THE HYDROGEOCHEMISTRY OF THE NDAVAYA-MRIMA AREA COAST PROVINCE KENYA

BY

MUSYOKI MUNYAO MUTHUKA

A thesis submitted in partial fulfilment for the award of a degree of Master of Science in Geology in the University of Nairobi

1994

DECLARATION

This thesis is my work and has not been presented for a degree in any University.

MUSYOKI MUNYAO MUTHUKA

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

Anyumba John

DR. J. ANYUMBA

Gaciri

Prof. S.J. GACIRI

ABSTRACT

The study involved hydrochemical determination, occurrence and distribution analysis in a 554km^2 area between Ndavaya and Mrima Hill in the Coast Province of Kenya bounded within the latitudes 4^0,14'S; $4^0$30'S and longitudes 39^0,10'E and $39^0$and 39^0,21'E and lying to the Southwest of Kwale town. This study is aimed at determining the physio-chemical properties for the water resources in the Ndavaya-Mrima Area, assess the extent of their contamination and identify the possible sources of pollution.

Borehole, spring, river and waterhole waters were sampled for analysis of both major constituents and trace elements. Temperature, pH, dissolved oxygen, electrical conductivity, total dissolved solids, total alkalinity, total hardness and total suspended solids were also determined. Analytical techniques used in chemical analysis include atomic absorption spectroscopy for the determination of Na$^+$, K$^+$, Ca^{2+}; Cu^{2+}; Fe^{2+}; Pb^{2+}and Zn^{2+}ion; specific ton electrode for fluoride ion measurement and X-ray fluorescence for the analysis of Fe^{2+}; and Mn^{2+}; ions and trace metals. Turbidimentry and titrimetric techniques were employed for the measurement of sulphate (SO_4^{2-}) ion and chloride (Cl$^-$), total alkalinity and total hardness, respectively. Magnesium (Mg^{2+}) ion was calculated from the total hardness and calcium (Ca^{2+}) ion concentration values. Trilinear diagrams, concentration maps and correlation coefficient analysis were also used in the synthesis of the physio-chemical data.

The groundwater flow in the Ndavaya-Mrima area is greatly influenced by topography, lithology and geological structures and is generally South-easterly. The concentration of the physical and chemical parameters determined show a general increase from north to south. Sulphate and silica ions are highly concentrated in the southern part of the study area with their contents decreasing in all directions away from this region. The ground water in the area have relatively high salinities, moderate alkalinities and in some boreholes high hardness. Iron and bicarbonate ion contents in the water resources are relatively high while the surface water has low fluoride concentration. Sodium and chloride ions are the most dominant cation and anion, respectively, with sodium values ranging from 13ppm to 1985ppm and chloride ion concentration values of between 18ppm and 3750ppm. The concentration of trace elements in the water resources of the Ndavaya-Mrima area is very low, generally below 0.1ppm surface waters have dissolved oxygen contents within the acceptable levels at the surface temperatureof determination. The thermal Kitoni spring- and Maji Moto river water are highly mineralised.

Surface waters in the study area are of sodium-chloride type. Other possible types of ground water found in some parts of the area are Calcium-magnesium-bicarbonate-carbonate and calcium-magnesium-chloride-sulphate waters. The hydrochemical study reveal that there is no notable contamination of the water resources by human activity in the Ndavaya-Mrima Area and the values of the physical and chemical parameters determined can virtually be attributed to geology. Minor organic pollution of surface water, largely from decomposing vegetation and some domestic and livestock wastes may be responsible for the diminished dissolved oxygen content observed in some water samples.

"Modern" sea water intrusion has insignificant influence on the ground water chemistry. "Ancient" sea water contamination of inland fresh water aquifers may account for the remarkably high concentration of mineral salts in the ground water. Hence the main source of the markedly high chemical constituents observed in the water resources is geological and there is hardly any external influence on the water quality.

Though general saline, with minor treatment most groundwater and all surface waters (except for the thermal Kitoni spring-and Maji Moto river waters) are suitable for all man's activities, namely domestic, industrial and agricultural use. However, of major concern are high salinities and hardness of some borehole waters, high bicarbonate, iron and silica and the relatively low concentration of fluoride ion in some water resources.

ACKNOWLEDGEMENTS

Acknowledgement s are greatly extended to Prof. S.J. Gaciri and Dr. J. Anyumba of the Department of Geology, University of Nairobi for their invaluable assistance and advice during this study. The preparation of this thesis owes much to the financial assistance given to me by the University of Nairobi. I am greatly indebted to the management of Kenya Marine and Fisheries Research Institute for facilitating necessary instruments to the staff of the Ministry of Water Development for their unlimited supply of borehole and water quality data and assistance in analysis of major cations and anions and some physical properties and the Kwale Water Sanitation Project for the provision of borehole log data and inevitable logistics.

My sincere thanks to Mr. Mureithi and Mr. Mangala of the Nuclear Science Centre, University of Nairobi for their assistance in trace element analysis using XRF MCA machine the Department of Geology for the provision of pH meter, conductivity meter and other valuable instruments. I am also greatful to Miss J. Dalu of Jomo Kenyatta Foundation and Miss D. Waita of the Ministry of Water Development for assisting in the typing of this work.

