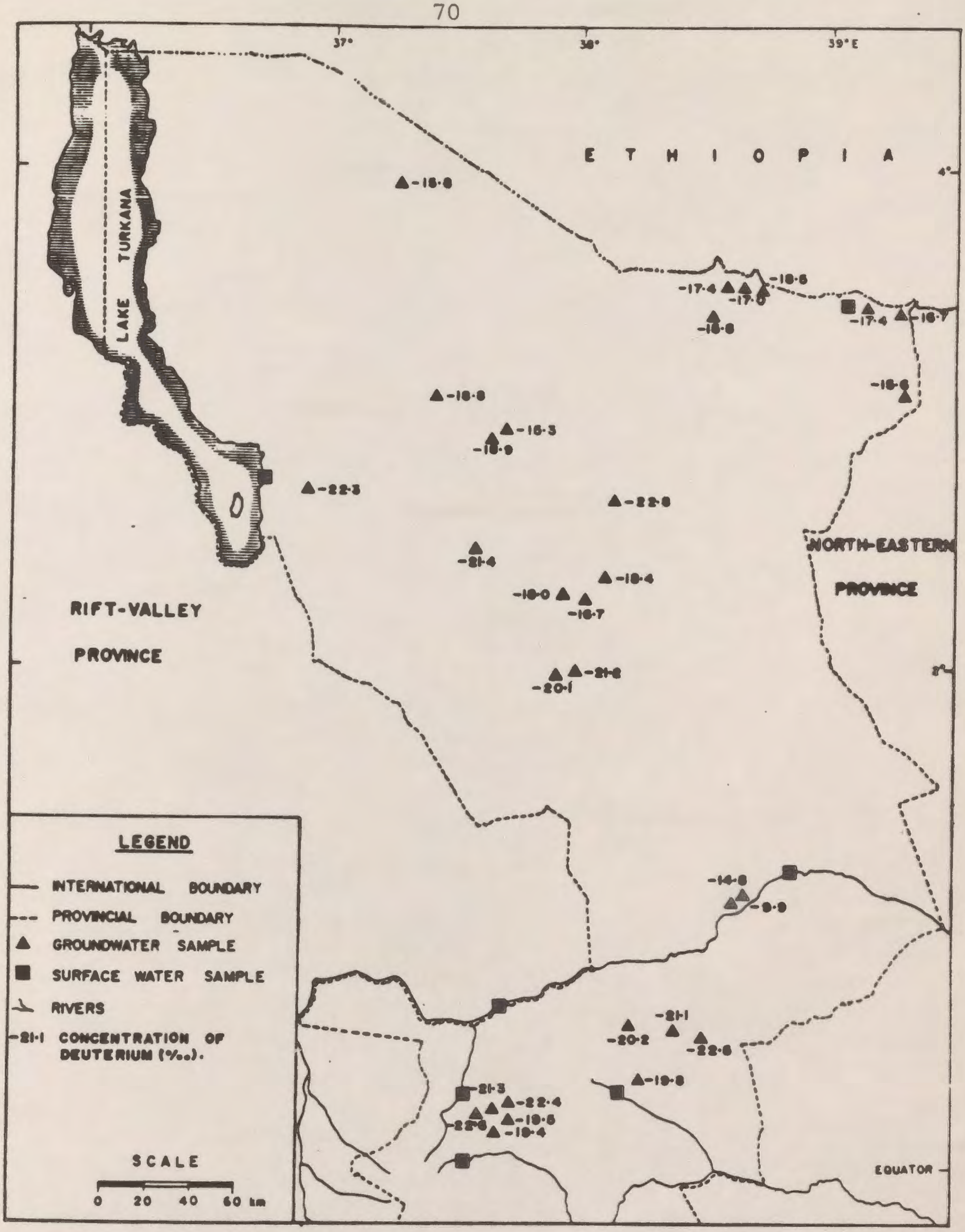

Figure 5.2 Areal distribution map of δD in groundwater.

water as it flows from the higher elevation and higher rainfall areas towards the lower and drier areas as discussed below.

Although there is a general decrease in the δ values for both $\delta^{18}O$ and δD in groundwaters from the higher elevation to lower elevation areas, groundwaters from some sites do not conform to this trend and show more depleted values than other groundwaters from similar environments. The groundwaters show δ values that are conformable to those of groundwaters from higher elevation areas. Best examples of this "anomaly" are the groundwaters from sites MM-25 (Kargi) and MM-26 (Bubisa) whose $\delta^{18}O$ and δD values are -3.76‰ and -21.4‰, and -3.70‰ and -22.8‰, respectively. This strongly suggests distant recharge from precipitation on high elevation ares.

Excluding sites MM-1 (Moyale reservoir) and MM-23 (Lake Turkana), the stable isotopic composition for surface water and groundwater are plotted on the conventional δ diagram (Figure 5.3). The results from MM-1 and MM-23 show values of +0.46‰ and +6.36‰ for $\delta^{18}O$ and +2.5‰ and +38.2‰ for δD, respectively. These values indicate high enrichment of the heavy isotopes by evaporation, which is expected for surface water bodies in arid areas.

All the groundwater samples, except those from sites MM-18, MM-24, MM-27 and MM-32 plot below the global meteoric water line, $\delta D = 8\delta^{18}O + 10$. The groundwater

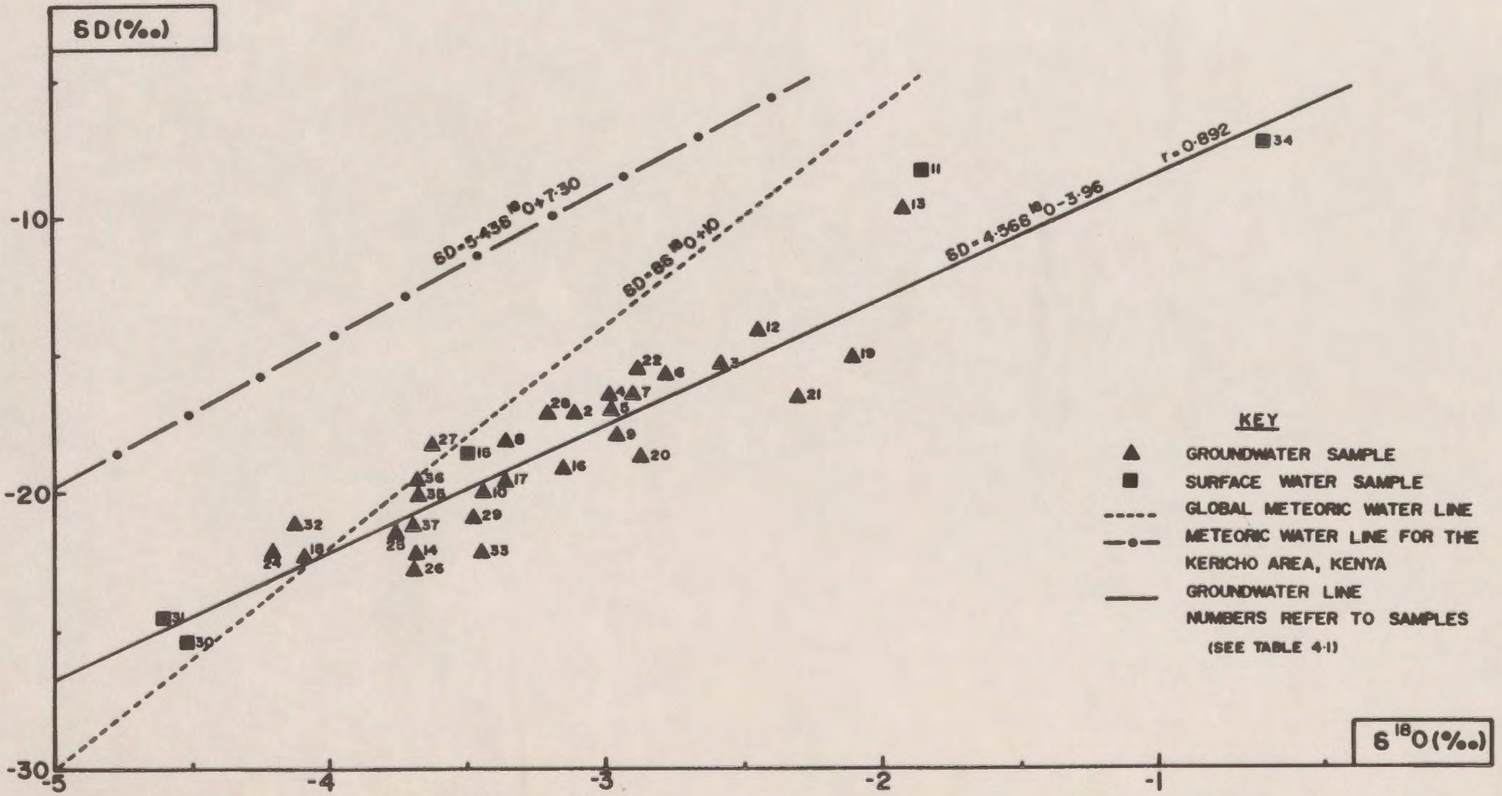

Figure 5.3 Plot of $\delta^{18}O$ versus δD for surface water and groundwater.

samples have d values of less than +10 which indicate that evaporation occurred before the groundwater was recharged. According to Gat (1971), the enrichment of the heavy isotopes of a water molecule during evaporation proceeds along a line of slope less than 8 on the δ diagram and that the isotopic composition of partially evaporated surface waters have relatively high δ values and low d values. The results of this study are consistent with these tendencies. The δD versus $\delta^{18}O$ line for the groundwater in this study is:

$$\delta D = 4.56\delta^{18}O - 3.96$$

with a correlation coefficient of +0.892. The slope of this line indicates evaporated water.

Since there is no IAEA-WMO station for collecting precipitation samples for isotopic analyses within the study area, nearby stations were examined. The nearest stations are Entebbe, Uganda; Dar es Salaam, Tanzania; and Kericho, Kenya. Figures 5.4 to 5.6 are plots of monthly variations of tritium and oxygen-18 in precipitation at Entebbe, Dar es Salaam, and Kericho, respectively.

The following observations can be made about oxygen-18 from these plots:

(a) Most rainfall episodes have $\delta^{18}O$ values between -4‰ and 0‰.

(b) More depleted $\delta^{18}O$ values are associated with the two rainfall seasons (March to May and October to

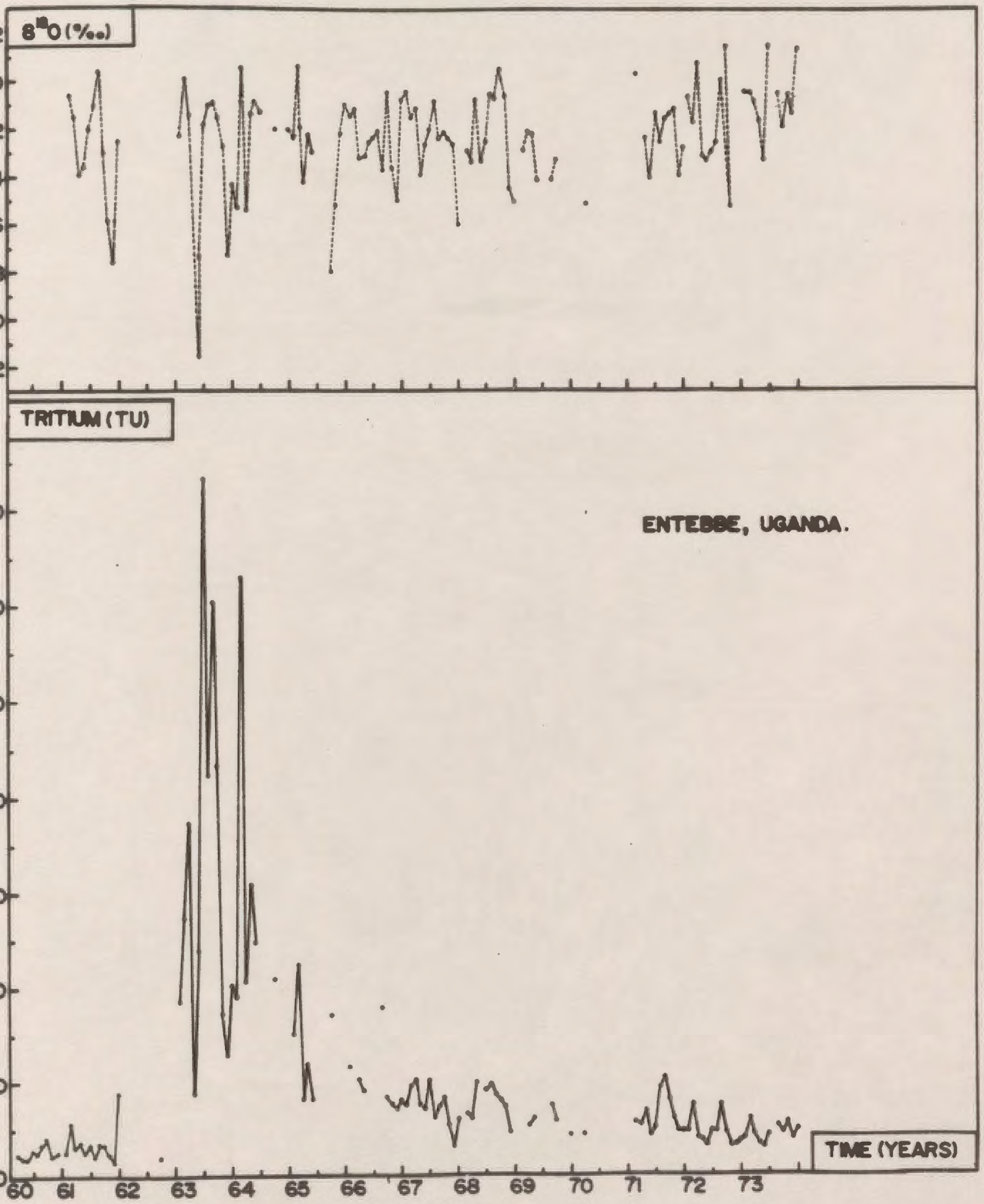

Figure 5.4 Plot of monthly variations of tritium and $\delta^{18}O$ in precipitation at Entebbe, Uganda, from 1969-73. (Source of data: IAEA, 1969, 1970, 1971, 1973, 1975, 1979).

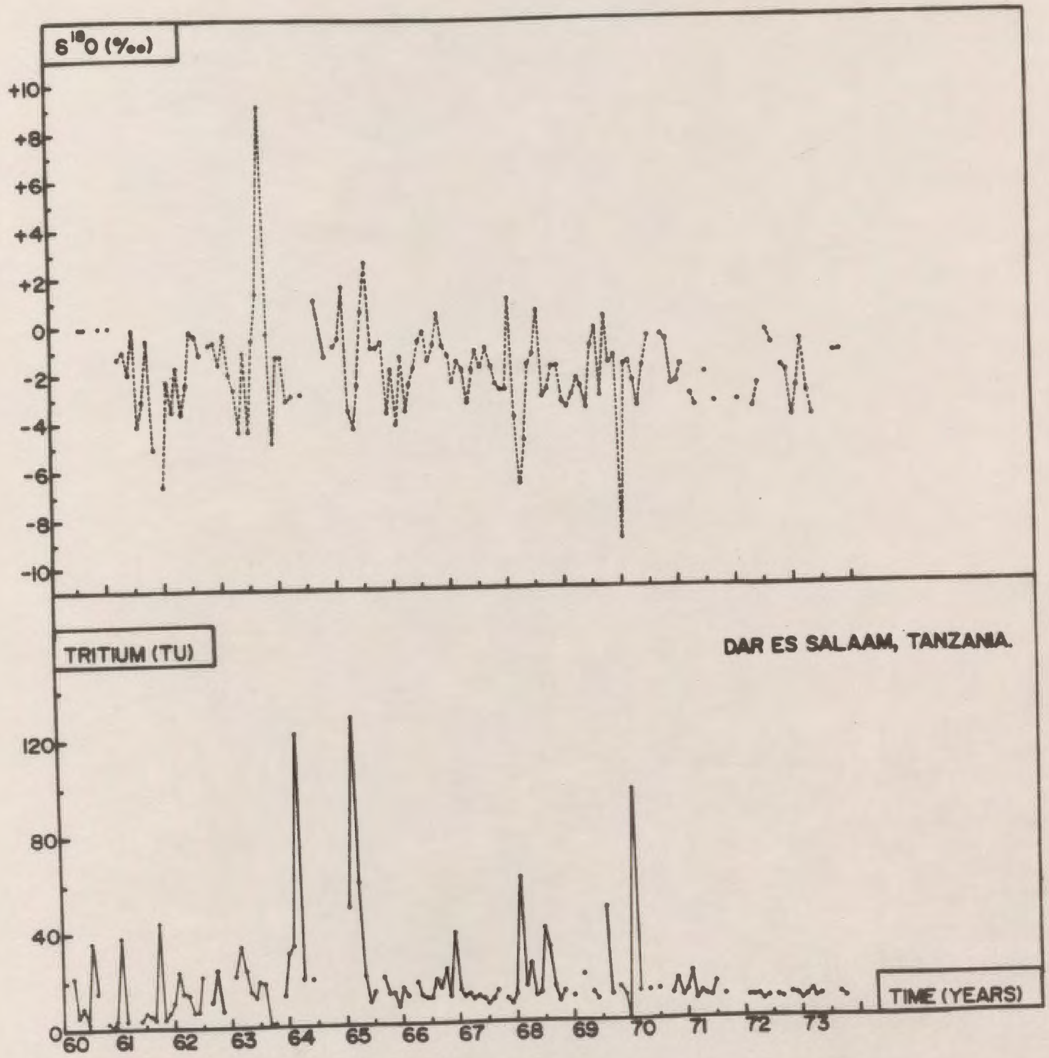

Figure 5.5 Plot of monthly variations of tritium and $\delta^{18}O$ in precipitation at Dar es Salaam, Tanzania, from 1969-73. (Source of data: IAEA, 1969, 1970, 1971, 1973, 1975, 1979).