Finally thanks are due to all my colleagues Mr. G. Mailu, Mr.M.N. Masibo, Mr. K.T. Chege, and Mr. M.C. Gichaba for their helpful suggestions and encouragement and to my family for their courage, support and patience during the entire study.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

1. INTRODUCTION

Water is the most important natural resource in the world since without it there would be no life. Available reliable supply of water is one of the prerequisites to establishment and civil development of a community, and this calls for careful management of water resources so that demand for increasing supplies for the growing population and its civil development requirements are assured. In addition to being adequate in quantity, water must be of acceptable quality in order to sustain a health population. Thus, hydrochemical studies to determine water quality plays a vital role in attaining any meaningful economic planning and effective development. Due to water's strong dissolving capacity, all natural water bodies contain mineral salts in solution, the composition of these chemical constituents being strongly influenced by the elemental composition of the aquifer rocks.

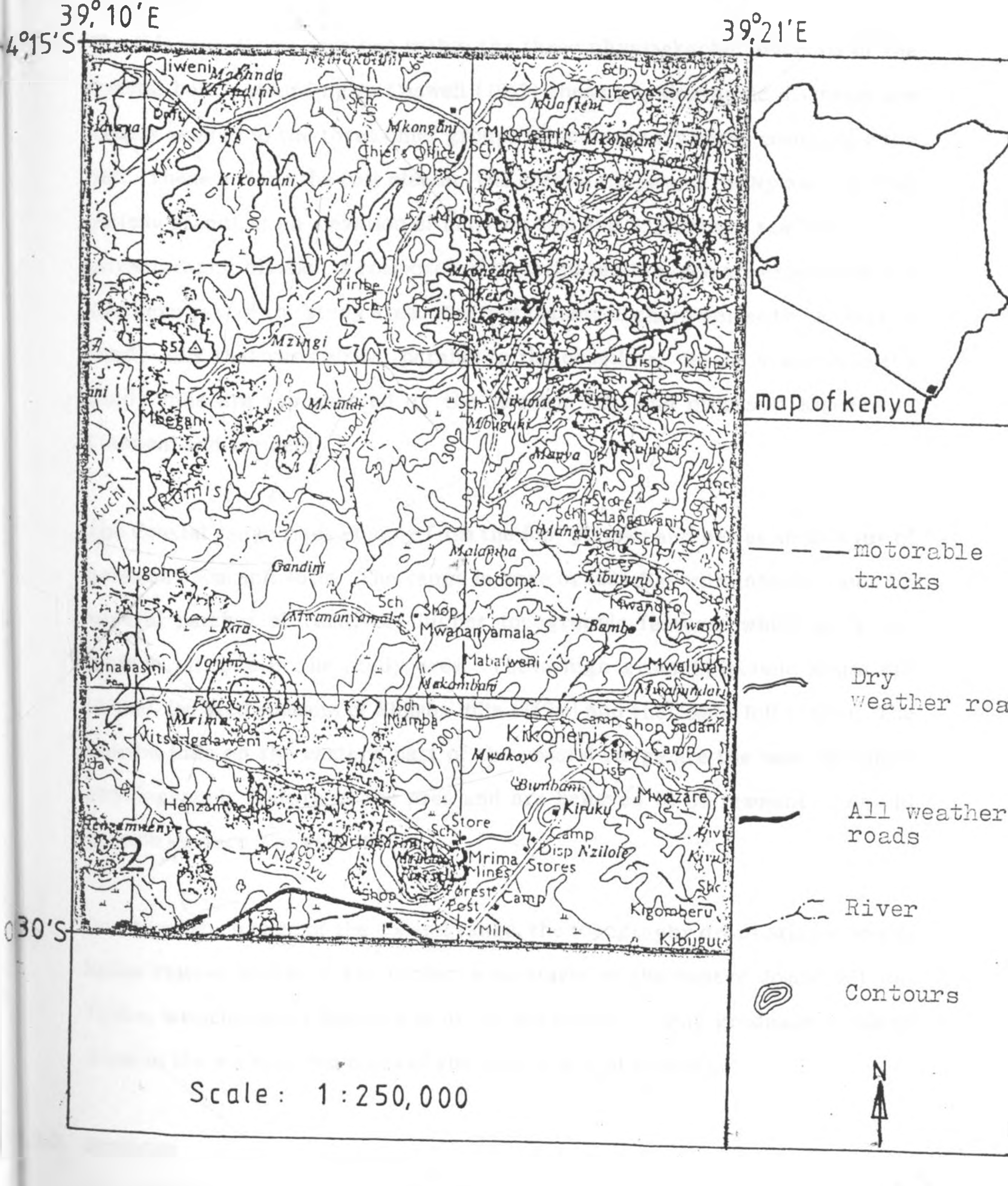
The Ndavaya-Mrima area has a typical geology of the coastal region, which consists of the Maji ya Chumvi beds, the Mariakani sandstones, the Mazeras sandstones and Shimba grits and the Magarini sands. Despite the expectedly high potential yields of these sedimentary formations most water obtained from these rocks is of poor quality and has for many years posed a serious problem to water planning and development projects in the areas. The population in the study area relies largely on ground and spring water supplies for its water requirements. The quality of these waters has been impaired by the saline nature of the aquifers which resulted from unfavourable Paleogeologic conditions under which the rocks were laid down. Surface water sources mainly rivers, water holes, ponds and earth dams have been identified as the most promising alternative water supplies to poor quality groundwater, not only in the Ndavaya area but also in most parts of Kenya. However, these water systems may drain saline catchments, consequently their quality would deteriorate with time as salts dissolve and precipitate from the underlying rocks.