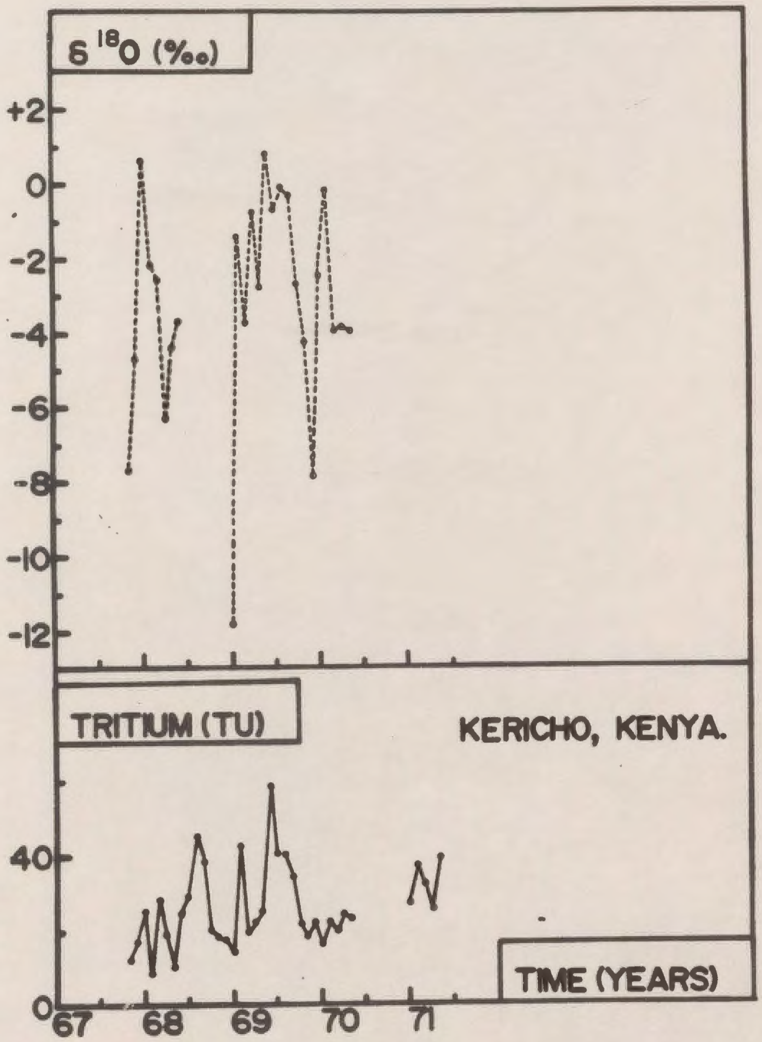

Figure 5.6 Plot of monthly variations of tritium and $\delta^{18}O$ in precipitation at Kericho, Kenya, from 1967-71. (Source of data: IAEA, 1971, 1973, 1975).

December) in East Africa.

(c) More enriched $\delta^{18}O$ values are associated with rains that occur during the dry seasons (January to February and June to September). The enrichment of oxygen-18 in rainfall could be the result of evaporation and exchange of raindrops with the dry atmospheric air.

The meteoric water line for the Kericho station based on 1967-71 precipitation samples is:

$$\delta D = 5.43\delta^{18}O + 7.30$$

and is plotted in Figure 5.3. This line has a lower slope and d value than the global meteoric water line. This suggests that precipitation is partially evaporated before reaching the ground surface. This observation is consistent with the finding of Cerling and Hay (1977) that rain partially evaporates as it falls through the dry East African atmosphere.

Since the $\delta^{18}O$ values of groundwater lie between -4.21‰ and -1.93‰ and those of most precipitation between -4‰ and 0‰, it can be concluded that precipitation is the major source of the groundwater recharge in the study area. The differences in δ values for groundwater between different sites can be attributed to differences in altitude and temperature of the recharge areas, the season and the amount of rainfall in the recharge areas as well as at specific sites. Proximity of groundwater to seasonal streams also dictates the ultimate isotopic composition of the groundwater.

Besides the samples from sites MM-1 and MM-23, which are reservoir and lake waters respectively, the stable isotopic composition of surface water ranges from -4.60‰ to -0.63‰ for $\delta^{18}O$, and from -25.4‰ to -7.4‰ for δD. The following two observations can be made about the stable isotopic composition of surface water:

(a) Surface water that is more depleted in heavy isotopes occurs in the source regions on the mountain slopes. Samples from sites MM-30 and MM-31, on the northern slopes of Mt. Kenya, are good examples.

(b) As the surface water flows away from the source regions, it is progressively enriched in heavy isotopes by evaporation associated with the high temperatures found at lower elevations. The samples collected from sites MM-11 and MM-34 in the Ewaso Nyiro River, clearly demonstrate this trend. The isotopic compositions for sites MM-11 and MM-34, separated by about 150 km, are -1.86 and -0.63‰ for $\delta^{18}O$, and -8.4 and -7.4‰ for δD, respectively. Evaporation has been cited by Matheson (1971) as a major factor contributing to the loss of surface flow of the Ewaso Nyiro River downstream of Archer's Post.

5.1.2 Tritium

Monthly variations of tritium and oxygen-18 in precipitation at Entebbe and Dar es Salaam stations are shown in Figures 5.4 and 5.5, respectively. The following can be said about tritium:

(a) Peak levels of tritium in precipitation in East Africa occurred between 1963 and 1965. This sharp increase in tritium in precipitation was the result of tritium input in the atmosphere from nuclear testing activities. The maximum recorded tritium values are 292 TU for the Entebbe station and 126.9 TU for the Dar es Salaam station.

(b) High tritium values are associated with precipitation that occurs during the dry seasons (January to February and June to September). This could be due to the absence of moist maritime (monsoon) winds during these seasons which would otherwise impart a dilution effect on the continental tritium.

(c) Compared to Entebbe, the precipitation at the Dar es Salaam station shows lower tritium levels. This could be attributed to the coastal location of Dar es Salaam in which the continental tritium is diluted by the moist maritime winds.

(d) Tritium fallout in precipitation in East Africa during early 1970's was about 20 TU. The current tritium fallout in precipitation is less than 20 TU.

The tritium levels in groundwater of the study area (Table 5.2 and Figure 5.7) range from less than 0.8 TU to 32 TU. High tritium levels are found in boreholes located in weathered Basement System Rocks and along seasonal streams. This is evident from the groundwater collected from sites MM-3, MM-4, MM-12 and MM-13 whose tritium concentrations are 32, 29, 22 and 11 TU, respectively. Another group of boreholes with high tritium levels occurs in topographically high areas covered with weathered lava and pyroclastic materials. This group includes groundwater from sites MM-7 (23 TU) and MM-9 (15 TU) on the slopes of Mt. Marsabit. High tritium levels suggest high permeabilities in the soils and rocks and that groundwater was recharged relatively recently.

Low tritium levels are associated with groundwater struck in unweathered Basement System Rocks and volcanic lava (basalts) where groundwater can only be found in fractures (secondary porosity). Low tritium levels in groundwater could indicate mixing of old (pre-bomb) water with recent (post-bomb) water or long flow paths (hence long residence time) from the recharge areas.

The average annual natural tritium level in precipitation before the inception of thermonuclear tests in 1952 is estimated to have been between 5 and 20 TU (Payne, 1972). According to Fontes (1980), pre-nuclear tritium levels in groundwater when collected for decay are

TABLE 5.2: TRITIUM CONTENT OF THE WATER

Sample number	Tritium (TU)	Enriched Tritium (TU)
MM-1	<6+/-7	
MM-2	<6+/-7	
MM-3	32+/-10	
MM-4	29+/-7	
MM-5	<6+/-7	3.3+/-0.6
MM-6	8+/-7	2.1+/-0.7
MM-7	23+/-7	
MM-8	<6+/-7	1.0+/-0.6
MM-9	15+/-7	
MM-10	6+/-7	
MM-11	7+/-7	
MM-12	22+/-7	
MM-13	11+/-7	
MM-14	<6+/-7	
MM-15	17+/-7	
MM-16	<6+/-7	
MM-17	13+/-7	
MM-18	7+/-7	
MM-19		3.0+/-0.6
MM-20	<6+/-8	
MM-21		<0.8+/-0.6
MM-22		2.2+/-0.7
MM-23	10+/-8	
MM-24	<6+/-8	
MM-25		<0.8+/-0.6
MM-26	<6+/-8	
MM-27	<6+/-8	
MM-28	<6+/-8	
MM-29		1.5+/-0.6
MM-30	<6+/-8	
MM-31		2.8+/-0.6
MM-32		<0.8+/-0.6
MM-33		<0.8+/-0.6
MM-34	<6+/-8	
MM-35	<6+/-8	
MM-36	<6+/-8	
MM-37	<6+/-8	

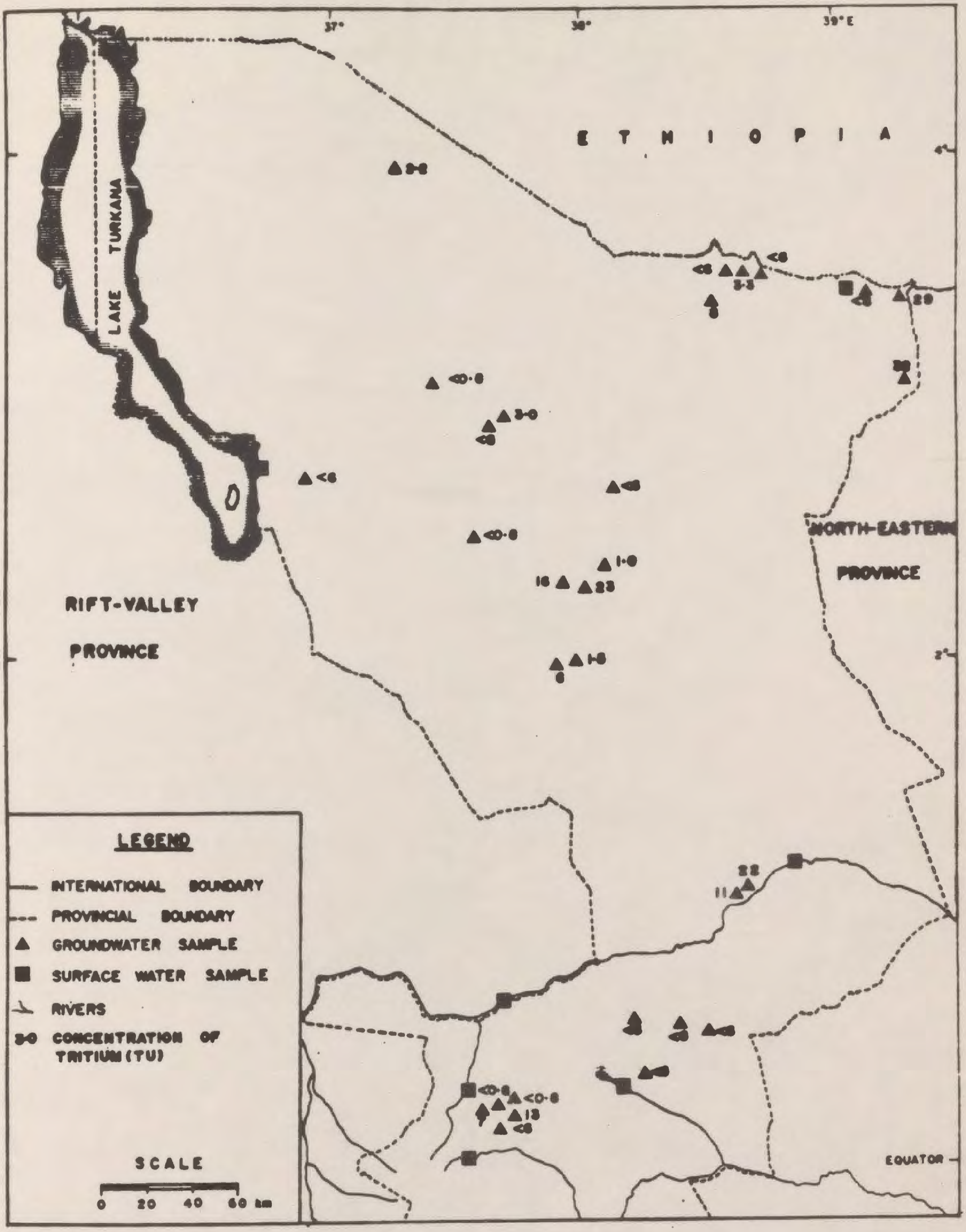

Figure 5.7 Areal distribution map of tritium in groundwater.

everywhere below 5 TU. Groundwater that was recharged before 1952 by precipitation that had a tritium level of 5 TU should now have less than 1.3 TU. Therefore, all groundwaters with more than 1.3 TU should contain a component of recharge from precipitation during the last 35 years. A similar study was conducted in the Kalahari Desert by Verhagen et al. (1974) who concluded that all the groundwaters of the area with more than 2 TU must have been recharged after 1952.

From these arguments, therefore, the groundwaters of the study area could be classified into two groups depending on their tritium levels. The first group consists of groundwater with measurable tritium but not more than 1.3 TU. This tritium level indicates that either the groundwater is more than 35 years old and thus has slow recharge from precipitation or, the groundwater is a mixture of old water with small amounts of recent water. This group includes groundwater from sites MM-8 (Sagante), MM-21 (Kalacha), MM-25 (Kargi), MM-32 (Rwarera), and MM-33 (Muramba).

Secondly, groundwater with a tritium level of more than 1.3 TU indicates that the groundwater contains recent water. Included in this group are groundwaters from sites MM-3 (Dabel), MM-4 (Godoma), MM-5 (Sololo), MM-6 (Walda), MM-7 (Bakuli), MM-9 (Ura Ura), MM-10 and MM-29 (Log-Logo), MM-12 and MM-13 (Merti), MM-17 (Ruiri), MM-18 (Njuruta), MM-19 (Maikona), MM-22 (Dukana),

Groundwaters with tritium levels given as less than 6 (<6) TU (Table 5.2) were assumed to have levels of less than 1.3 TU in this classification. This include groundwater from sites MM-2 (Oda), MM-14 (Garba Tula), MM-16 (Ruiri), MM-20 (Maikona), MM-24 (Loiyangalani), MM-26 (Bubisa), MM-27 and (MM-28 Sololo), MM-35 (Kula Mawe), MM-36 (Kinna), and MM-37 (Boji).

Since tritium levels in seasonal streams are similar to those shown by the groundwater from boreholes near them, it is evident that the seasonal streams contribute to the groundwater recharge. This is well illustrated by comparing the groundwater from sites MM-12 (22 TU) and MM-13 (11 TU), which lie in the flood plain of the Ewaso Nyiro River, with the groundwater from sites MM-14 (<6 TU), MM-35 (<6 TU) and MM-37 (<6 TU) located in the Kula Mawe-Garba Tula area about 2 km away from any seasonal stream.

This hypothesis is also supported by the evidence of the stable isotopic compositions of the groundwater from boreholes around Merti (sites MM-12 and MM-13) which are comparable to those of the surface water from the Ewaso Nyiro River. Sites MM-12 and MM-13 have δ values of -2.45 and -1.93‰ for $\delta^{18}O$ and -14.5 and -9.9‰ for δD, respectively. Upstream and downstream of Merti, the river water has δ values of -1.86 and -0.63‰ for $\delta^{18}O$, and -8.4

and -7.4‰ for δD, respectively. The enriched δ values for the groundwater could be the result of evaporated river water.

This hypothesis is further supported by the occurrence of a high number of hand-dug wells used by the local communities as sources of domestic and livestock water supplies. Such wells, some of which may have permanent supplies, are found only along the seasonal streams and channels. This hypothesis correlates with the suggestion made by Bake (1984) that under and beside the seasonal streams (laggas) in southwestern Marsabit district, there are usually unconfined and often perched aquifers, seasonally or even episodically recharged from the runoff in these streams.

5.2 Chemistry

The concentrations (meq/L) of the major ions: calcium, magnesium, sodium, chloride, sulphate, and bicarbonate; in surface water and groundwater, are shown in Table 5.3. The analyses for these ions were conducted at the Water Quality and Pollution Control Laboratory of the Ministry of Water Development, Nairobi, Kenya, by using the standard methods (except for the bicarbonate ion). The results were reported in milligrams/litre (mg/L) as shown in the Appendix. These results were then converted into milliequivalents/litre (meq/L) by dividing the

TABLE 5.3: CONCENTRATION OF THE MAJOR IONS IN THE WATER (meq/L)

Sample number	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}
MM-1	3.59	3.46	5.83	2.40	3.21	5.19
MM-2	5.99	4.36	7.83	9.03	2.77	7.27
MM-3	0.17	8.47	0.74	1.24	0.37	7.11
MM-4	11.98	27.97	11.96	22.71	13.12	8.75
MM-5	9.48	4.20	13.92	15.23	5.85	7.27
MM-6	1.95	5.27	3.61	2.76	3.06	12.27
MM-7	0.68	1.65	0.52	0.87	0.04	3.08
MM-8	3.14	5.02	0.91	1.83	0.06	7.95
MM-9	0.95	2.39	1.04	0.62	0.07	4.12
MM-10	0.40	2.80	4.22	1.72	0.23	6.23
MM-11	0.14	0.39	0.85	0.25	0.01	1.40
MM-12	0.05	0.14	8.96	1.52	0.62	7.51
MM-13	0.06	0.08	10.0	1.30	0.60	7.27
MM-14	0.38	7.16	9.57	4.63	0.83	14.79
MM-15	1.15	1.89	2.13	0.28	0.09	6.07
MM-19	0.05	0.18	12.61	3.55	1.04	8.07
MM-20	0.47	4.20	20.44	12.27	1.73	9.55
MM-21	0.75	4.44	6.09	3.55	2.17	3.34
MM-22	2.50	3.29	2.13	0.62	0.29	3.40
MM-23	0.07	0.30	43.93	14.41	0.62	23.54
MM-25	0.43	2.71	3.83	27.64	6.37	14.11
MM-26	1.50	10.53	17.83	19.18	4.21	10.39
MM-27	3.34	7.98	7.39	6.49	5.04	9.11
MM-28	5.29	2.88	4.13	3.86	8.43	5.23
MM-29	2.35	6.01	3.18	3.81	0.98	5.97
MM-3I	0.07	0.12	0.48	0.08	0.20	0.72
MM-32	0.19	1.32	1.83	0.34	0.08	5.85
MM-33	0.85	1.32	1.26	0.31	0.04	2.12
MM-35	3.94	11.76	1.91	2.23	0.79	14.91
MM-36	0.05	5.18	0.52	1.18	0.12	9.91
MM-37	1.60	8.47	6.11	2.23	0.37	14.99

concentration in mg/L of each ion by its respective molecular weight.