In addition to natural contamination, artificial pollution of water resources threatens the utility of this natural resource for domestic, industrial and agricultural uses. Hence it is important to have a knowledge of the chemical composition of the water and understand the geologic and chemical factors, among others, contributing to anomalous concentration of salts in the water. The chemical analysis of water resources is necessary since the quality of water as determined by its chemical and biological constituents, its sediment content, among other properties, is of great importance in ascertaining the suitability of a particular water source for a certain use. Water quality management is an important phase of water resources development and it is only by maintaining constant monitoring and paying attention to water quality control that can guarantee reliable and good quality water supplies to the population.

1.1. Location and Communication

The Ndavaya-Mrima area is situated on the extreme South-Eastern corner of Kenya immediately South West of Kwale town, Coast Province (Fig.1). The study area covers approximately 554 km^2 and is bounded by the latitudes 4^0,15'S and 4^0,30'S and longitudes 39^0,10'E and 39^0,21'E. The entire project area includes the three hydrogeological zones of Kwale district as described by Norconsult (1985). Hydrogeologically the western and half of the northern portion of the study area falls within the Kwale hinterland while the central and north-eastern regions lie within the Shimba Hills, with the southern part lying within the Coastal zone.

The area under investigation is well served with a network of roads. However majority of these are earth roads which are generally impassable during wet seasons (Fig.2, in pocket). The only tarmacked road is the nearly East-West running Mombasa Mrima-Lungalunga road that traverses the area on the southern end.



Fi. 1. Locational Map of the Study Area.

1.2. Physiography

1.2.1. Topography

The Ndavaya-Mrima area lies within the three physiographic divisions of the Coastal belt. According to Caswell (1953) these physiographic divisions are closely related to the three chief groups of sedimentary rocks comprising the belt. These include the foot plateau, the coastal range and the Nyika. The foot plateau stands at an elevation of between 50m and 135m above sea level. This physiographic division is composed of Magarini sands which are exposed on the southern part of the study area. The foot plateau is characterised by a ridge of sandy hills that runs almost parallel to the coastline. In the study area the sandy hills are represented by the Marenje hill, and others at Kigombero, Kikoneni and Kivuleni.

The Coastal range rises steeply from the foot plateau and lies at an altitude of between 150m and 462m. The range is more or less flat with interruptions by several patches of relatively higher topographic features which mark the highest altitude in the study area. These high grounds include Mrima Hill (323m), isolated summits of Shimba Hills (350m) and the Jombo Hill (462m). The Shimba Hills on the eastern part of the coastal range are the most dominant physiographic feature in the area and are believed to be remnant of an old erosion surface (Caswell, 1953).

On the western edge of the coastal range, the topography drops steeply to the Nyika Plateau which, in the project area starts on the west of Jombo Hill and Tiribe, Mkomba up to Ndavaya at about 200 contour rising gradually to about 300m on the western boundary of the area (Fig.2, in pocket).

1.2.2. Drainage

The drainage system in the area consists of the Ramisi river and its tributaries Mkanda, Lovu, Chorochoro, Mkundi and Maji Moto.

The Ramisi river drains a rather saline catchment area in the dry lowlands of the coastal ranges and Nyika Plateau in the north-west (MOWD, 1974). It flows in an easterly direction before changing its course south of Mwaluvangaeshu where it takes a south-easterly direction. River Mkundi and Chorochoro drains the coastal ranges and flows along a north-easterly direction, while the Mkanda and Lovu rivers which drain the southern slopes of Shimba Hills have a north-south flow direction. River Maji Moto, which assumes a nearly east-west flow direction, drains the Agglomerate hill at Nguluku and discharges highly mineralised thermal waters into the Ramisi river. The general principal drainage trend follows the regional dip of the geological formations to the E-S-E direction with a secondary trend highly controlled by the geological structure, at right angles along the strike (Figs.2 and 3), Caswell (1953).

In the lowlands of the Nyika plateau the tributaries of the Ramisi river are known to contribute little to the runoff but are augmented by tributaries draining the coastal ranges, Mailu, (1983) and the springs east of Jombo Hill.

Numerous springs drain the coastal range particularly the Mazeras sandstones and Shimba grits, and the perennial ones among these maintain the dry season flow of the rivers. Many streams and springs flow during the wet season and tremendously increase the discharge of Ramisi river and its tributaries.

1.3. Climate and Vegetation

1.3.1. Climate

The climate of the study area is generally related to the regional climatic pattern of Kwale district, which according to Ojany and Ogendo (1973) falls within the modified equatorial climatic zone typical of the coastal region.

The dominant long rainy season is experienced from March to June with maximum peak over April - May period while the short rains fall within the months of October to December. The wettest areas are the southern and eastern parts with the climate getting drier towards the west and north of the study area. However, this pattern is not always consistent and occasionally there are local sporadic down pours, especially over the months of December and January. Table 1 below shows the rainfall distribution in the study area.

The annual maximum average temperature in the study area is about 32°C, generally higher in the hinterland areas in the west and slightly lower in the hilly eastern and son parts of the project area; while the minimum annual temperatures average at about 24°C, National Environment Secretariat, (1985). The maximum temperatures are felt over the months of January to March, while the period June -August experience the lowest temperatures in the year. Table 2 shows average monthly variation of temperature for the period 1985-1988 recorded at the Associated Sugar Factory Station.

1.3.2. Vegetation

The vegetation in the area varies with the climatic zones and is generally modified by man's activities. On the western slopes of the Shimba Hills the forest reserves lies within the lowland rain-forest vegetation zone, characterised by hardwood species like Chlorophora excelsa, while the lowland dry forest zone around Ndavaya and the wooded lowlands found to the west of Jombo Hill are dominated by Azekia quanzensis and Branchylaena hutchisii acacia species, shrubs and herbs. The lowland moist savanna vegetation zone found in the eastern and southern coastal lands is characterised by the tree species Vitex mobassae, Fernandoa magnitica and Ziziphus Mauritania. However, in most areas only small patches of remnants of these originally dense forests are visible as most of the vegetation has been cleared to give way to farming (NES, 1985).