The concentrations of the bicarbonate ion were determined by the calculation method from the results of the total alkalinity (as calcium carbonate). The concentrations of the sodium ion in samples MM-11, MM-35 and MM-37 were also done by the calculation method. Potassium ion was not included in this study in view of the low concentrations reported. It was assumed that the low concentrations of the ion in groundwater do not affect the water chemistry on any significant level.

Table 5.4 shows the pH, electrical conductivity (EC), and the total dissolved solids (TDS) of the surface water and groundwater. The values in groundwater range from 7.2 to 8.7, 245 to 5,590 μS/cm and from 148 to 3,354 mg/L for pH, EC and TDS, respectively. The pH values show the groundwater is alkaline.

The relationship between EC and TDS is shown in Figure 5.8. These two geochemical parameters are linearly correlated and the relationship can be represented by the regression line

$$EC = 1.67TDS + 0.54$$

with a correlation coefficient +1.0 (+0.999) indicating a very strong positive correlation. The best approximate of the dissolved solids in groundwater is, therefore,

$$TDS = 0.67EC$$

TABLE 5.4: pH, EC AND TDS OF THE WATER

Sample number	pH	EC (µS/cm)	TDS (mg/L)
MM-1	8.2	990	595
MM-2	8.7	1,925	1,154
MM-3	8.1	815	488
MM-4	7.7	3,850	2,309
MM-5	8.2	2,665	1,598
MM-6	8.1	1,450	870
MM-7	8.2	370	222
MM-8	7.6	860	515
MM-9	8.2	445	266
MM-10	8.1	800	480
MM-11	7.7	185	112
MM-12	8.6	930	560
MM-13	8.7	890	533
MM-14	7.9	1,780	1,066
MM-15	8.5	550	329
MM-19	7.4	2,990	1,794
MM-20	7.5	2,860	1,716
MM-21	7.3	1,430	858
MM-22	7.4	845	507
MM-23	9.0	4,290	2,574
MM-25	7.3	5,590	3,354
MM-26	7.7	3,640	2,184
MM-27	7.8	2,080	1,248
MM-28	7.3	2,730	1,638
MM-29	7.2	2,210	1,326
MM-31	6.9	70	43
MM-32	7.6	565	338
MM-33	8.2	245	148
MM-35	8.4	1,665	998
MM-36	8.7	1,075	645
MM-37	8.2	1,410	845

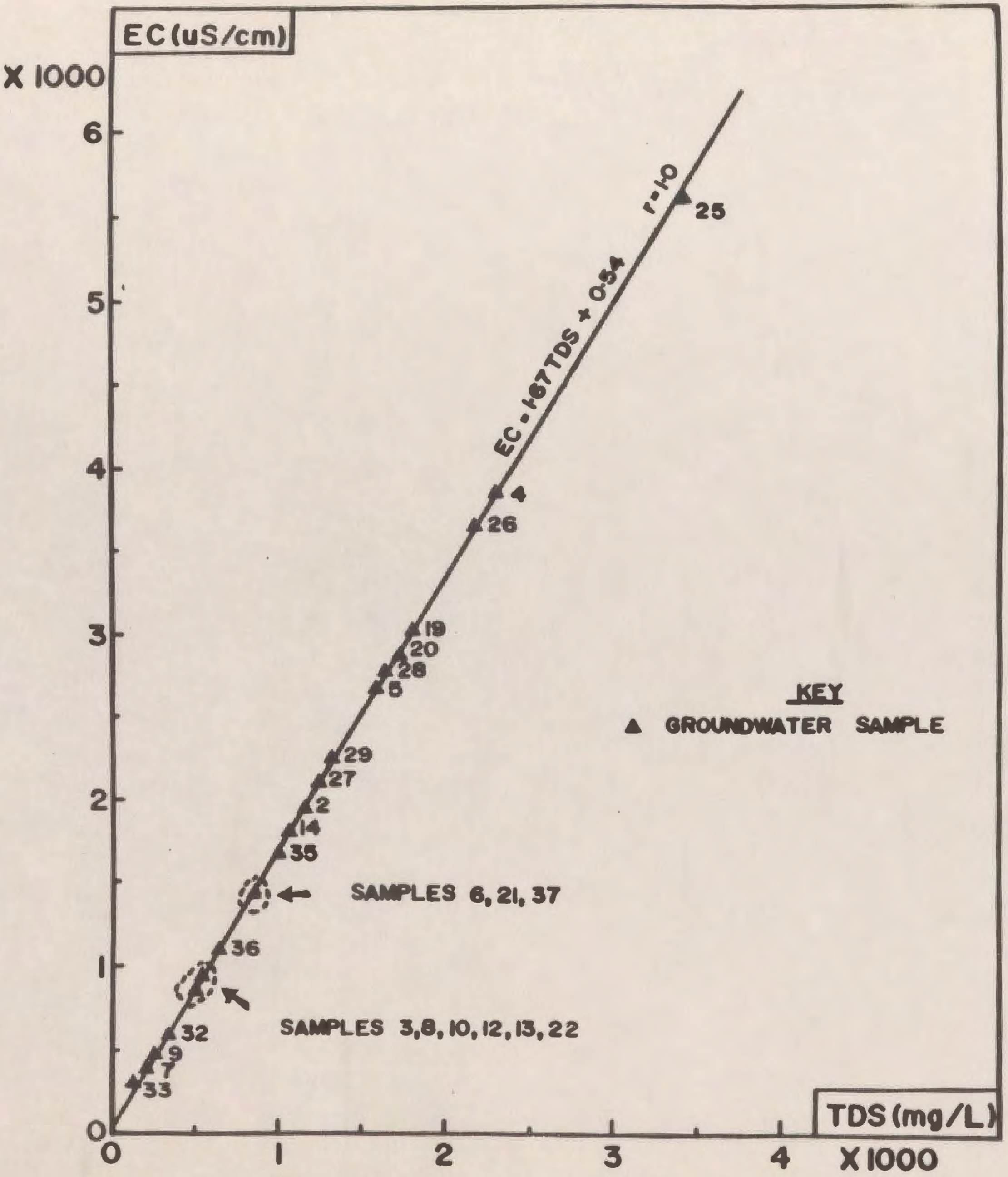

Figure 5.8 Relationship between electrical conductivity and total dissolved solids for groundwater.

with the conversion factor, 0.67, lying within the range (0.55 to 0.75) proposed by Hem (1970).

Table 5.5 shows a classification of groundwater based on TDS as first proposed by Davis and DeWiest (1966) and on the dominant ions (Kurlov formula) as suggested by Zaporozec (1972). The Kurlov formula attempts to characterize groundwater on the basis of the dominant ions. An outstanding feature from Table 5.5 is the dominancy of magnesiun among the cations. Magnesium is the dominant cation in samples MM-3, MM-4, MM-6, MM-7, MM-8, MM-9, MM-22, MM-27, MM-29, MM-33, MM-35, MM-36 and MM-37 which account for 50% of all the samples analysed. The concentration ranges from 1 to 340 mg/L.

Sodium is equally important being the dominant cation in 46% of the samples. These samples are MM-2, MM-5, MM-10, MM-12, MM-13, MM-14, MM-19, MM-20, MM-21, MM-25, MM-26 and MM-32. The concentration of the ion ranges from 12 mg/L to 320 mg/L. Calcium is the dominant cation in only one sample (MM-28) and its concentration ranges from 1 to 240 mg/L.

Among the anions, bicarbonate is the dominant ion in 69% of the total samples. These samples include MM-3, MM-6, MM-7, MM-8, MM-9, MM-10, MM-12, MM-13, MM-14, MM-19, MM-22, MM-27, MM-29, MM-32, MM-33, MM-35, MM-36 and MM-37. The concentration ranges from 129 to 914 mg/L. Bicarbonate is followed by chloride (29%) and sulphate (4%). The

TABLE 5.5: CLASSIFICATION OF GROUNDWATER BASED ON TOTAL DISSOLVED SOLIDS AND ON THE DOMINANT IONS

Sample number	TDS (mg/L)	Category	Dominant ions
MM-2	1,154	Brackish	Na^+, Ca^{2+}; Cl^-, HCO_3^-
MM-3	488	Fresh	Mg^{2+}; HCO_3^-
MM-4	2,309	Brackish	Mg^{2+}; Cl^-, SO_4^{2-}
MM-5	1,598	Brackish	Na^+, Ca^{2+}; Cl^-, HCO_3^-
MM-6	870	Fresh	Mg^{2+}, Na^+; HCO_3^-
MM-7	222	Fresh	Mg^{2+}; HCO_3^-
MM-8	515	Fresh	Mg^{2+}, Ca^{2+}; HCO_3^-
MM-9	266	Fresh	Mg^{2+}; HCO_3^-
MM-10	480	Fresh	Na^+, Mg^{2+}; HCO_3^-
MM-12	560	Fresh	Na^+; HCO_3^-
MM-13	533	Fresh	Na^+; HCO_3^-
MM-14	1,066	Brackish	Na^+, Mg^{2+}; HCO_3^-
MM-19	1,794	Brackish	Na^+; HCO_3^-, Cl^-
MM-20	1,716	Brackish	Na^+; Cl^-, HCO_3^-
MM-21	858	Fresh	Na^+, Mg^{2+}; Cl^-, HCO_3^-
MM-22	507	Fresh	Mg^{2+}, Ca^{2+}, Na^+; HCO_3^-
MM-25	3,354	Brackish	Na^+, Mg^{2+}; Cl^-, HCO_3^-
MM-26	2,184	Brackish	Na^+, Mg^{2+}; Cl^-, HCO_3^-
MM-27	1,248	Brackish	Mg^{2+}, Na^+; HCO_3^-, Cl^-
MM-28	1,638	Brackish	Ca^{2+}, Na^+; SO_4^{2-}, HCO_3^-
MM-29	1,326	Brackish	Mg^{2+}, Na^+; HCO_3^-, Cl^-
MM-32	338	Fresh	Na^+; HCO_3^-
MM-33	148	Fresh	Mg^{2+}, Na^+; HCO_3^-
MM-35	998	Fresh	Mg^{2+}; HCO_3^-
MM-36	645	Fresh	Mg^{2+}; HCO_3^-
MM-37	845	Fresh	Mg^{2+}, Na^+; HCO_3^-

(After Davis and DeWiest, 1966; Zaporozec, 1972).

samples in which chloride is the dominant anion are MM-2, MM-4, MM-5, MM-20, MM-21, MM-25 and MM-26 while sulphate is sample MM-28. The concentrations of the chloride and sulphate ions range from 11 to 980 mg/L and 2 to 630 mg/L, respectively.

Figure 5.9 is a plot of Stiff diagrams for groundwater. Stiff diagrams allow a visual comparison of the water chemistry between different waters. From Figure 5.9 and Table 5.5, the following observations are discernable:

(a) In some locations, groundwater from different sources (boreholes, wells and springs) and in close proximity show similar water chemistry. Similarities exist between different groundwater sources in the following areas:

  (i) Around Mt. Marsabit, where groundwater was collected from two springs (Bakuli and Ura Ura) and one borehole. These groundwater sources are represented by samples MM-7, MM-8, and MM-9. The groundwater is mainly magnesium bicarbonate in composition.

  (ii) On the northeastern slopes of Mt. Kenya and the northern slopes of the Nyambeni Range. The groundwater was collected from a spring (MM-32), a well (MM-37) and from four boreholes (MM-14, MM-33, MM-35 and MM-36).

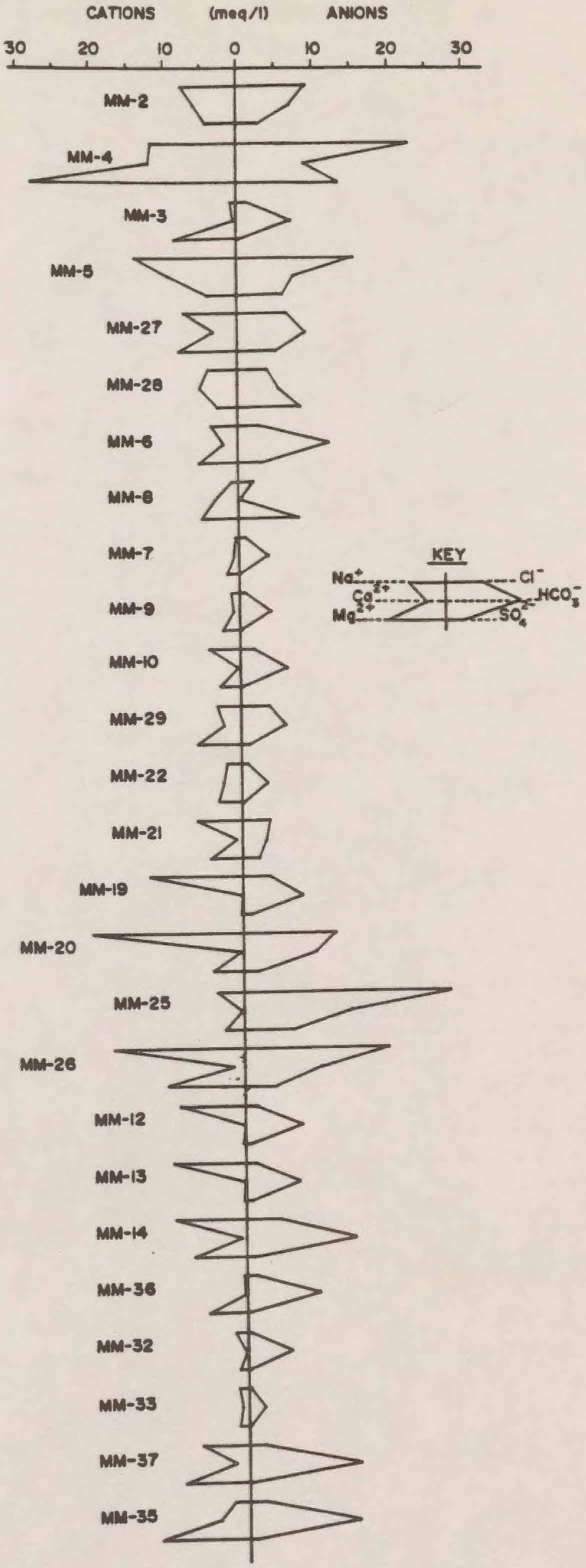

Figure 5.9 Plot of Stiff-diagrams for groundwater

The groundwaters from these sources are basically similar and predominantly magnesium bicarbonate or sodium-magnesium bicarbonate in composition. However, the TDS vary from source to source and generally show a gradual increase from the higher elevation and relativelly higher rainfall area at site MM-33 (148 mg/L) to lower elevation and lower rainfall area around site MM-14 (1,066 mg/L).

(iii) Around Merti, where groundwater was collected from two boreholes (sites MM-12 and MM-13). The groundwater for this area is mainly sodium bicarbonate. The TDS values are 560 and 533 mg/L for sample MM-12 and MM-13, respectively. Considering the semi-arid type of climate in this area, these values are "anomalously low". Other boreholes drilled in the vicinity (Sericho) have struck brackish water (Swarzenski and Mundorff, 1977; Ministry of Water Development, 1985). It is the opinion of the author that the boreholes at Merti are currently being recharged from the surface flow of the Ewaso Nyiro River. The EC and TDS values of the river at Archer's Post are 185 uS/cm and 112 mg/L, respectively. Downstream of, and at Merti, these values should be higher because of evaporation. Unfortunately, the river was not sampled at Merti.

(iv) At Kargi (MM-25) and Bubisa (MM-26), where although the boreholes are located to the north and northwest of Mt. Marsabit and possibly not hydrogeologically interconnected, show similar groundwater chemistry. The groundwater is mainly sodium-magnesium chloride-bicarbonate in composition.

(b) In other locations, groundwater from sources in close proximity to one another show differences in their water chemistry. Differences are observed in the following areas:

(i) Around Sololo, where groundwater was collected from three boreholes (sites MM-5, MM-27 and MM-28) all located within a radius of approximately 0.5 km. Sites MM-5 and MM-28 are about 100 m apart. Although the groundwaters from these three boreholes are brackish, they show differences in terms of the dissolved ions. Groundwater from site MM-05 is principally sodium chloride while site MM-28 has calcium sulphate water. Magnesium carbonate groundwater is found in site MM-27. The variations in groundwater chemistry could be the result of the differences in the chemical composition of the metamorphic rocks of the Basement System Rocks in the Sololo area.

(ii) In the Log-Logo area, the groundwater from the two boreholes sampled, sites MM-10 and MM-29 (about 1 km apart) show differences in TDS levels and chloride ion concentration. The groundwater is mainly sodium or magnesium bicarbonate and a possible origin is around Mt. Marsabit. Ndombi (1983) indicated that these boreholes are located on faults. If this were the case, and the faults were not interconnected, then the differences would be the result of different flow paths from the recharge area. Each fault would behave as a separate "aquifer".

(iii) Further differences in chemistry are shown by the groundwater from the boreholes (sites MM-2, MM-3 and MM-4) located in the Oda-Godoma-Dabel area at the northeastern corner of the study area. These boreholes lie in different river valleys and groundwater was struck at different levels (Table 2.1) at these sites. Site MM-2 has brackish, sodium chloride water while site MM-3 has fresh, magnesium carbonate water. Site MM-4 has dominatly brackish, magnesium chloride water. Differences in water chemistry could be the result of the heterogeneous composition of the Basement System Rocks found in the area.

Figure 5.10 is an areal distribution map of chloride ion in groundwater. It is discernable from Figures 5.9 and 5.10 that the concentration of chloride in groundwater increases from areas of higher elevation and higher rainfall to areas of lower elevation with semi-arid climate.

Chloride is a conservative ion whose concentration in groundwater increases proportionally with mineralization (Yaalon, 1967). Yaalon (1967) also suggested that mineralization in groundwater increases with distance from the recharge areas, and is dependent on factors such as hydraulic gradient and effective porosity which control the groundwater flow. Mineralization is also dependent on the lithological composition of the recharge areas and the aquifer materials which the groundwater has passed through. However, some ions, such as chloride, may be introduced into a groundwater system through leaching of materials deposited on the surface as dry fallout. Chloride may also be concentrated on the surface by evaporation and subsequently flushed into the saturated zone.

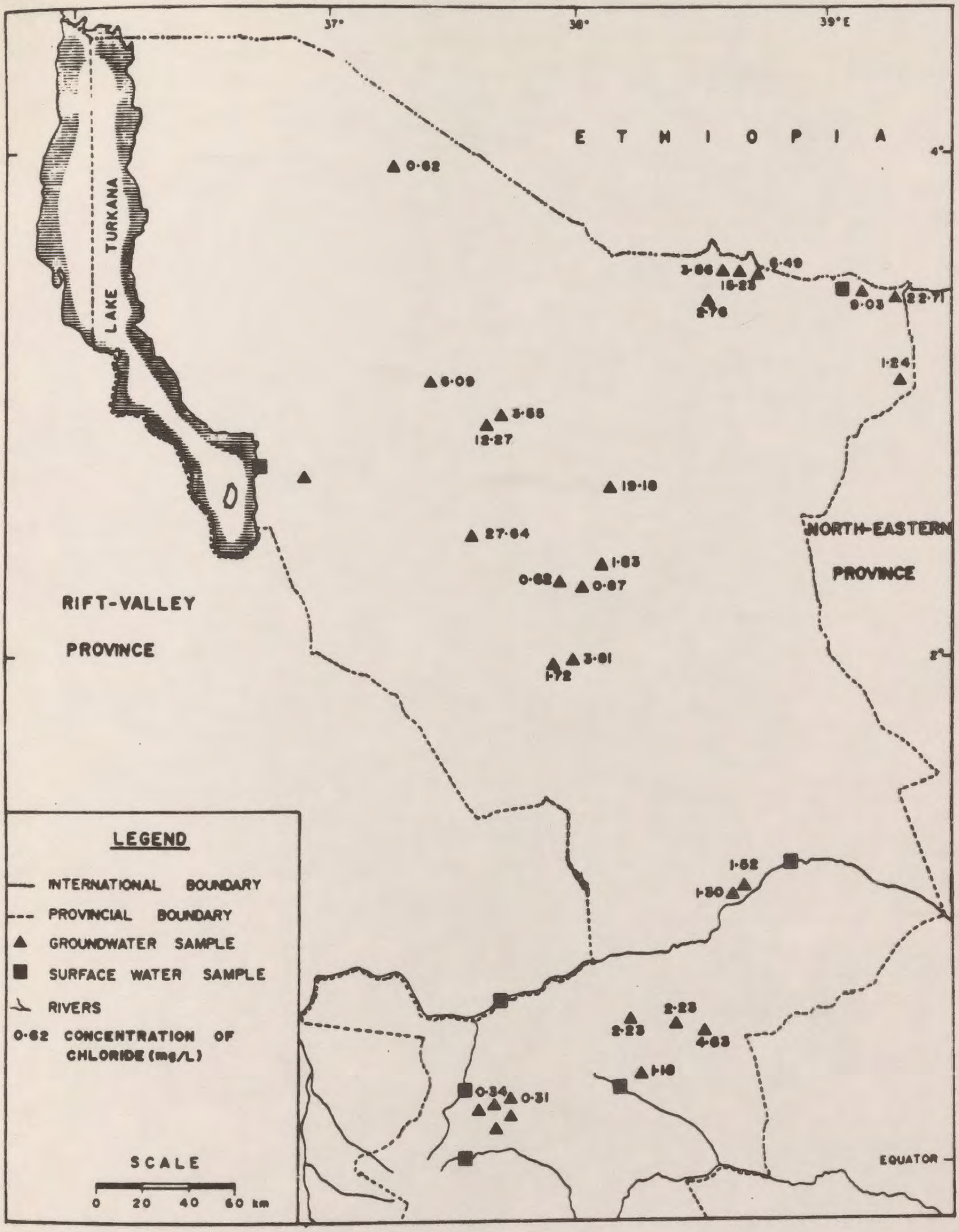

Figure 5.10 Areal distribution map of chloride in groundwater.

The following distribution patterns are shown by the chloride ion concentration in groundwater:

(a) An increase in the concentration from Mt. Marsabit towards the Chalbi Desert and the southeastern direction.

(b) An increase in the concentration from the Huri Hills towards the Chalbi Desert.

(c) An increase in the concentration from the northeastern slopes of Mt. Kenya and the northern slopes of the Nyambeni Range towards the Ewaso Nyiro Valley.

(d) An increase of the concentration from the Moyale Hills towards the southern and southwestern directions.

Similar patterns are demonstrated by the EC and TDS areal distributions in groundwater as shown in Figures 5.11 and 5.12.

It is conceivable from the foregoing discussions that the groundwater chemistry of the study area is controlled by three interacting factors: altitude, climate (rainfall and temperature) and geology. While higher elevation areas have higher rainfall and lower temperatures, the converse is true for low-lying areas.

The geology of the Eastern Province of Kenya is not uniform and consists of volcanics, metamorphics, and sediments of variable chemical composition. The volcanic

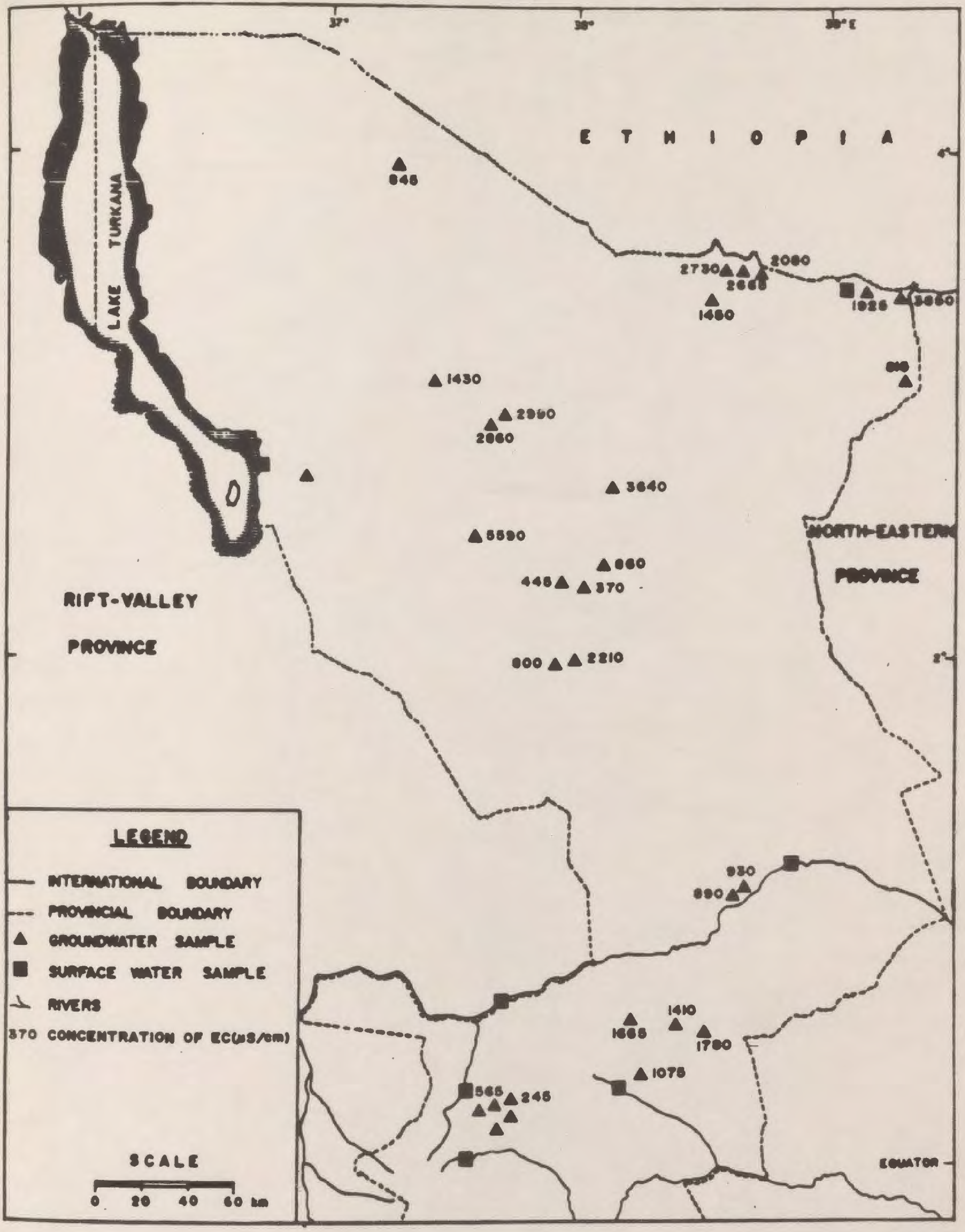

Figure 5.11 Areal distribution map of electrical conductivity (EC) in groundwater.

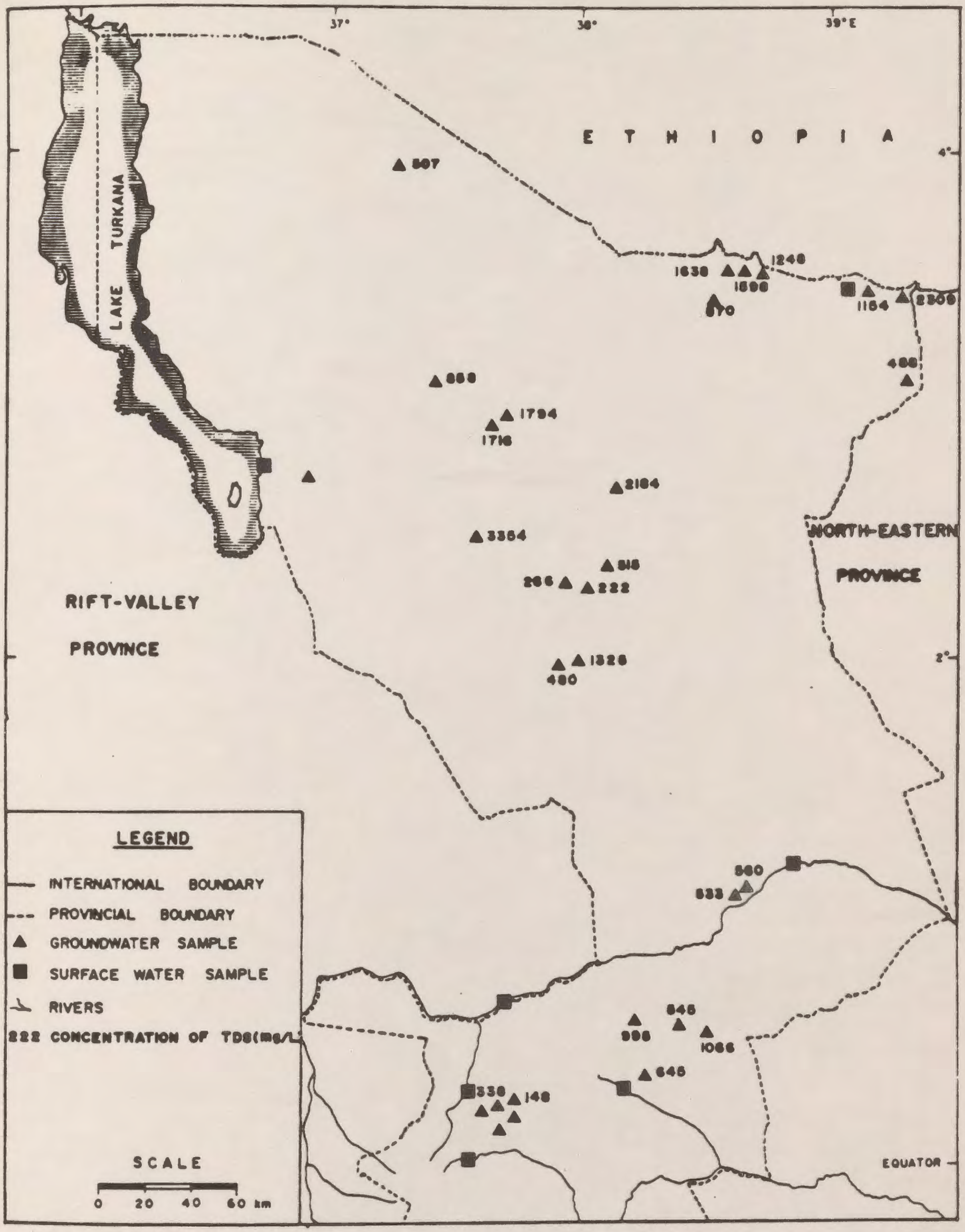

Figure 5.12 Areal distribution map of total dissolved solids (TDS) in groundwater.

rocks are mainly alkaline olivine basalts and groundwater derived from them show uniformity in chemical composition. On higher elevations (volcanics), the groundwater is fresh with magnesium and bicarbonate as the dominant ions. Examples include groundwater from sites MM-7, MM-8, and MM-9 on Mt. Marsabit, and sites MM-33, MM-35, MM-36 and MM-37 on the slopes of Mt. Kenya and the Nyambeni Range. It is suggested that the source of the dominant ions is exclusively the dissolution of the alkaline olivine basalts.

It is also noted that the water quality deteriorates and the TDS level increases towards the low-lying areas with sporadic rainfall. The TDS level in groundwater from the volcanic rocks may exceed the fresh water limit (1,000 mg/L) as shown by samples MM-26 (2,184 mg/L) and MM-29 (1,326 mg/L). Low rainfall and high temperatures favour the concentration by evaporation of salts in the soils. The salts may ultimately be flushed into the saturated zone following high rainfall events. Besides being a key factor in the evaporation process, higher temperatures assist the chemical breakdown of silicates (Schoeller, 1959).

Groundwaters struck in metamorphic rocks exhibit variable chemical compositions. The groundwaters are brackish but show differences in dominant dissolved ions. Examples of groundwater from this group include samples MM-2, MM-3, MM-4, MM-5, MM-6, MM-14, MM-27 and MM-28. The differences in water chemistry is likely the result of variable chemical composition of the metamorphic rocks.

Groundwaters derived from both consolidated and unconsolidated sediments in the Chalbi Desert, and the low-lying Lorian Swamp are either fresh or brackish, with the TDS level increasing away from the seasonal streams. One salient characteristic of the groundwaters is that they contain sodium as the dominant cation and either chloride or bicarbonate as the dominant anion. Examples of groundwater from the sedimentary rocks are samples MM-12, and MM-13 in the Lorian Swamp, and samples MM-19, MM-20, MM-21, and MM-25 in the Chalbi Desert.

5.3 Relationships

Figure 5.13 is a plot of tritium versus TDS for groundwater. On the basis of the concentration of TDS, the groundwaters are grouped into fresh and brackish water categories. The highest concentration of TDS is observed in sample MM-25, whose concentration exceeds 3,000 mg/L. Other groundwater samples with more than 1,000 mg/L TDS (brackish water) are MM-2, MM-4, MM-5, MM-14, MM-19, MM-20, MM-26, MM-27, MM-28 and MM-29. It is noted that the brackish waters have low tritium levels (from less than 0.8 to 3.3 TU) except for groundwater from sample MM-4 which has a tritium level of 29 TU. The high tritium concentration in this sample is due to recharge from a

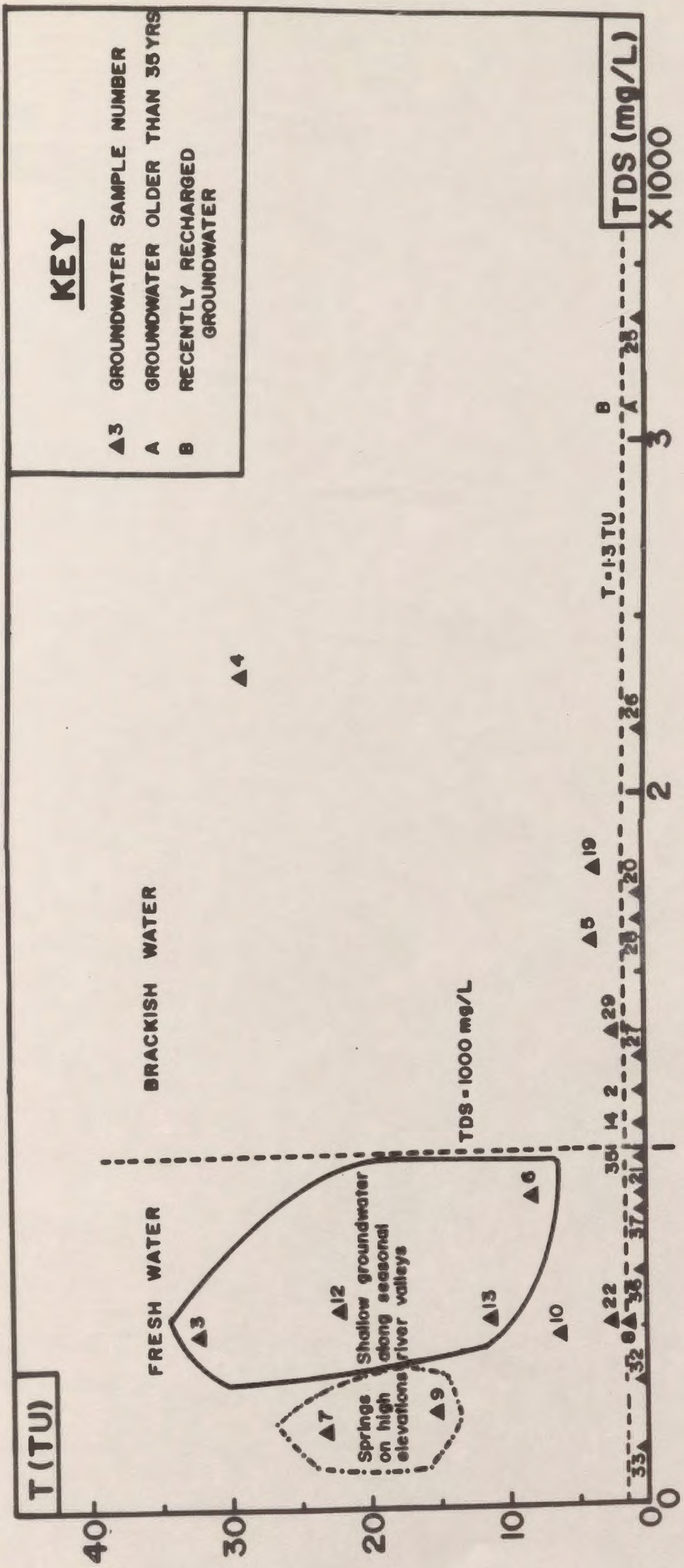

Figure 5.13 Plot of tritium versus TDS for groundwater.

seasonal stream.