The gazetted Mrima, Jombo and Marenje forests in the south are covered by dense vegetation of natural (indigenous) tree species with thick undergrowth of tall elephant grass. The dominant grasses in the area are the tall Digitoria mombassana (elephant grass), Parricum Maximum and Evagrotia rerbella species, National Environmental Secretariat (1985).

Table I. Average Monthly Rainfall(in mm) for Ten (10) Stations Recorded Over the Period 1982 - 1989

(Source of Data: Department of Meteorology, Ministry of Transport and Communication, Nairobi)

STATION	JAN	FEB	MAR	APR	MAY	JUNE	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	ANNUAL TOTAL (mm)
Associated Sugar Factory	53	204	81	160	170	79	64	57	65	61	99	110	1203
Kikoneni Agricultural Station	92	118	114	190	212	129	77	62	114	90	111	12	1321
Lukore Primary School	36	32	54	192	187	139	98	73	74	157	93	208	1343
Shimba Hills Marenje I	45	25	101	138	155	70	77	64	120	95	96	76	1062
Shimba Hills Settlement Scheme	81	51	71	153	218	108	116	95	77	135	121	138	1364
Kwale Forest Station	65	49	82	130	142	73	77	58	66	87	116	89	1034
Magarini Chief's Camp	154	70	86	164	166	113	74	82	51	84	134	181	1359
Ndavaya	110	39	106	174	139	78	58	62	49	99	90	106	1110
Kinango Agricultural Office	72	68	76	156	158	80	87	69	65	54	142	68	1095
Kinango Pumping Station	92	45	84	154	124	58	69	55	52	70	78	121	1002

Table 2. Average Monthly Temperatures for the Years 1985 - 1988 recorded at Associated Sugar Factory Station.

(Source of Data: Department of Meteorology, Ministry of Transport and Communication)

Temp. °C	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Max.	36.1	35.3	35.7	32.6	32.7	29.6	28.4	28.1	33.5	31.3	33.2	33.0	32.8
Min.	23.9	26.4	27.0	24.9	23.7	22.7	22.9	23.9	23.3	24.1	26.0	27.1	24.8

1.4. Soils and Agriculture

The soils found in the area vary with the vegetation, topography and geology. The relatively flat Nyika plateau in the western part and central region of the area is overlain by poor clay soils, except for occasional patches of better quality reddish brown sandy soils all of which are weathering products of the underlying Maji ya Chumvi and Mariakani shales, siltstone and sandstones. The regions underlain by the Magarini sands in the southern end are overlain by loosely consolidated brown, with reddish coating, sandy soils and alluvial deposits. The northern and eastern parts, where the Mazeras sandstones and Shimba grits outcrop, are characterised by relatively good agricultural brown to red sandy soils. The valleys and swampy lowland areas situated between the sandy ridges and hills are covered by alluvial, loam and waterlogged clay soils. However, the sandy soils in areas intruded by igneous rocks are greyish-black in colour.

A large part of the area is heavily cultivated with extensive growth of cashewnuts, coconut and citrus fruits and bixa as cash crops, while maize, cassava, rice, sweet potatoes, bananas and vegetables are the main food crops grown. However, the western parts are marginal agricultural areas although they are suitable for crops like maize, sorghum, cassava, millet and pulses. Until recently sugarcane has been extensively cultivated on commercial scale on the swampy lowlands and on the sandy ridges, especially in areas covered by Magarini sands.

Local farming methods are still adopted in the area with few cases of modern mechanization. Fertilizers are rarely used except in dusting tomato plants, citrus fruits and bixa trees.

1.5. Previous Work in the Study Area

Quite a substantial amount of hydrogeological work has previously been carried out in Kwale district as a whole.

Sikes (1934) carried out a nationwide study of ground water occurrence in Kenya. In his hydrogeological investigations it is observed that besides the rich characteristics of the water bearing Duruma sandstone series the quality of the ground water yielded is poor and generally bitter in taste. The Spring water from the Mazeras sandstone was found to be of good quality while the Jurassic Shales and limestones yield low quantities and very saline water. Despite the high ground water potential of the Magarini and Kilindini sands, Sikes (1934) noted that the water obtained from them, was too saline with high contents of calcium and magnesium sulphate and sodium chloride which greatly degraded its potability. The Pleistocene coral limestone and coral breccia of the coastal belt hold localised quantities of relatively fair quality water. However, this low mineralised but hard water exists only as shallow layers underlain by saline seawater.

In his geological mapping of the area between Mariakani and Mackinon Road, Miller (1952) observed that the Maji ya Chumvi beds have good groundwater potential where they are poorly cemented and well jointed but yield rather very saline water. The unevenly bedded Mariakani sandstones were found to yield water of slightly better quality and this was attributed to their placement in areas with relatively heavy rainfall.

Caswell (1953), in his detailed geological studies of Kwale/Mombasa area, remarked that the coastal sedimentary rocks are wholly unsuitable for large scale water supplies development. He attributed the high salinity of the water in these rocks to the nature of depositional environments of the rocks. He observed that water from Magarini sands was generally potable but due to the ferruginous nature of the sands the iron content of the water in some places was objectionably high. The coral limestone and coral breccia and Kilindini sands were noted to yield a hard but potable water.