High TDS and low tritium levels could suggest two things. Firstly, the levels suggest that the groundwater is relatively old and that the high TDS has resulted from the interaction, over a long time, between the groundwater and the aquifer materials. This, of course, does not rule out the possibility of recent recharge.

Secondly, high TDS and low tritium levels suggest a distant recharge area. This would mean a long transit time between the recharge and discharge area, and as such, the groundwater would be able to dissolve more salts from the geological materials along its path. Hence, there would be a high TDS level in this groundwater.

Low TDS (fresh water) is associated with groundwaters with high tritium levels. This observation is discernable in the shallow groundwaters found along the seasonal streams. Examples are samples MM-3, MM-6, MM-12 and MM-13 (Figure 5.13). This observation is also discernable in the spring samples from Mt. Marsabit (MM-7 and MM-9).

It is further observed that except for those groundwaters along the seasonal streams, all groundwaters with low TDS are exclusively found on higher elevation and higher rainfall areas. Low TDS and high tritium levels strongly suggest that the groundwater is currently being recharged with meteoric water.

Figure 5.13 also shows cases of low TDS and low tritium levels. These levels could suggest mixing of old water with recent water in areas where rocks are more resistant to dissolution by groundwater.

Figure 5.14 is a plot of $\delta^{18}O$ versus TDS. The plot shows no apparent relationship between $\delta^{18}O$ and TDS as both fresh and brackish waters have conformable δ values. Since paleowaters of past cool climate are more depleted in heavy isotopes and would have higher TDS levels than recently recharged groundwater (Gat and Issar, 1974; IAEA, 1981), the groundwaters of the study area are not paleowaters. The groundwaters have δ values that are conformable to those of present-day precipitation.

Figures 5.15 and 5.16 are plots of $\delta^{18}O$ and δD versus tritium for groundwater, respectively. These two plots are similar because $\delta^{18}O$ and δD are linearly correlated. High tritium values are shown by groundwater either more enriched or more depleted in $\delta^{18}O$. It is further noted that the data points show a scatter pattern. It is established, on this basis that there is no correlation between either $\delta^{18}O$ or δD with tritium.

Figure 5.17 is a plot of $\delta^{18}O$ versus chloride. The plot shows that low chloride concentrations are found in groundwaters on high elevation areas of Mt. Marsabit, the Nyambeni Range, and the Huri Hills. These areas also show low δ values. Low chloride levels also occur in

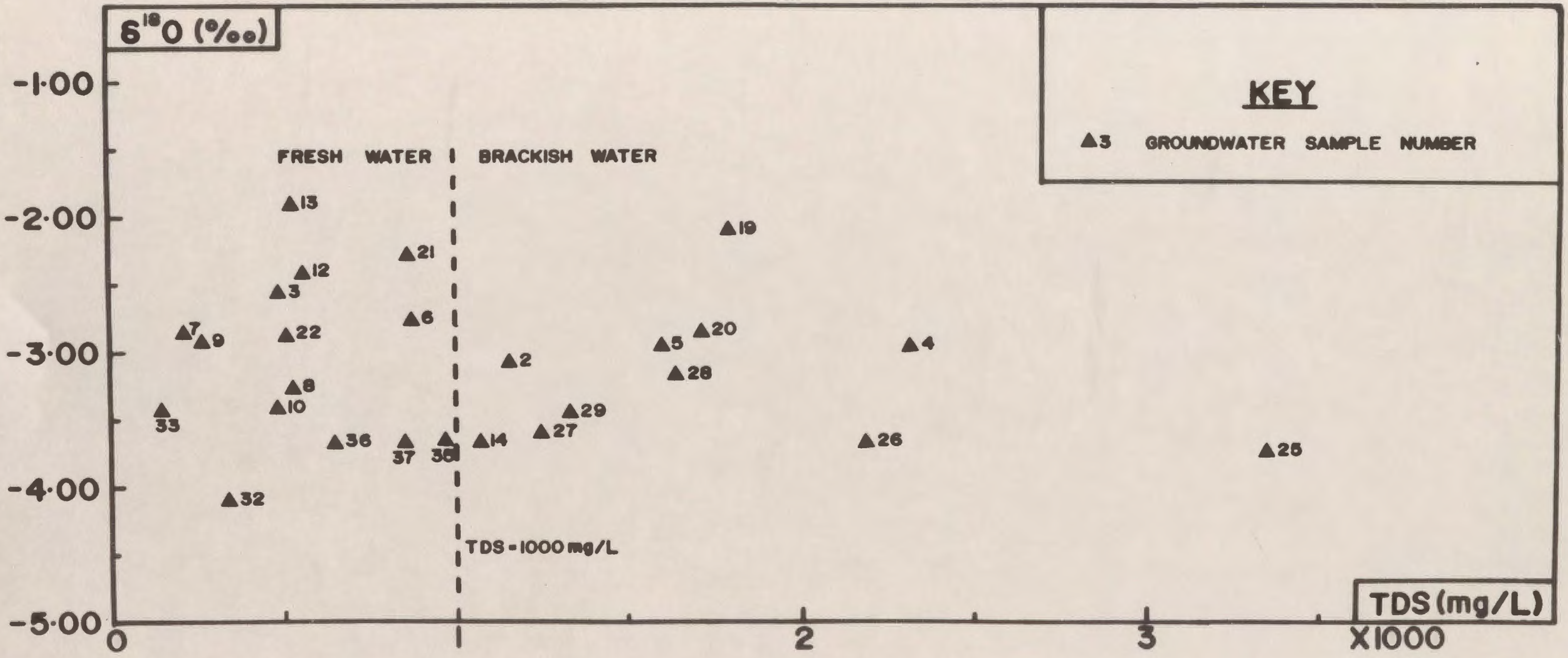

Figure 5.14 Plot of $\delta^{18}O$ versus TDS for groundwater.

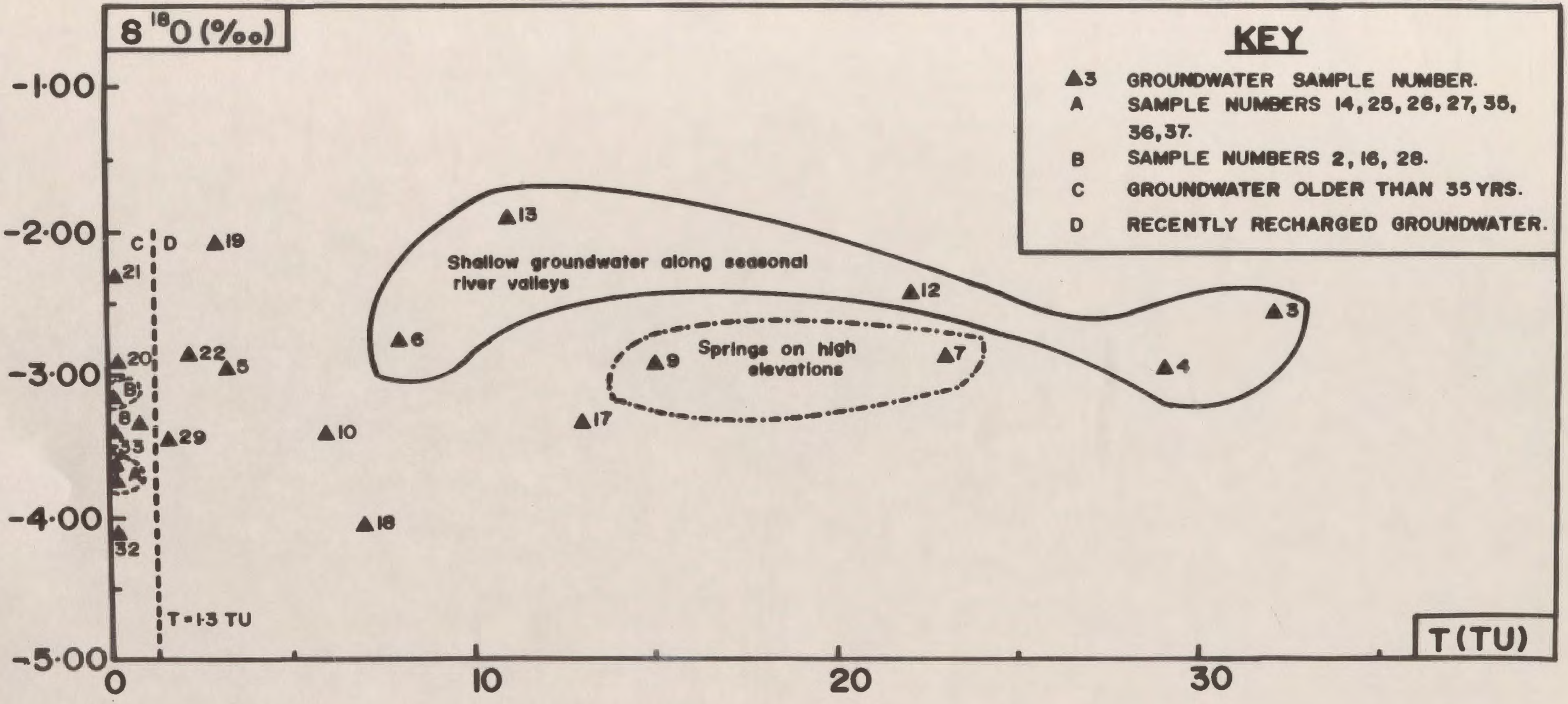

Figure 5.15 Plot of $\delta^{18}O$ versus tritium for groundwater.

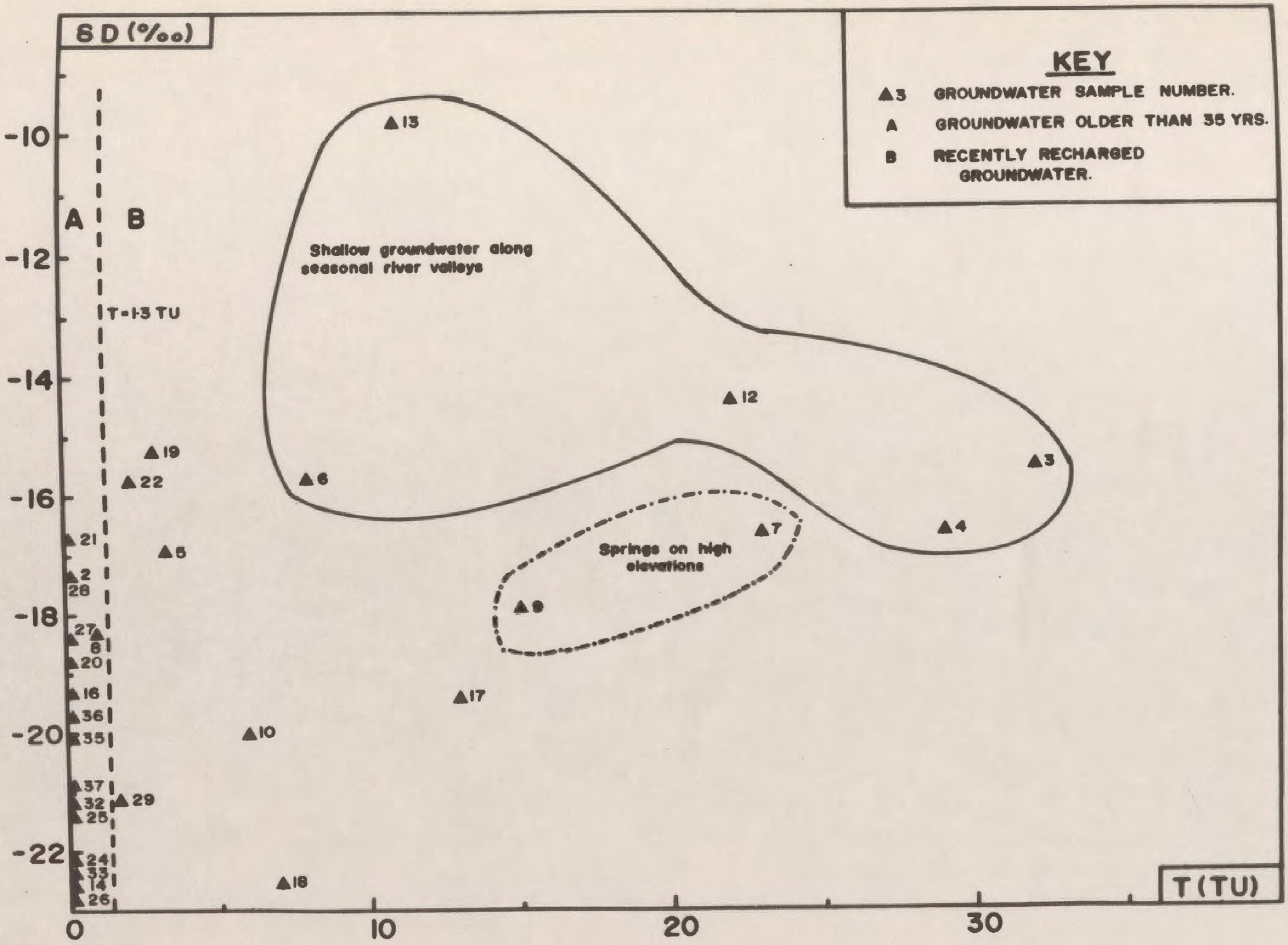

Figure 5.16 Plot of δD versus tritium for groundwater.

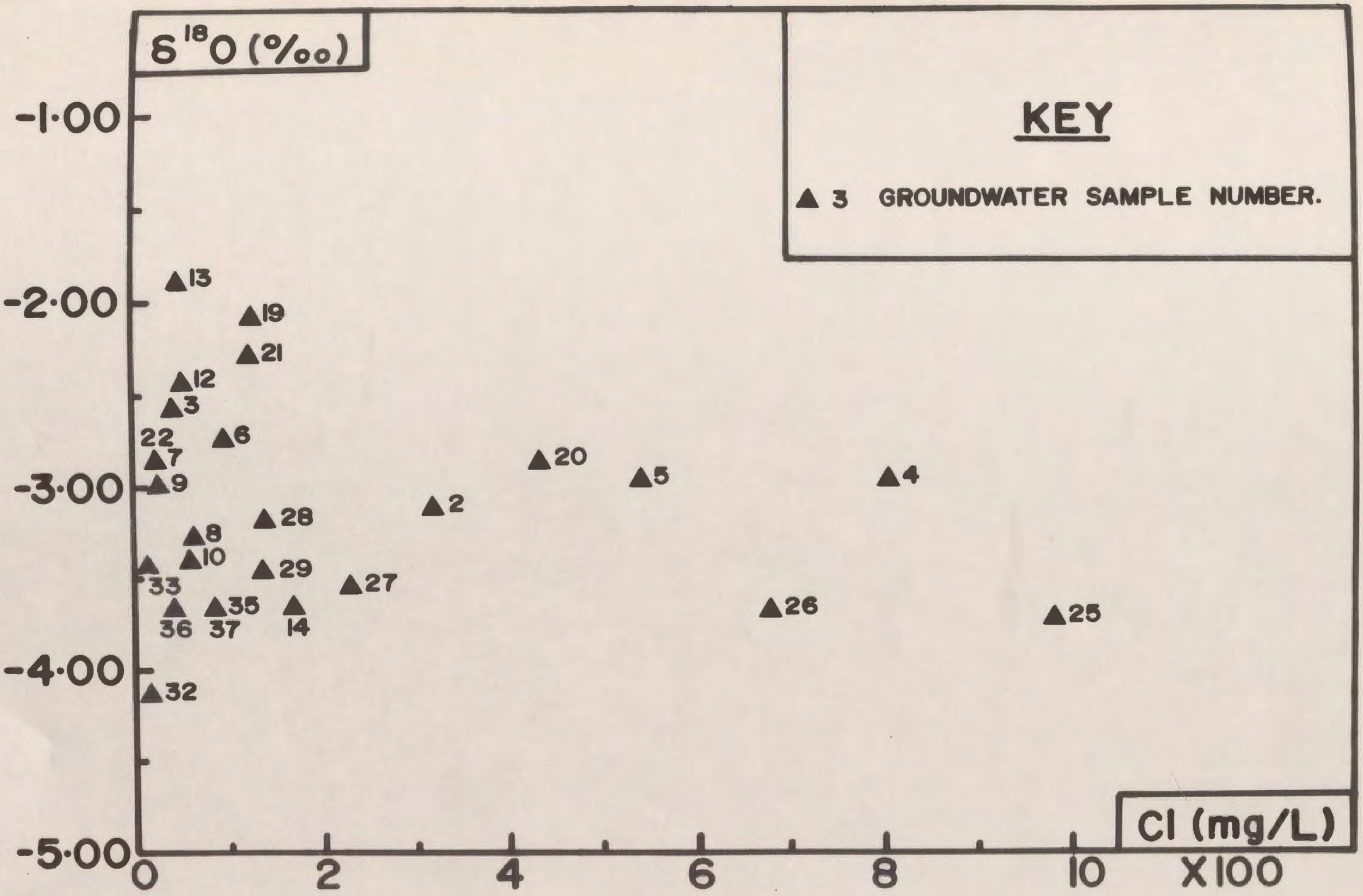

Figure 5.17 Plot of $\delta^{18}O$ versus chloride for groundwater.

groundwaters in the unconfined aquifers along the seasonal streams.

High chloride values are found in groundwaters from the low-lying arid areas. Groundwaters from the arid areas also show values which are similar to those shown by the groundwaters from the high elevation areas. Sites MM-25 (Kargi) and MM-26 (Bubisa) are good examples. Their values strongly suggest that they are recharged on the high elevation areas, and that the high concentration of chloride is the result of long transit distance.

Figure 5.18 is a plot of tritium versus chloride for groundwater. This plot is similar to Figure 5.13 which is a plot of tritium versus TDS. Since the concentration of chloride increases proportionally as TDS, the same arguments presented in respect of tritium versus TDS can be said for tritium versus chloride.

Although the relationships between individual isotopic and geochemical parameters are generally weak, it has been shown that the concentrations of these parameters in groundwater are controlled in one way or another by three factors: altitude, climate and geology. Thus, from the isotopic and geochemical interpretations presented above, together with the available hydrogeological information and field observations, the following three groundwater systems are recognised (Figure 5.19):

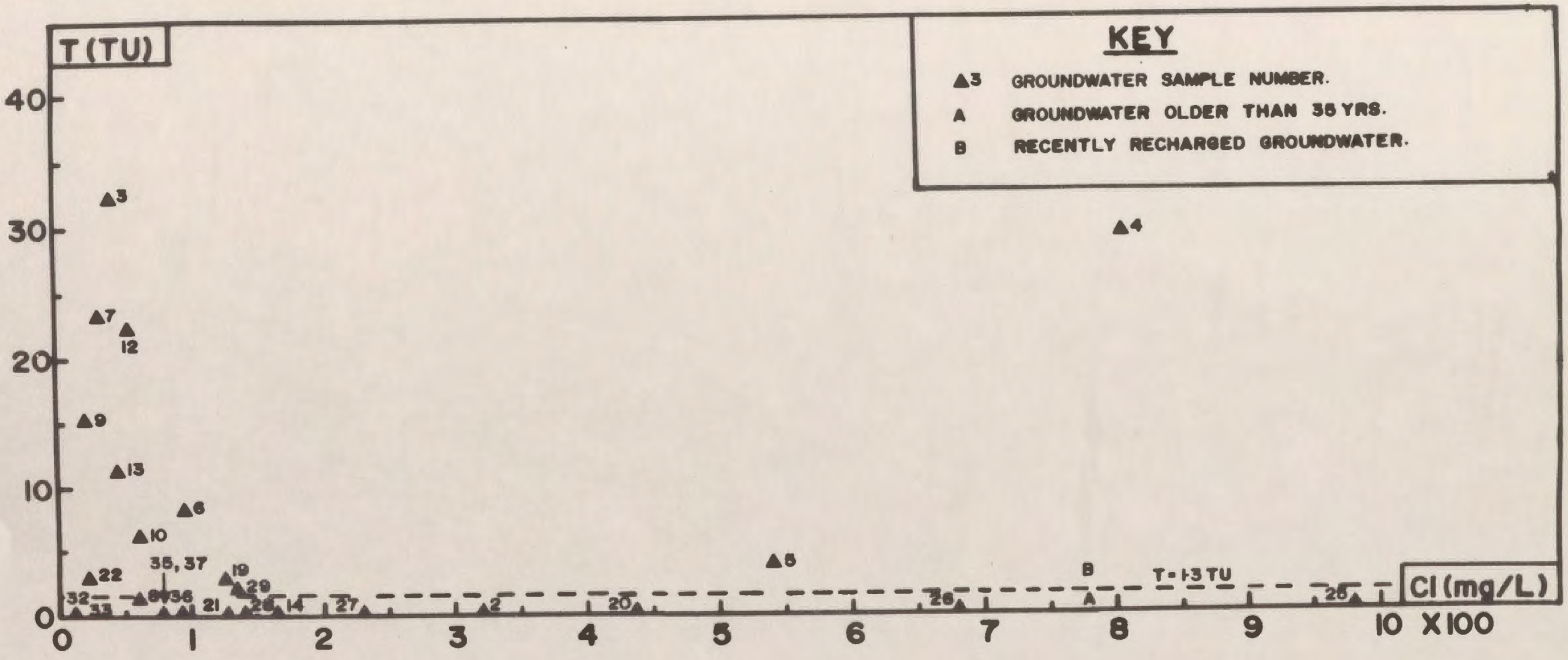

Figure 5.18 Plot of tritium versus chloride for groundwater.

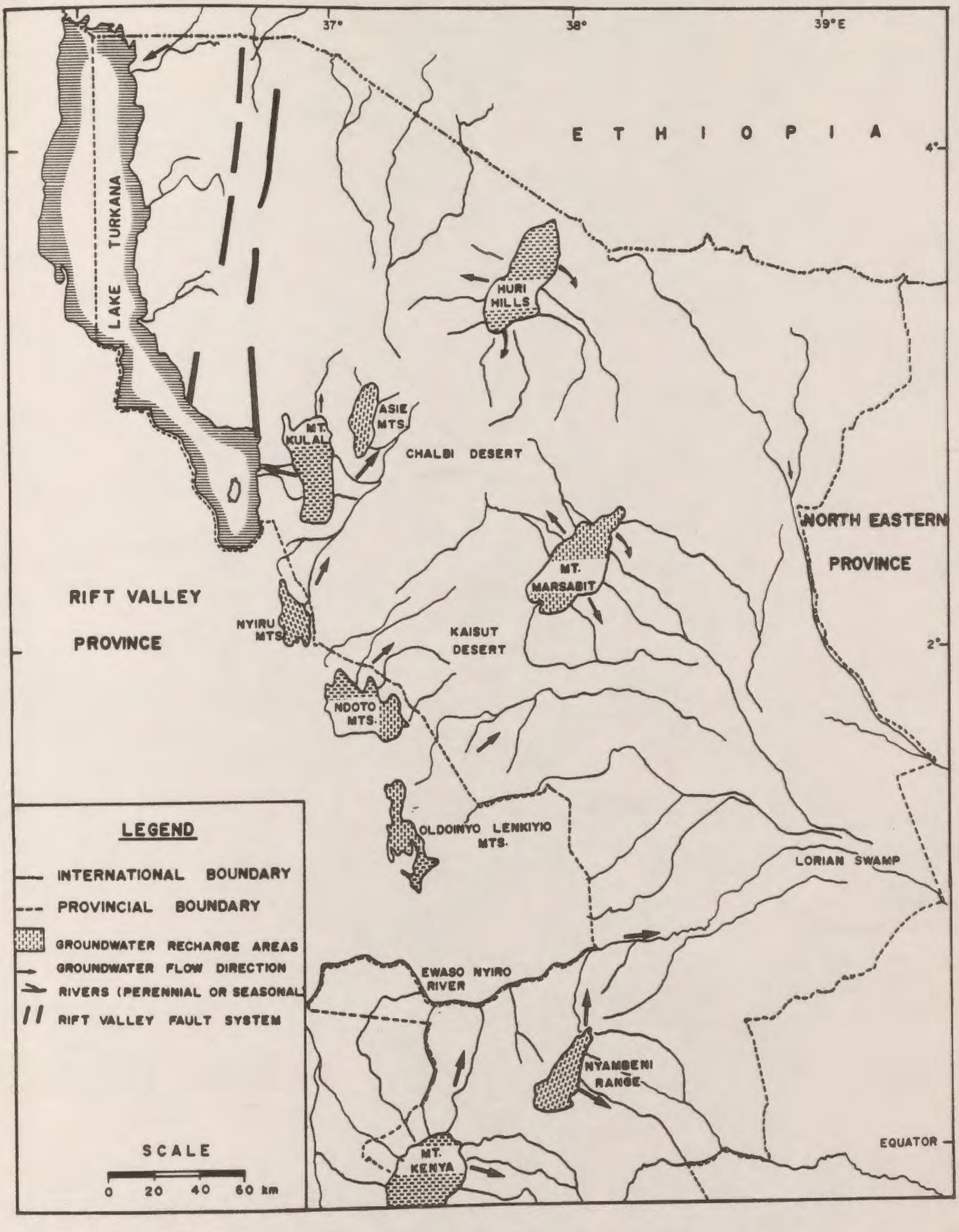

Figure 5.19 Map showing the groundwater systems of the Eastern Province.

(a) The Chalbi-Kaisut Deserts Groundwater System.

This groundwater system occurs to the west of the study area and includes the Chalbi and Kaisut Deserts. The system is bounded to the north, east and west by the Huri Hills, Mt. Marsabit, and Mt. Kulal and Nyiru-Ndoto Mountains, respectively. It is also bounded to the northwest by north-south trending fault systems of the Rift Valley. The southeast outflow of the groundwater from the Chalbi and Kaisut Deserts is impeded by a pyroxinite intrusion that runs in a north-south direction near Log-Logo (Ndombi, 1983). This has been confirmed from the yields of the boreholes drilled in the vicinity of the intrusion. Boreholes drilled immediately to the west of the pyroxinite intrusion have higher yields than those drilled immediately to the east, except those drilled along north-south trending faults (Ndombi, 1983; Ministry of Water Development, 1985).

Groundwater is recharged from the higher elevation and higher rainfall areas of the surrounding mountains and hills. Groundwater may also be recharged from the high rainfall areas of the Ethiopian Highlands (not shown on the map). This conclusion is based on the fact that one of the ephemeral streams (Laga Balal) draining into the

Chalbi Desert, originates from the Ethiopian Highlands. Recharge from flood flows of the seasonal streams is important in this area. Direct groundwater recharge from local precipitation is sporadic owing to the aridity of the area.

The Chalbi and Kaisut Deserts are the discharge areas of the groundwater system. This is evident from the occurrences of springs and shallow hand-dug wells at the contact between the volcanics and the desert sediments. Depths to water level in the drilled boreholes decrease towards the Chalbi Desert (Ministry of Water Development, 1985). The same trend has been shown by geophysical work (electrical resistivity soundings) conducted by Ndombi (1983).

Two aquifers were encounterd during drilling activities in the Dukana-Kalacha-Kargi area. While the upper aquifer is unconfined, and sometimes perched with the depth to water table lying between the surface (springs) and 32 m, the lower aquifer is confined and is encountered between depths of 62 and 88 m (Ministry of Water Development, 1985). At Log-Logo, only the lower aquifer was encountered at a depth of 70 m. The occurrence of dry boreholes (even to depths of more than 100 m) at Log-Logo, Laisamis, Korr, Kaisut, and Marsabit, suggests that the aquifers are not laterally extensive. The upper aquifer is, principally, found beneath and along the seasonal streams.

The groundwater quality deteriorates away from the recharge areas (and the seasonal streams), toward the deserts.

(b) The Ewaso Nyiro-Lorian Swamp Groundwater System.

This groundwater system lies to the east and southeast of the Chalbi-Kaisut Deserts Groundwater System. The system is laterally extensive running from the Ethiopian border in the north to Mt. Kenya and the Nyambeni Range in the south. The system also extends east into the North Eastern Province.

The most important recharge areas for this system are the high elevation areas of northern Mt. Kenya and the Nyambeni Range, where heavy rains and substantial stream runoff are common phenomena. Other areas of groundwater recharge are the eastern slopes of the Huri Hills, Mt. Marsabit, the Oldoinyo Lenkiyio Mountains and other isolated hills within the area. The groundwater is also recharged from the flood flows of the seasonal streams after heavy rains. Owing to aridity, direct groundwater recharge from local precipitatation is sporadic, occurring only after heavy rains.

Because of differences in altitude, climate and geology, different unconnected aquifers and/or fractured zones are found within the groundwater system. As a result, the groundwaters from the system exhibit marked differences in chemistry, with the greatest differences occurring in groundwaters from the metarmorphic rocks.

The most important groundwater bearing-formation is the Merti aquifer. The areal extent of this aquifer in Eastern Province is not known. Nevertheless, the aquifer has an extensive fresh water zone that approximately follows the alignment of the Ewaso Nyiro channelways (Swarzenski and Mundorff, 1977). The depth to water level in the confined aquifer ranges between 30 and 140 m (Swarzenski and Mundorff, 1977; Ministry of Water Development, 1985). Shallow unconfined and usually perched aquifers are, however, found beneath and along the seasonal streams at favourable sites.

The southeastern slopes of Mt. Kenya and the Nyambeni Range are recharge areas for groundwater flowing towards the Tana River valley.

(c) East Lake Turkana Groundwater System.

This system occurs at the northwestern corner of the study area in the Lake Turkana Basin. The area is remote and very arid. The main recharge for this system occurs on the Ethiopian Highlands in the north. According to Yuretich and Cerling (1983), the annual influx of shallow groundwater into the Lake is unknown. However, the flow should be small owing to the extreme aridity of the lake basin which is a closed system.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following six conclusions are made from this study:

(a) The higher elevation and higher rainfall areas are the recharge zones of the low-lying arid areas of the Eastern Province of Kenya.

(b) Groundwater of the Eastern Province of Kenya is recharged principally from evaporated precipitation. Direct groundwater recharge from precipitation on the low-lying arid areas is sporadic and occurs only after exceptionally high rains.

(c) Unconfined and perched aquifers found beneath and along the seasonal streams are recharged with evaporated stream water.

(d) The large scatter in isotopic composition of the groundwater sources is the result of differences in altitude and temperature of the recharge areas, the season and the amount of rainfall in the recharge areas, and proximity of groundwater bearing zones (aquifers and/or fractures) to seasonal streams.

(e) Local and regional variations in groundwater chemistry in the Eastern Province are the result of differences in altitude, climate (precipitation and temperature), and geology of the recharge and discharge areas. Groundwater that is either magnesium bicarbonate or sodium-magnesium bicarbonate is found in volcanic terrains on high elevations. Sodium chloride or sodium bicarbonate groundwater occurs in sedimentary deposits of low-lying arid areas. Groundwater from the metamorphic rocks of the Basement System is more variable in chemical composition and any of the cations (calcium, magnesium, and sodium) or the anions (bicarbonate, chloride, and sulphate) may be the dominant cation or anion, respectively.

(f) Three groundwater systems occur in the Eastern Province: the Chalbi-Kaisut Deserts; Ewaso Nyiro-Lorian Swamp, and East Lake Turkana. Different and unconnected aquifers and/or fractures bearing groundwater are found within each of these systems. As a result, differences in isotopic and geochemical compositions, and yields are common phenomena.

6.2 Recommendations

The following four recommendations are proposed for implementation:

(a) There is an urgent need to establish an IAEA-WMO station in the Eastern Province. The station would provide precipitation samples for isotopic and geochemical analyses. Information obtained from the

question of whether over-exploitation of groundwater resources is occurring or not, in the Eastern Province and other regions of Kenya will remain unanswered.

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APPENDIX

WATER ANALYSIS REPORTS

MINISTRY OF WATER DEVELOPMENT
Water Quality and Pollution Control Laboratory

Tel. No. 557088, Ext. 93
P.O. Box 30521
NAIROBI.

Date 17th November, 1986

WATER ANALYSIS REPORT

Sample No. 1582
Source Holale Dam Moyale
Date of Sampling 23-8-86

Date Recieved 10-9-86
Submitted by Rimberia-PC Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	8.2	
Colour	mg pt/l	5	
Turbidity	N.T.U.	7.2	
Permanganate No. (20 min. boiling)	mgO_2/l	5.5	
Conductivity (25°C)	µS/cm	990	
Iron	mgFe/l	1	
Manganese	mgMn/l	0.22	
Calcium	mgCa/l	72	
Magnesium	mgMg/l	42	
Sodium	mg/Na/l	134	
Potassium	mgK/l	9	
Aluminium	mgAl/l	-	
Total Hardness	mg$CaCO_3$/l	328	
Total Alkalinity	mg$CaCO_3$/l	260	
Chloride mg Cl/l	mgCl/l	85	
Flouride	mgF/l	0.3	
Nitrate	mgN/l	0.22	
Nitrite	mgN/l	0.05	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO_4/l	154	
Orthophosphate	mgP/l	0.01	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	7	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	595	
Others Silica	MgSiO_2/1	3.1	

COMMENTS: Colourless hard water thatmay require only filtration and disinfection before use.

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Date 17-11-86

WATER ANALYSIS REPORT

Sample No. 1581
Source Oda B/H (Old)C3959 Marsabit
Date of Sampling 23-8-86

Date Recieved 10-9-86
Submitted by Rimberia-PC Emb
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	8.7	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	1.6	
Permanganate No. (20 min. boiling)	mg0$_2$/l	2.1	
Conductivity (25°C)	µS/cm	1925	
Iron	mgFe/l	0.2	
Manganese	mgMn/l	0.01	
Calcium	mgCa/l	120	
Magnesium	mgMg/l	53	
Sodium	mg/Na/l	180	
Potassium	mgK/l	6	
Aluminium	mgAl/l	-	
Total Hardness	mgCaCO$_3$/l	546	
Total Alkalinity	mgCaCO$_3$/l	364	
Chloride mg Cl/l	mgCl/l	320	
Flouride	mgF/l	0.70	
Nitrate	mgN/l	1.3	
Nitrite	mgN/l	0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO$_4$/l	133	
Orthophosphate	mgP/l	0.06	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	18	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	1154	
Others Silica	MgSiO$_2$/L	22	

COMMENTS: Hard water that requires softening before use.