Ongweny (1973) observed that there exists some close relationship between ground water chemistry and the mineralogical composition of the water bearing rocks besides other environmental and geographic factors which may modify the groundwater chemistry within any one given rock unit such that there is a considerable variation in the mineral content. On the variation of ground water chemistry with geology, Ongweny (1973) made the following conclusion about water quality in sedimentary formations:-

i) The soluble sedimentary rocks of coastal salinity contain groundwater of very high purposes, but with relatively low fluoride content. Chloride and sodium concentration in these rocks are found to by anomalously high.

ii) In the sedimentary formation of the semi-arid and arid north-eastern Kenya the ground waters have high content of dissolved solids.

Preliminary investigation of the water demand of the Mkongani and Mwaluphamba supply areas were conducted by Carl Bro. (K) Ltd. Consulting Engineers (1979) for the Mkongani water supply preliminary design project.

The study revealed that the groundwater resource in the area are insufficient and a borehole sunk to a depth of 130m at Mkongani proved unsatisfactory with very low yields.

Following a resistivity survey carried by Mwangi (1981) for groundwater in Msambweni area it was suggested that the sea water intrudes into the coral limestone from the sea in a "Wedge" form. He noted that the depth to the brackish water zone varies from about 10m to 40m and it extends inland from a few meters to 100m. Anomalously thick layers of very low resistivity values (20Ωm) were observed in the north-east and south-west of Msambweni area. Mwangi (1981) recommended that more geological investigations be carried out to establish the cause for the low resistivity values. He further suggested that water chemistry and resistivity investigations be carried out for each yielding horizon.

While studying the hydrogeology of the Athi River basin Mailu (1983) observed that the main aquifer types of the coastal area are those associated with Permo-Triassic sedimentary rocks and the Magarini and Kilindini sands. The Cainozoic sandy deposits form the shallowest aquifers in the area while deeper aquifers are observed in the Duruma sandstones which are normally associated with faulting. He noted that water from the sedimentary rocks is characterised by very high salinity hazards and medium to very high sodium hazards. Water from Kilindini sands was found to have relatively medium salinity hazards and extremely low sodium hazards and had the lowest dissolved solids.

In 1985, the National Environmental Secretariat carried out an environmental assessment of Kwale district. The study indicated that the surface and groundwater was contaminated by industrial effluent, agricultural chemicals, siltation and pesticide chemicals. The Kenya Lime Products Factory and the Kenya Bixa Factory were noted to be potential sources of contamination of groundwater. The Ramisi Sugar Factory which discharges untreated effluent into the Ramisi river was found to be a major source of pollution. The factory has since been closed. It was pointed out that besides inadequate water resources and financial limitations, provisions of potable or improved water in the area is constrained by the chemical nature of groundwater in some areas, siltation and contamination of surface water sources.

Geochemical studies of the geothermal area east of the Jombo Hill intrusion carried out by Tole (1985) revealed that the hot springs east of this intrusion consists of slightly saline and alkaline waters of pH 7.5. to 8.5 with surface discharge temperatures averaging 59°C to 70°C. He further noted that the Ramisi river water had a pH value of 7.8 and total dissolved solids values of 254ppm to 2622ppm.

A spring survey conducted by Norconsult (1986) for the Kwale community water and sanitation project in the Shimba Hills area found that the water quality of the springs is suitable for human consumption after some further treatment.

1.6. Justification and Objectives of the Research Project

1.6.1. Justification

Water is an excellent solvent and as a result all ground and surface - waters contain chemical constituents (mainly salts) in solution . The nature and content of these chemical constituents which determine the quality of the groundwater is influenced considerably by the composition of the subsurface formation, environmental factors and man's activities. The geochemical reactions between groundwater and thus, in effect, most of the observations made previously on the general quality conditions of the groundwater resources in the area are based on inadequate chemical data.

In areas like Ndavaya-Mrima where there is notably great variation in the quantity and quality of groundwater resources, a multi-disciplinary approach in investigating every available water resource in the area is necessary. This can only be achieved if the quality of all possible water sources is known.

According to reports by the Ministry of Water Development (1974) and Norconsult (1985), streams, rivers, waterholes, water pans, springs and in some areas surface water dams, serve as the most promising alternative water supply sources in many parts of the study area since groundwater of low salt content is scarce. However, for provision of health hazard-free water, the chemical quality of these water sources should also be known. Therefore, knowledge of the water quality and an understanding of the geologic and chemical factors (among others) contributing to the anomalous amounts of the chemical constituents in the water is of prime importance. The chemical analysis of water is necessary since the quality of the water as determined by its chemical and biological constituents, its sediment content, in addition to other properties, is of great importance in ascertaining the suitability of a particular water source for a certain use.

Besides the hydrogeologic environment and geographical factors, the quality of ground and surface water can also be affected by man's activities, particularly through the discharge of industrial and agricultural wastes. Though the area under investigation, is not so heavily urbanized to warrant any threat of industrial contamination of the water supplies, the increased modernization of the agricultural activities call for a careful and continuous observation of the effect of these practises on the water quality. The water quality data obtained in this study can be very important as a base for future water quality monitoring and other hydrogeological studies. This study intends in part, to establish the "ancient" seawater contamination of the groundwater quality as a possible source of the high mineral contents as this seems to be responsible for the great variations in the quality of ground water experienced in a large section of the coastal belt.

1.6.2. Objective of the Research Project

It is in a bid to achieve the above aims in the current hydrogeological investigation that the following objectives are considered:

i) To define the hydrogeological boundaries and identify the aquifers through a study of surface and shallow subsurface geology

ii) To determine the physio-chemical properties of surface and ground water and to assess the extent of their distribution in the study area

iii) To define and determine the anomalies of some heavy metals of the water in the study area

iv) To assess other possible sources of water contamination in the area.

CHAPTER 2

2. GEOLOGY

2.1. General

The geology of the study area is dominated by sedimentary rocks of ages varying from permo-Triassic to Recent, with minor projections of post-Cretaceous igneous intrusions. The main sedimentary rock formation found in the area fall into two well marked divisions,

1. The Duruma sandstone series and

2. The Cainozoic rocks.

A modified geological succession of the sedimentary rocks found in the area is shown in table 3 below.

2.2. Sedimentary Rocks

The sedimentary formation in this area are wholly composed of Cainozoic rocks and the Duruma sandstone series. The Duruma standstone series is the main sedimentary formation occurring in the study area. The series is divided into three broad lithological units with coarse sandstones and grits at the top and bottom of the succession and finer sandstones and shales in the middle of the succession (Caswell, 1953 and 1956; Miller, 1952; Williams 1962).

The various lithological subdivisions comprising the series are:

1. Upper Duruma sandstone series - Mazeras sandstone, and Shimba grits

2. Middle Duruma sandstone series - Mariakani sandstones, Maji ya Chumvi beds

3. Lower Duruma sandstones series - Taru grits

However, in this study area only the upper and middle series are evidenced.

Table 3: Strategraphic Succession in the Study Area

(Modified from Caswell, 1953)

ERA		PERIODS			LOCAL REPRESENTATIVE			LITHOLOGY	ENVIRONMENT	CLIMATE
CAIN-OZOIC	QUARTERNANRY	RECENT			River Deposits, Residuals			Alluvium, Colluvium & Residuals	-	-
		PLIOCENE			**Magarini Sands**			**Sands, Gravels**	**Deltaic and Continental**	**Semi arid**
MESOZOIC		**KAROO**	**TRIASSIC**	**UPPER**	**DURUMA SANDSTONE**	UPPER	Shimba Grits, Mazeras Sandstone	Grits and Arkosic Sandstone	Continental and Deltaic	Generally Semi-arid with periods of increased aridity
PALAEOZOIC				LOWER						
			PERMIAN	UPPER		MIDDLE	Mariakani Sandstone, Maji ya Chumvi beds	Thin Sandstone and Shales, Siltstone	Lacustrine One Marine Intercalation	
				LOWER		LOWER	TARU GRITS	Grits and Arkosic Sandstone	Lacustrine One Marine Intercalation	
			CARBONIFEROUS	UPPER						

The Duruma sandstone rocks are believed, for most part, to have been deposited under lacustrine or deltaic, and possible neritic conditions. Caswell (1953 & 1956) and Miller (1952) pointed out that the detritus which gave rise to the beds was eroded from the basement system further to the west and deposited in fluviatile, lacustrine, pludal and marine environment. A marine intercalation of carbonaceous material and limestone consisting of flora and fauna fossils in the lower part of the succession is known to exist from evidence obtained from a deep borehole drilled near Maji ya Chumvi (Miller, 1952). This suggests the possibility of the Maji ya Chumvi beds having been deposited in a marine environment, but of shallow brackish water.

2.2.1. The Middle Duruma Sandstones

The middle Duruma sandstones include the Mariakani sandstones at the top of the succession and the Maji ya Chumvi beds which conformably lie below the former. The Mariakani sandstone is observed in the North-Western part of the study area. The formation is composed of fine to medium grained flaggy sandstones, siltstone and silty shales. The Mariakani sandstone formation is divided into three units, lower, middle and upper Mariakani sandstones.

The lower succession consists of fine grained sandstones, and according to Caswell (1956), it dips North Eastwards at angles varying from 1^0 to 3^0. The rocks of the lower subdivision have widely spaced joints, many of which have been filled with secondary crystalline calcite with the muscovite occurring in bedding partings and is often associated with carbonaceous material. The middle and upper strata of the formation consist of shales and siltstone with occasionally massive gritty sandstone layers.

The Mariakani sandstones are composed largely of quartz and feldspar grains with mica (muscovite) as a common constituent of the shale intercalations. Other common minerals noted in these rocks are carbonaceous material, tourmaline, hornblende, silicon and apatite grains, while iron and manganese staining is commonly present along bedding planes and weathered rocks. The mottled

The Mariakani sandstones are composed largely of quartz and feldspar grains with mica (muscovite) as a common constituent of the shale intercalations. Other common minerals noted in these rocks are carbonaceous material, tourmaline, hornblende, silicon and apatite grains, while iron and manganese staining is commonly present along bedding planes and weathered rocks. The mottled siltstone are composed of the same constituents, with limonite and chloride acting as cementing agents. The shale gragements included in the mottled siltstone are evidence of penecontemptoraneous erosion (Miller, 1952).

In his detailed microscopic studies of the Mariakani sandstone formation, Miller (1952) observed that the constituent mineral grains of the sandstones are cemented by calcite, limonite and chlorite, and to some extent fine mica (muscovite) grains.

The Mariakani sandstone formation is well jointed and heavily fractured and faulted. These geological structures have greatly improved the permeability of the rocks thus making them be of good groundwater potential. But this is only so when the ground water recharge is substantial. The ancient sediments composing the rocks are thought to have been deposited in lacustrine environment, especially as can be observed from their generally relative consistence in grain size of the rocks, the frequent occurrence of ripple marks and the general absence of the series of marine fossils (Miller, 1952).