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Date 17-11-86

WATER ANALYSIS REPORT

Sample No. 1577
Source Dabel Well-Marsabit
Date of Sampling 22-8-86

Date Recieved 10-9-86
Submitted by Rimberia-P.C. Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	8.1	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	15	
Permanganate No. (20 min. boiling)	mgO_2/l	3.1	
Conductivity (25°C)	µS/cm	815	
Iron	mgFe/l	3.4	
Manganese	mgMn/l	0.35	
Calcium	mgCa/l	3.4	
Magnesium	mgMg/l	103	
Sodium	mg/Na/l	17	
Potassium	mgK/l	5.3	
Aluminium	mgAl/l	-	
Total Hardness	mg$CaCO_3$/l	428	
Total Alkalinity	mg$CaCO_3$/l	356	
Chloride mg Cl/l	mgCl/l	44	
Flouride	mgF/l	0.06	
Nitrate	mgN/l	0.07	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO_4/l	18	
Orthophosphate	mgP/l	0.10	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	12	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	488	
Others Silica	MgSiO_2/L	15	

COMMENTS: Very hard water with excessive contents of iron and manganese. Requires softening and iron and manganese removal before use.

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Date 17-11-86

WATER ANALYSIS REPORT

Sample No. 1578
Source Godoma B/H - C 5901 Marsabit
Date of Sampling 22-8-86
Date Recieved 10-9-86
Submitted by Rimberia - PC Embu
Purpose of Sampling Domestic

PARAMETERS	UNIT	RESULTS	REMARKS
pH	pH Scale	7.7	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	9	
Permanganate No. (20 min. boiling)	mgO_2/l	3.2	
Conductivity (25°C)	µS/cm	3850	
Iron	mgFe/l	0.9	
Manganese	mgMn/l	0.06	
Calcium	mgCa/l	240	
Magnesium	mgMg/l	340	
Sodium	mg/Na/l	275	
Potassium	mgK/l	1.6	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	1960	
Total Alkalinity	$mgCaCO_3/l$	438	
Chloride mg Cl/l	mgCl/l	805	
Flouride	mgF/l	0.25	
Nitrate	mgN/l	0.08	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	630	
Orthophosphate	mgP/l	0.07	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	52	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	2309	
Others Silica	$MgSiO_2/1$	10	

COMMENTS: Very hard, saline water which requires demineralization before use.

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Date 17th November, 1986

WATER ANALYSIS REPORT

Sample No. 1580
Source B/H Sololo Mission Hosp. Marsabit
Date of Sampling 23-8-86

Date Recieved 10-9-86
Submitted by Rimberia-PC Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	8.2	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	8.0	
Permanganate No. (20 min. boiling)	mg0$_2$/l	1.7	
Conductivity (25°C)	µS/cm	2665	
Iron	mgFe/l	Less than 0.1	
Manganese	mgMn/l	0.02	
Calcium	mgCa/l	190	
Magnesium	mgMg/l	51	
Sodium	mg/Na/l	320	
Potassium	mgK/l	15	
Aluminium	mgAl/l	-	
Total Hardness	mgCaCO$_3$/l	665	
Total Alkalinity	mgCaCO$_3$/l	364	
Chloride mg Cl/l	mgCl/l	540	
Flouride	mgF/l	2.7	
Nitrate	mgN/l	1.10	
Nitrite	mgN/l	0.08	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO$_4$/l	281	
Orthophosphate	mgP/l	0.03	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	26	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	1598	
Others Silica	MgSiO$_2$/L	34	

COMMENTS: Hard water that requires softening before use.

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Date 17th November, 1986

WATER ANALYSIS REPORT

Sample No. 1579
Source Walda B/Hole C 3896 Marsabit
Date of Sampling 23-8-86

Date Recieved 10-9-86
Submitted by Rinberia-PC Embu
Purpose of Sampling Domestic

PARAMETERS	UNIT	RESULTS	REMARKS
pH	pH Scale	8.1	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	8	
Permanganate No. (20 min. boiling)	mgO_2/l	0.16	
Conductivity (25°C)	μS/cm	1450	
Iron	mgFe/l	0.1	
Manganese	mgMn/l	0.01	
Calcium	mgCa/l	39	
Magnesium	mgMg/l	64	
Sodium	mg/Na/l	83	
Potassium	mgK/l	11	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	800	
Total Alkalinity	$mgCaCO_3/l$	614	
Chloride mg Cl/l	mgCl/l	98	
Flouride	mgF/l	0.44	
Nitrate	mgN/l	0.01	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	147	
Orthophosphate	mgP/l	0.09	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	18	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	870	
Others Silica	$mgSiO_2/l$	12	

COMMENTS: Very hard, alkaline water, which requires softening and lowering of alkalinity before use.

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Date 17-11- 86

WATER ANALYSIS REPORT

Sample No. 1573
Source Bakuli Springs - Marsabit
Date of Sampling 20-8-86

Date Recieved 10-9-86
Submitted by Rimberia-P.C. Embu
Purpose of Sampling Domestic

PARAMETERS	UNIT	RESULTS	REMARKS
pH	pH Scale	8.2	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	1.5	
Permanganate No. (20 min. boiling)	mgO_2/l	0.63	
Conductivity (25°C)	µS/cm	370	
Iron	mgFe/l	0.3	
Manganese	mgMn/l	0.03	
Calcium	mgCa/l	13.6	
Magnesium	mgMg/l	20	
Sodium	mg/Na/l	12	
Potassium	mgK/l	1.0	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	172	
Total, Alkalinity	$mgCaCO_3/l$	154	
Chloride mg Cl/l	mgCl/l	31	
Flouride	mgF/l	0.10	
Nitrate	mgN/l	0.08	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	1.8	
Orthophosphate	mgP/l	0.06	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	4	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	222	
Others Silica	$MgSiO_2/1$	21	

COMMENTS: Other water with good chemical quality. Suitable for domestic use.

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Date 17th November, 1986

WATER ANALYSIS REPORT

Sample No. 1574
Source B/H-Sagante C-4582, Marsabit
Date of Sampling 20-8-86

Date Recieved 10-9-86
Submitted by Rimberia-PC Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	7.6	
Colour	mg pt/l	5	
Turbidity	N.T.U.	0.5	
Permanganate No. (20 min. boiling)	mgO_2/l	0.80	
Conductivity (25°C)	µS/cm	860	
Iron	mgFe/l	0.1	
Manganese	mgMn/l	Less than 0.01	
Calcium	mgCa/l	63	
Magnesium	mgMg/l	61	
Sodium	mg/Na/l	21	
Potassium	mgK/l	4.0	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	462	
Total Alkalinity	$mgCaCO_3/l$	398	
Chloride mg Cl/l	mgCl/l	65	
Flouride	mgF/l	0.14	
Nitrate	mgN/l	0.10	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	2.8	
Orthophosphate	mgP/l	0.13	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	44	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	515	
Others Silica	$MgSiO_2$/1	22	

COMMENTS: Very hard, clear water which requires softening before use.

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Date 17th November, 1986

WATER ANALYSIS REPORT

Sample No. 1572
Source Ura Ura Springs Marsabit
Date of Sampling 20-8-86

Date Recieved 10-9-86
Submitted by Rimberia-PC. Embu
Purpose of Sampling Domestic

PARAMETERS	UNIT	RESULTS	REMARKS
pH	pH Scale	8.2	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	1.0	
Permanganate No. (20 min. boiling)	mgO_2/l	0.88	
Conductivity (25°C)	µS/cm	445	
Iron	mgFe/l	1.2	
Manganese	mgMn/l	0.05	
Calcium	mgCa/l	19	
Magnesium	mgMg/l	29	
Sodium	mg/Na/l	24	
Potassium	mgK/l	2.6	
Aluminium	mgAl/l	-	
Total Hardness	mg$CaCO_3$/l	200	
Total Alkalinity	mg$CaCO_3$/l	206	
Chloride mg Cl/l	mgCl/l	22	
Flouride	mgF/l	0.23	
Nitrate	mgN/l	Less than 0.01	
Nitrite	mgN/l	0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO_4/l	3.6	
Orthophosphate	mgP/l	0.10	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	13	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	266	
Others Silica	MGSiO_2/L	18	

COMMENTS:

Clear water with an excess of iron content. May be used when no other alternative is available.

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Date 18th November, 1986

WATER ANALYSIS REPORT

Sample No. 1583
Source Logologo B/Hole-Marsabit
Date of Sampling 26-8-86

Date Recieved 10-9-86
Submitted by Rimberia-P.C. Embu.
Purpose of Sampling Domestic

PARAMETERS	UNIT	RESULTS	REMARKS
pH	pH Scale	8.1	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	3.6	
Permanganate No. (20 min. boiling)	mgO$_2$/l	1.8	
Conductivity (25°C)	µS/cm	800	
Iron	mgFe/l	0.7	
Manganese	mgMn/l	0.13	
Calcium	mgCa/l	8.1	
Magnesium	mgMg/l	34	
Sodium	mg/Na/l	97	
Potassium	mgK/l	15	
Aluminium	mgAl/l	-	
Total Hardness	mgCaCO$_3$/l	180	
Total Alkalinity	mgCaCO$_3$/l	312	
Chloride mg Cl/l	mgCl/l	61	
Flouride	mgF/l	0.28	
Nitrate	mgN/l	1.2	
Nitrite	mgN/l	0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO$_4$/l	11	
Orthophosphate	mgP/l	0.31	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	11	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	480	
Others Silica	MgSiO$_2$/l	28	

COMMENTS: The water is chemically suitable for domestic use.

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Date 18th November, 1986

WATER ANALYSIS REPORT

Sample No. 1585
Source B/H Merti W/S - C 4514
Date of Sampling 26-8-86
Date Recieved 10-9-86
Submitted by Rimberia-P.C. Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	8.6	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	0.2	
Permanganate No. (20 min. boiling)	mgO_2/l	0.71	
Conductivity (25°C)	μS/cm	930	
Iron	mgFe/l	0.1	
Manganese	mgMn/l	0.04	
Calcium	mgCa/l	1.1	
Magnesium	mgMg/l	1.7	
Sodium	mg/Na/l	206	
Potassium	mgK/l	13	
Aluminium	mgAl/l	-	
Total Hardness	mg$CaCO_3$/l	13	
Total Alkalinity	mg$CaCO_3$/l	376	
Chloride mg Cl/l	mgCl/l	54	
Flouride	mgF/l	2.1	
Nitrate	mgN/l	0.01	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO_4/l	30	
Orthophosphate	mgP/l	0.09	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	Nil	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	560	
Others Silica	MgSiO_2/l	3.6	

COMMENTS: Clear, colourless, alkaline water with an excess of fluoride content.

ANALYTICAL SERVICES [illegible].
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Date 18th November, 1986

WATER ANALYSIS REPORT

Sample No. 1584
Source B/Hole-Merti Mission C 4543
Date of Sampling 28-8-86

Date Recieved 10-9-86
Submitted by Rimberia-PC Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	8.7	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	0.4	
Permanganate No. (20 min. boiling)	mg0$_2$/l	1.1	
Conductivity (25°C)	μS/cm	890	
Iron	mgFe/l	Less than 0.1	
Manganese	mgMn/l	0.02	
Calcium	mgCa/l	1.2	
Magnesium	mgMg/l	1.0	
Sodium	mg/Na/l	230	
Potassium	mgK/l	13	
Aluminium	mgAl/l	-	
Total Hardness	mgCaCO$_3$/l	6	
Total Alkalinity	mgCaCO$_3$/l	364	
Chloride mg Cl/l	mgCl/l	46	
Flouride	mgF/l	1.8	
Nitrate	mgN/l	0.01	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO$_4$/l	29	
Orthophosphate	mgP/l	0.17	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	Nil	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	533	
Others Silica	MgSiO$_2$/1	10	

COMMENTS: Clear, colourless, alkaline water with a slight excess of fluoride content.

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Date 1 8 th November, 1986

WATER ANALYSIS REPORT

Sample No. 1587
Source Well-Garbatula W/Supply
Date of Sampling 28-8-86

Date Recieved 10-9-86
Submitted by Rimb eria-P.C.- Embu
Purpose of Sampling Domestic

PARAMETERS	UNIT	RESULTS	REMARKS
pH	pH Scale	7.9	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	0.2	
Permanganate No. (20 min. boiling)	mgO_2/l	Less than 0.1	
Conductivity (25°C)	µS/cm	1780	
Iron	mgFe/l	0.3	
Manganese	mgMn/l	Less than 0.01	
Calcium	mgCa/l	7.6	
Magnesium	mgMg/l	87	
Sodium	mg/Na/l	220	
Potassium	mgK/l	18	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	498	
Total Alkalinity	$mgCaCO_3/l$	740	
Chloride mg Cl/l	mgCl/l	164	
Flouride	mgF/l	0.74	
Nitrate	mgN/l	1.40	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	40	
Orthophosphate	mgP/l	0.20	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	46	
Dissolved Oxygen	mg/l	~~1066x~~ -	
TDS ~~Silica~~	mg/l	1066	
Others Silica	$mgS10_2/1$	26	

COMMENTS: Hard, alkaline water that requires softening and lowering of alkalinity before use.

ANALYTICAL SERVICES SECTION,
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Date 18th November, 1986

WATER ANALYSIS REPORT

Sample No. 1586
Source Bisnadi River at Gale-Isiolo
Date of Sampling 28-8-86

Date Recieved 10-9-86
Submitted by Rimberia-P.C Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	8.5	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	1.3	
Permanganate No. (20 min. boiling)	mgO_2/l	2.3	
Conductivity (25°C)	μS/cm	550	
Iron	mgFe/l	0.3	
Manganese	mgMn/l	0.04	
Calcium	mgCa/l	23	
Magnesium	mgMg/l	23	
Sodium	mg/Na/l	49	
Potassium	mgK/l	16	
Aluminium	mgAl/l	-	
Total Hardness	mg$CaCO_3$/l	198	
Total Alkalinity	mg$CaCO_3$/l	304	
Chloride mg Cl/l	mgCl/l	10	
Flouride	mgF/l	0.30	
Nitrate	mgN/l	0.10	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO_4/l	4.4	
Orthophosphate	mgP/l	0.19	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	Nil	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	329	
Others Silica	mgSiO_2/1	23	

COMMENTS: The water is chemically suitable for domestic use.

[illegible]

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Date 9.12.87

WATER ANALYSIS REPORT

Sample No. 1241

Source MAIKONA PRI. SCHOOL WELL MARSABIT

Date of Sampling 10.9.87

Date Recieved 24.9.87

Submitted by J.K. RIMBERIA

Purpose of Sampling DOMESTIC

PARAMETERS	UNIT	RESULTS	REMARKS
pH	pH Scale	7.4	
Colour	mg pt/l	5	
Turbidity	N.T.U.	0.8	
Permanganate No. (20 min. boiling)	mgO_2/l	13	
Conductivity (25°C)	µS/cm	2990	
Iron	mgFe/l	0.5	
Manganese	mgMn/l	Less than 0.1	
Calcium	mgCa/l	1.0	
Magnesium	mgMg/l	2.2	
Sodium	mg/Na/l	290	
Potassium	mgK/l	-	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	41	
Total Alkalinity	$mgCaCO_3/l$	404	
Chloride mg Cl/l	mgCl/l	126	
Flouride	mgF/l	0.6	
Nitrate	mgN/l	-	
Nitrite	mgN/l	0.02	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	50	
Orthophosphate	mgP/l	0.1	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	14	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	1794	
Others			

COMMENTS:

A slightly saline water. May be used.

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Date 10.12.87

WATER ANALYSIS REPORT

Sample No. 1242
Source Maikona Communal Well, Marsabit
Date of Sampling 10.9.87

Date Recieved 24.9.87
Submitted by J.K. Rimberia-PC-
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	7.5	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	2.1	
Permanganate No. (20 min. boiling)	mgO_2/l	14	
Conductivity (25°C)	µS/cm	2860	
Iron	mgFe/l	0.5	
Manganese	mgMn/l	Less than 0.1	
Calcium	mgCa/l	9.4	
Magnesium	mgMg/l	51	
Sodium	mg/Na/l	470	
Potassium	mgK/l	-	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	225	
Total Alkalinity	$mgCaCO_3/l$	478	
Chloride mg Cl/l	mgCl/l	435	
Flouride	mgF/l	0.3	
Nitrate	mgN/l	-	
Nitrite	mgN/l	0.05	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	83	
Orthophosphate	mgP/l	0.1	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	30	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	1776	
Others			

COMMENTS: A slightly saline moderately hard water. May be used for domestic use in the absence of a better source.

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Date 9.12.87

WATER ANALYSIS REPORT

Sample No. 1240
Source KALACHA B/HOLE MARSABIT
Date of Sampling 10.9.87

Date Recieved 24.9.87
Submitted by J.K. RIMBERIA PC-EMB
Purpose of Sampling DOMESTIC

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	7.3	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	2.4	
Permanganate No. (20 min. boiling)	mgO_2/l	13	
Conductivity (25°C)	µS/cm	1430	
Iron	mgFe/l	0.3	
Manganese	mgMn/l	Less than 0.1	
Calcium	mgCa/l	15	
Magnesium	mgMg/l	54	
Sodium	mg/Na/l	140	
Potassium	mgK/l	-	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	296	
Total Alkalinity	$mgCaCO_3/l$	167	
Chloride mg Cl/l	mgCl/l	126	
Flouride	mgF/l	0.6	
Nitrate	mgN/l	-	
Nitrite	mgN/l	0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	104	
Orthophosphate	mgP/l	0.06	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	22	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	858	
Others			

COMMENTS:

Chemically suitable for domestic purposes.

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Date 9.12.87

WATER ANALYSIS REPORT

Sample No. 1243
Source DURKANA B/HOLE MARSABIT
Date of Sampling 14.9.87

Date Recieved 24.9.87
Submitted by J.K. RIMBERIA PC-EMBU
Purpose of Sampling DOMESTIC

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	7.4	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	1.1	
Permanganate No. (20 min. boiling)	mgO_2/l	14	
Conductivity (25°C)	μS/cm	845	
Iron	mgFe/l	0.6	
Manganese	mgMn/l	0.1	
Calcium	mgCa/l	50	
Magnesium	mgMg/l	40	
Sodium	mg/Na/l	49	
Potassium	mgK/l	-	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	227	
Total Alkalinity	$mgCaCO_3/l$	170	
Chloride mg Cl/l	mgCl/l	22	
Fiouride	mgF/l	0.5	
Nitrate	mgN/l	-	
Nitrite	mgN/l	1.2	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	14	
Orthophosphate	mgP/l	0.1	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	30	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	507	
Others			

COMMENTS:

Chemically suitable for domestic purposes.