The Maji ya Chumvi beds are the most shally, but the least massive of the Duruma sandstones. These rocks are observed in the Central, South Western and the extreme North-Western of the area. The mentioned formation is composed of bluish black and greenish grey, grit and often micaceous shales with interbedded yellow, white silty sandstones. The formation is divided into three lithological units, namely lower, middle and upper Maji ya Chumvi beds. The lower Maji ya Chumvi bed consist of shales and siltstone with surbodinate sandstones and fragmental limestones. The succession overlie the highest beds of the Taru grits. Flora fossils have been found to occur in these shales, but are generally poorly preserved and rarely identifiable Caswell (1953). The middle and the upper successions of the Maji ya Chumvi formation are characterised by coarser sediments.

The middle strata consists of micaceous shales and siliceous sandstones and hard white calcareous siltstone and shales. The upper beds consists of sandstones, siltstone and shales. In the study area only the upper strata is represented.

Numerous fish fossils occur well preserved in the middle Maji ya Chumvi beds Miller, (1952). According to Caswell (1953 and 1956), these marine fish fossils furnish the only reliable evidence that marine horizons exist in the Duruma sandstone series. The Maji ya Chumvi formation is essentially considered to be a fluviolacustrine origin.

2.2.2. The Upper Duruma Sandstone Series

Rocks of the upper Duruma sandstone series comprise the Mazeras sandstone and Shimba grits. The formation consists of massive, cross-bedded quartzofeldspathic sandstones and grits with interbedded shales in the lower horizons Caswell, (1953). The rocks, are underlain by the Mariakani sandstones, but their relationship at the southern contact is uncertain. Like the middle Duruma sandstone series rocks, the upper Duruma sandstones are subdivided into the upper, middle and lower Mazeras sandstones and Shimba grits. The upper succession consists of coarse sandstones and grits of feldspathic composition with Shimba grits forming a resistant capping on top of the readily weathered Mazeras sandstones. The middle Mazeras formation consists of fine grained sandstones with interbedded shales while the lower beds are coarse feldspathic sandstones, with shally horizons. In the project area only the middle member of the upper Duruma sandstone series is found outcropping. The upper Mazeras sandstone and Shimba grits are believed to have been deposited under deltaic and lacustrine conditions. Mineralogical analysis of these rocks have revealed that the Mazeras sandstone and Shimba grits are cemented together by mica, feldspar, silica or calcite Caswell, (1953).

The upper Duruma sandstones are well jointed and fractured and their boundary with the middle Duruma sandstone rocks is often marked by intense fracturing and faulting (Fig.3, in pocket) which greatly improve the intrinsic permeability of the rocks.

2.2.3. The Cainozoic Rocks

The Cainozoic rocks in the area include representatives of Pliocene and Recent periods. The rocks include the upper Pliocene Magarini sands and the Quaternary deposits. In the study area they are exposed in the extreme southern and south-eastern regions. The sediments comprising the Magarini sands are mainly quartzose consisting largely of unconsolidated sands and gravels with silty and clayey enrichments. Included in the sands are fragments of Jurassic shales, salicified wood and pebbles of Precambrian Basement System gneiss. The quartzose and feldspar grains and other peblic gravels are believed to have been derived from the Duruma sandstones, the bulk of which the material comprising the Magarini sands was derived Caswell, (1953 & 1956) and Williams, (1962).

The Magarini sands form a belt of low hills running parallel to the coastline, and on their western side they are found abutting against the Duruma sandstones. Alluvial, colluvial and residual deposits of Quaternary period are common in the area and are mainly found in the swampy lowlands and river basins and also forming thin overburden layers blanketing the older Duruma sandstones from which they are weathered. Due to their poor consolidation, the Cainozoic rocks have excellent permeability and form good potential aquifers.

2.3. Igneous Rocks

Igneous rocks in the area comprise the alkaline complex of Jombo Hill which intrudes the middle Duruma sandstones in the south-western region (fig. 3, in pocket). This igneous complex consists of a major intrusive body at Jombo Hill, three associated satellite intrusions at Mrima, Kiruku and Nguluku hills and their subsidiary dykes Caswell, (1953). These intrusions largely form a plutonic complex composed essentially of agglomerates, carbonate and finite.

CHAPTER III

3. WATER RESOURCES

The study area relies mostly on groundwater and surface water resources for its domestic supplies and other uses. Direct rainfall water tapped from roofing contribute some important part to the water supplies, especially in the western part of the project area.

3.1. Surface Water Resources

The surface water supplies can be categorised into river stream, spring, waterholes and water pan supplies. The availability of surface water resources depends on the amount of rainfall, particularly its distribution in the area and over the year with the amount of surface runoff infiltration and evaporation being the principal determining factors on the river and stream discharges.

The major rivers and streams that drain the Ndavaya Mrima area have developed clear drainage channels throughout the shales and weathered geological zones such as the upper Duruma sandstone rocks, MOWD, (1974) and Norconsult, (1986). The drainage system is composed almost entirely of the Ramisi river and its tributaries Lovu, Mkanda, Mkundi, Maji Moto and chorochoro. Nearly all the stream and rivers are found draining the eastern half of the study area, have their origins on the southern and western flanks of Shimba Hills. This is the region which receives the highest rainfall in the area, and is also underlain by the relatively less massive upper Duruma sandstone rocks and the incoherent Magarini sands. The western half of the area underlain by the compact and massive middle Duruma sandstones, shales and siltstones is rather dry and except for the Ramisi river, is hardly drained by large streams. The Ndavaya-Mrima area, like most areas in the Kenyan Coast, Ongweny, (1973) and Majlu, (1983) is characterised by high diurnal temperatures and very high evaporation rates. Because of the relatively high infiltration rates due to thick unconsolidated and relatively permeable soil overburdens discharges are low and most of the surface runoff is lost through evaporation and infiltration.