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Date 9.12.87

WATER ANALYSIS REPORT

Sample No. 1245
Source LAKE TURKANA AT LONYANGALINI
Date of Sampling 15.9.87

Date Recieved 24.9.87
Submitted by J.K. RIMBERIA PC-EMB
Purpose of Sampling MONITORING

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	9.0	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	2.5	
Permanganate No. (20 min. boiling)	mgO_2/l	14	
Conductivity (25°C)	µS/cm	4290	
Iron	mgFe/l	4.2	
Manganese	mgMn/l	0.1	
Calcium	mgCa/l	1.5	
Magnesium	mgMg/l	3.6	
Sodium	mg/Na/l	1010	
Potassium	mgK/l	-	
Aluminium	mgAl/l	-	
Total Hardness	mg$CaCO_3$/l	22	
Total Alkalinity	mg$CaCO_3$/l	1178	
Chloride mg Cl/l	mgCl/l	511	
Flouride	mgF/l	8.0	
Nitrate	mgN/l	-	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO_4/l	30	
Orthophosphate	mgP/l	40	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	Nil	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	2574	
Others			

COMMENTS: An alkaline, slightly saline water, with high fluoride content. Unsuitable for domestic purposes

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Date 10.12.87

WATER ANALYSIS REPORT

Sample No. 1243
Source Kargi W/S B/H, Marsabit
Date of Sampling 13.9.87

Date Recieved 24.9.87
Submitted by J.K. Rimberia-Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	7.3	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	1.4	
Permanganate No. (20 min. boiling)	mgO_2/l	14	
Conductivity (25°C)	µS/cm	5590	
Iron	mgFe/l	0.2	
Manganese	mgMn/l	Less than 0.1	
Calcium	mgCa/l	8.6	
Magnesium	mgMg/l	33	
Sodium	mg/Na/l	88	
Potassium	mgK/l	-	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	93	
Total Alkalinity	$mgCaCO_3/l$	706	
Chloride mg Cl/l	mgCl/l	980	
Flouride	mgF/l	0.6	
Nitrate	mgN/l	-	
Nitrite	mgN/l	0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulpnate	$mgSO_4/l$	306	
Orthophosphate	mgP/l	0.1	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	96	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	3352	
Others			

COMMENTS: A moderately hard water, with excessive alkalinity. Should be avoided as a source of drinking water, and used only in the absence of a better source.

WATER QUALITY LABORATORY
P.O. BOX 30521, NAIROBI

J.M. Omwenga
Senior Chemist
Water Quality Laboratory
MINISTRY OF WATER DEVELOPMENT
NAIROBI

MINISTRY OF WATER DEVELOPMENT
Water Quality and Pollution Control Laboratory

Tel. No. 557088, Ext. 93
P.O. Box 30521
NAIROBI.

Date 10.12.87

WATER ANALYSIS REPORT

Sample No. 1249
Source Bubisa B/H Marsabit
Date of Sampling 16.9.87

Date Recieved 24.9.87
Submitted by J.K. Rimberia
Purpose of Sampling Domestic

PARAMETERS	UNIT	RESULTS	REMARKS
pH	pH Scale	7.7	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	1.2	
Permanganate No. (20 min. boiling)	mgO_2/l	14	
Conductivity (25°C)	µS/cm	3640	
Iron	mgFe/l	0.2	
Manganese	mgMn/l	Less than 0.1	
Calcium	mgCa/l	30	
Magnesium	mgMg/l	128	
Sodium	mg/Na/l	410	
Potassium	mgK/l	-	
Aluminium	mgAl/l	-	
Total Hardness	mg$CaCO_3$/l	694	
Total Alkalinity	mg$CaCO_3$/l	520	
Chloride mg Cl/l	mgCl/l	680	
Flouride	mgF/l	0.3	
Nitrate	mgN/l	-	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO_4/l	202	
Orthophosphate	mgP/l	0.1	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	62	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	2184	
Others			

COMMENTS: A slightly saline very hard water. Should be avoided as a source of drinking, and only used in the absence of better sources.

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Tel. No. 557088, Ext. 93
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Date 9th Dec. 1987

WATER ANALYSIS REPORT

Sample No. 1251
Source Sololo W/S, Marsabit
Date of Sampling 17.9.87

Date Recieved 24.9.87
Submitted by Rimberia-PC-Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	7.8	
Colour	mg pt/l	70	
Turbidity	N.T.U.	1.0	
Permanganate No. (20 min. boiling)	mgO_2/l	13	
Conductivity (25°C)	μS/cm	2080	
Iron	mgFe/l	0.2	
Manganese	mgMn/l	Less than 0.1	
Calcium	mgCa/l	67	
Magnesium	mgMg/l	97	
Sodium	mg/Na/l	170	
Potassium	mgK/l	-	
Aluminium	mgAl/l	-	
Total Hardness	mg$CaCO_3$/l	541	
Total Alkalinity	mg$CaCO_3$/l	456	
Chloride mg Cl/l	mgCl/l	230	
Flouride	mgF/l	0.3	
Nitrate	mgN/l	9	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO_4/l	242	
Orthophosphate	mgP/l	0.04	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	26	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	1248	
Others			

COMMENTS: Very g hard water. Should be avoided as a source of drinking Water.

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Water Quality and Pollution Control Laboratory

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P.O. Box 30521
NAIROBI.

Date 10.12.87

WATER ANALYSIS REPORT

Sample No. 1255
Source Sololo Mission B/H, Marsabit
Date of Sampling 18.9.87

Date Recieved 24.9.87
Submitted by Rimberia-PC-Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	7.3	
Colour	mg pt/l	10	
Turbidity	N.T.U.	4	
Permanganate No. (20 min. boiling)	mgO_2/l	13	
Conductivity (25°C)	µS/cm	2730	
Iron	mgFe/l	0.1	
Manganese	mgMn/l	0.1	
Calcium	mgCa/l	106	
Magnesium	mgMg/l	35	
Sodium	mg/Na/l	95	
Potassium	mgK/l	-	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	539	
Total Alkalinity	$mgCaCO_3/l$	262	
Chloride mg Cl/l	mgCl/l	137	
Flouride	mgF/l	1.2	
Nitrate	mgN/l	-	
Nitrite	mgN/l	Less then 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	405	
Orthophosphate	mgP/l	0.03	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	28	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	1638	
Others			

COMMENTS: A slightly saline hard water. May be used for drinking purposes only in the absence of a better source.

WATER QUALITY LABORATORY
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NAIROBI.

Date 9.12.87 ~~24x9x87x9. 12.9.87~~

WATER ANALYSIS REPORT

Sample No. 1257
Source LOGOLOGO B/HOLE, MARSABIT
Date of Sampling 19.9.87

Date Recieved 24.9.87
Submitted by J.K. RIMBERIA PC-EMB
Purpose of Sampling DOMESTIC

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	7.2	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	1.8	
Permanganate No. (20 min. boiling)	mgO_2/l	13	
Conductivity (25°C)	µS/cm	2210	
Iron	mgFe/l	0.3	
Manganese	mgMn/l	0.4	
Calcium	mgCa/l	47	
Magnesium	mgMg/l	73	
Sodium	mg/Na/l	73	
Potassium	mgK/l	-	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	421	
Total Alkalinity	$mgCaCO_3/l$	299	
Chloride mg Cl/l	mgCl/l	135	
Flouride	mgF/l	0.3	
Nitrate	mgN/l	-	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulpnate	$mgSO_4/l$	47[illegible].	
Orthophosphate	mgP/l	0.01	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	30	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	1326	
Others			

COMMENTS:

Slightly saline hard water, with high maganese content. Will require conventional treatment to improve the quality, otherwise an alternative source is recommended

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WATER QUALITY LABORATORY
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MINISTRY OF WATER DEVELOPMENT
Water Quality and Pollution Control Laboratory

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P.O. Box 30521
NAIROBI.

Date 18th Nowember, 1986

WATER ANALYSIS REPORT

Sample No. 1589
Source Raw Water-Kibirichia Furrow+ Meru
Date of Sampling 30-8-86

Date Recieved 10-9-86
Submitted by Rimberia-P.C. Embu
Purpose of Sampling Domestic

PARAMETERS	UNIT	RESULTS	REMARKS
pH	pH Scale	6.9	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	2	
Permanganate No. (20 min. boiling)	mgO_2/l	1.9	
Conductivity (25°C)	µS/cm	70	
Iron	mgFe/l	4	
Manganese	mgMn/l	0.09	
Calcium	mgCa/l	1.5	
Magnesium	mgMg/l	1.5	
Sodium	mg/Na/l	11	
Potassium	mgK/l	3.3	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	26	
Total Alkalinity	$mgCaCO_3/l$	36	
Chloride mg Cl/l	mgCl/l	3	
Flouride	mgF/l	0.22	
Nitrate	mgN/l	0.06	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	9.7	
Orthophosphate	mgP/l	0.06	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	4	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	43	
Others Silica	$MgSiO_2/l$	9.7	

COMMENTS:

The iron content is excessive. Requires its removal by flocculation, Sedimentation and filtration [illegible]

ANALYTICAL SERVICES SECTION,
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Senior Chemist
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MINISTRY OF WATER DEVELOPMENT
Water Quality and Pollution Control Laboratory

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NAIROBI.

Date 11th March, 1987

WATER ANALYSIS REPORT

Sample No. 1935
Source Murera Spring Meru
Date of Sampling 13-10-86

Date Recieved 31-10-86
Submitted by Rimberia P.C.Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	7.6	
Colour	mg pt/l	70	
Turbidity	N.T.U.	28	
Permanganate No. (20 min. boiling)	mgO_2/l	7.2	
Conductivity (25°C)	µS/cm	565	
Iron	mgFe/l	1.8	
Manganese	mgMn/l	0.05	
Calcium	mgCa/l	3.9	
Magnesium	mgMg/l	16	
Sodium	mg/Na/l	42	
Potassium	mgK/l	26	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	92	
Total Alkalinity	$mgCaCO_3/l$	293	
Chloride mg Cl/l	mgCl/l	12	
Flouride	mgF/l	0.33	
Nitrate	mgN/l	0.06	
Nitrite	mgN/l	-	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	4	
Orthophosphate	mgP/l	0.01	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	60	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	338	
Others		-	

COMMENTS: Slightly turbid water with excess iron content. Full conventional water treatment is recommended.

Senior Chemist
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NAIROBI.

MINISTRY OF WATER DEVELOPMENT,
WATER LABORATORY.

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NAIROBI.

6.5.85

CHEMICAL ANALYSIS OF WATER

Sample No....567....................... Date Received...1.4.85........

Source..Mwerabus B/Hole, Meru............ Submitted by..J.K. Rimberia...
P.C. Embu

Date of Sampling...21.3.85............ Purpose of Sampling..Domestic..........

PARAMETERS	-	RESULTS			
pH		8.2			
COLOUR	mg/pt/l	Less than 5			
Turbidity	N.T.U	1.2			
Permanganate No. (20 Min. Boiling)	$mgKmnO_4/l$	0.3			
Conductivity (25°C)	US/cm	245			
Iron	mgFe/l	0.2			
Manganese	MgMn/l	Less than 0.1			
Calcium	mgCa/l	17			
Magnesium	mgMg/l	16			
Sodium	mgNa/l	29			
Potassium	mgK/l	0.7			
Aluminium	mgAl/l	-			
Total Hardness	$mgCaCO_3/l$	120			
Total Alkalinity	mg CaCO3/l	106			
Chloride mg/Cl/l	mgCl/l	11			
Flouride	mgF/l	0.5			
Nitrate	mgN/l	-			
Nitrite	mgN/l	-			
Ammonia	mgN/l	-			
Total Nitrogen	mgN/l	-			
Sulphate	$mgSO_4/l$	2.1			
Orthophosphate	mgP/l	Less than 0.01			
Total Suspended Solids		-			
		-			
TDS		148			

COMMENTS:
Chemically suitable for domestic use.

J.M. Omwenga.
Chemist-In-Charge of Laboratory.

MINISTRY OF WATER DEVELOPMENT
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PROVINCIAL WATER OFFICE
RECEIVED
6 JAN 1987
P.O. Box 410 EMBU
EASTERN PROVINCE

Date 5th December, 1986

WATER ANALYSIS REPORT

Sample No. 1716
Source Kula Mawe B/Hole Isiolo
Date of Sampling 22-9-86
Date Recieved 26-9-86
Submitted by Rimberia P.C. Embu
Purpose of Sampling Domestic

PARAMETERS	UNIT	RESULTS	REMARKS
pH	pH Scale	8.4	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	0.5	
Permanganate No. (20 min. boiling)	mgO_2/l	Less than 0.1	
Conductivity (25°C)	μS/cm	1665	
Iron	mgFe/l	0.1	
Manganese	mgMn/l	0.01	
Calcium	mgCa/l	79	
Magnesium	mgMg/l	143	
Sodium	mg/Na/l	-	
Potassium	mgK/l	12.4	
Aluminium	mgAl/l	-	
Total Hardness	mg$CaCO_3$/l	640	
Total Alkalinity	mg$CaCO_3$/l	746	
Chloride mg Cl/l	mgCl/l	79	
Flouride	mgF/l	0.54	
Nitrate	mgN/l	2.1	
Nitrite	mgN/l	Less than 0.01	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO_4/l	38	
Orthophosphate	mgP/l	0.06	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	36	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	998	
Others		-	

COMMENTS: Hard, alkaline water which requires softening and alkalinity adjustment.

WATER QUALITY LABORATORY
P.O. BOX 30521, NAIROBI

for Senior Chemist
Water Quality Laboratory
MINISTRY OF WATER DEVELOPMENT
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MINISTRY OF WATER DEVELOPMENT
Water Quality and Pollution Control Laboratory

RECEIVED
13 APR 1987
P.O. [illegible] EMBU
EASTERN PROVINCE

Tel. No. 557088, Ext. 93
P.O. Box 30521
NAIROBI.

Date 17.3.88

WATER ANALYSIS REPORT

Sample No. 1937
Source Kinna B/H Meru
Date of Sampling 13.10.86

Date Recieved 31.10.86
Submitted by Rimberia-PC-Embu
Purpose of Sampling Domestic

PARAMETERS	*UNIT*	*RESULTS*	*REMARKS*
pH	pH Scale	8.7	
Colour	mg pt/l	Less than 5.0	
Turbidity	N.T.U.	0.7	
Permanganate No. (20 min. boiling)	mgO_2/l	Less than 0.1	
Conductivity (25°C)	µS/cm	1075	
Iron	mgFe/l	0.2	
Manganese	mgMn/l	Less than 0.01	
Calcium	mgCa/l	1	
Magnesium	mgMg/l	63	
Sodium	mg/Na/l	12	
Potassium	mgK/l	5	
Aluminium	mgAl/l	-	
Total Hardness	mg$CaCO_3$/l	300	
Total Alkalinity	mg$CaCO_3$/l	496	
Chloride mg Cl/l	mgCl/l	42	
Flouride	mgF/l	0.47	
Nitrate	mgN/l	0.72	
Nitrite	mgN/l	-	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	mgSO_4/l	6	
Orthophosphate	mgP/l	0.11	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	Nil	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	645	
Others -	-	-	

COMMENTS: A hard water that may require softening.

[illegible]
[illegible]
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Tel. No. 557088, Ext. 93
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NAIROBI.

Date 5th December, 1986

WATER ANALYSIS REPORT

Sample No. 1727
Source Boji wells Isiolo
Date of Sampling 22.9.86

Date Recieved 26-9-86
Submitted by Rimberia - Embu
Purpose of Sampling Domestic

PARAMETERS	UNIT	RESULTS	REMARKS
pH	pH Scale	8.2	
Colour	mg pt/l	Less than 5	
Turbidity	N.T.U.	7	
Permanganate No. (20 min. boiling)	mgO_2/l	0.95	
Conductivity (25°C)	µS/cm	1410	
Iron	mgFe/l	0.3	
Manganese	mgMn/l	0.03	
Calcium	mgCa/l	32	
Magnesium	mgMg/l	103	
Sodium	mg/Na/l	-	
Potassium	mgK/l	55	
Aluminium	mgAl/l	-	
Total Hardness	$mgCaCO_3/l$	582	
Total Alkalinity	$mgCaCO_3/l$	750	
Chloride mg Cl/l	mgCl/l	79	
Flouride	mgF/l	0.41	
Nitrate	mgN/l	2.0	
Nitrite	mgN/l	0.02	
Ammonia	mgN/l	-	
Total Nitrogen	mgN/l	-	
Sulphate	$mgSO_4/l$	18	
Orthophosphate	mgP/l	0.18	
Total Suspended Solids	mg/l	-	
Free Carbon Dioxide	mg/l	76	
Dissolved Oxygen	mg/l	-	
TDS	mg/l	845	
Others		-	

COMMENTS: Hard, alkaline water. Could be used in case there is no other source of suitable quality.

WATER QUALITY LABORATORY
P.O. BOX 30521, NAIROBI

for Senior Chemist
Water Quality Laboratory
MINISTRY OF WATER DEVELOPMENT
NAIROBI

VITA AUCTORIS

NAME: Martin Peter Mwangi

DATE OF BIRTH: May 21, 1955

NATIONALITY: Kenyan

EDUCATION AND EMPLOYMENT:

1962-1968	- Maragi Primary School, Murang'a, Kenya - sat for, and passed Kenya Certificate of Primary Education (C.P.E.).
1969-1972	- Murang'a High School, Murang'a, Kenya - sat for, and passed East African Certificate of Education (E.A.C.E.).
1973-1974	- Kianyaga High School, Kirinyaga, Kenya - sat for, and passed East African Advanced Certificate of Education (E.A.A.C.E.).
1975-1978	- University of Nairobi, Kenya - graduated with a B.Sc. (Hons.) degree in Geology.
1978-	- Hydrogeologist, Ministry of Water Development, Kenya.
1985-1988	- University of Windsor, Ontario, Canada, - to graduate with a M.Sc. degree in Geology with specialization in Hydrogeology.