Though surface water supplies play a vital role in providing the community with relatively fresh water, the majority of these rivers and streams are seasonal, hence these supplies are in a large part of only local importance. Lovu and Chorochoro rivers are dry in a large part of the year while Mkanda, Mkundi and Maji Moto depend solely on springs for their dry season flow. The Ramisi river is generally saline in most of its length in the north-western zone of the study area. However, most of its tributaries, which maintain its perennial flow, are saline free.

According to the Kwale district Hinterland and water Resources Report (1974) high salinity of the rivers observed even during seasons can be attributed to saline headwaters (catchments). The saline sediments of formation through which the rivers drain and the saline thermal springs (such as Kitoni Spring), can be sited as the source of the high mineral salts. Due to its proximity to the ocean the high salt content of surface waters in the area can probably be partly attributed to cyclic salting phenomena, especially sea spray from the ocean and salty dry fall out. Despite the relatively high salinity of some rivers, these waters augment waterholes, water pans and surface dam supplies in areas where groundwater quality is poor. River and streams are the main source of water for livestock in the area.

There are numerous springs that exist in the eastern part of the study area; these springs originate from the Mazeras sandstone and Shimba grits. Springs are a major source of water supply in this section of the area since they provide fairly good quality water. Except for the highly mineralised Kitoni spring all the springs investigated proved to be of moderately fresh water. As a result there is increased development and protection of these water sources from contamination by the Ministry of Water Development/SIDA project as they offer water of low mineral salt content than boreholes sunk in the same formations. However, many of the springs found in the study area are intermittent flowing only during rainstorm and shortly after MOWD, (1974) and Norconsult, (1985).

Seasonal water holes tapping shallow groundwater and water pans provide major source of water in a large part of the western region of the study area where groundwater quality have proven to be poor. Unfortunately many of these waterholes and pans dry up shortly after the rainy period though more water can be obtained by excavating in the alluvial sand deposits along the river valleys. In the hinterland area the Ramisi river water and other surface water resources are saline thus handicapping this water supply source. However, several earth dams have been constructed in these regions to tap rainwater and surface runoff in a bid to curb the salinity problem.

3.2. Groundwater Resources

The groundwater resources in the study area can be considered with respect to the various geological units forming the aquifer systems. The geology in the area studied can be distinguished into two major formations, the Duruma sandstone series which outcrop in most of the area, and the Cainozoic rocks composed almost entirely of unconsolidated or poorly cemented Magarini sands, alluvial and colluvial deposits in the southern part of the area.

The groundwater potential of the various rock units is very much dependent upon the degree of consolidation of the rocks, geological structures, climatic factors. The occurrence and content of shales, clay and siltstone intercalations and the degree of jointing, fracturing and weathering also influence the potential of groundwater occurrence in these formations. The more weathered, fractured and jointed the shales and siltstone are, the higher the potential for ground water occurrence and vice versa. The presence of these fine grained and less permeable shale and clay lenses has in some instances resulted in occurrences of minor multiple aquifers. This can be seen to be the case from some borehole logs drilled in the area (Appendix I). Otherwise from the borehole logs it can be observed that the shales and siltstone, when fractured, jointed and weathered, act as good water bearers. In general the logs indicate that the main water bearing formation in the study area are sandstones, particularly the poorly consolidated and coarse grained, fractured, or jointed and weathered strata. Even in most cases where the outcropping lithologies are sands, the boreholes tap water from sandstones underlying these sediments.

The yield of a given aquifer is determined by not only the lithological properties of the rock formation but also the borehole depth, groundwater recharge potential in the area and presence of geological structures. Thus, these other underlying factors do explain the poor correlation trend in the variation of borehole yields and the different aquifer materials (Table 4).

Table 4: Aquifer and Borehole Characteristics

Sample No. Location/Name		Forma -tion	Aquifer	Depth(m)	Water rest Level (m)	Elevation (m)	Borehole Yield (l/h)
C7265	Henzamwenye	MYCU	Weathered Sandstone	21	99.03	93.3	300
C7356	Mamba	MYCU.	Weathered Sandstone	40	6.0	133.3	1098
C7100	Makambani I	MYCU	Gravel	30	12.7	147.0	3600
C7369	Lira Majimoto	MYCU	Weathered Siltstone/Sandstone	40	13.4	70.0	2280
C856	Ndavaya	MYCU	Weathered Sandstone	109	16.0	142.0	1640
C8180	Mwananyamala	MYCU	Fractured/Weathered Shale/Siltstone	36	21.30	117.0	1118
C7354	Mrima Mabovu	MYCU	Weathered Sandstone	27	4.6	58.3	2400
C7368	Lira Godoma	MYCU	Weathered Sandstone	40	27.0	80.0	3630
C7279	Mkuduru III	MYCU	Weathered Sandstone	22	17.0	57.0	2280
C6731	Masimbani	MYCU	Weathered Sandstone	30	10.9	72.0	2598
C6732	Kikonde	MYCU	Weathered Sandstone	24	4.4	117.0	480
C7101	Makambani	MYCU	Weathered Sandstone	30	12.0	92.0	2024

C7355 Dzuni	MYCU	Weathered Sandstone	40	18.5	108.3	696
C7273 Mkuduru II	MYCU	Weathered Sandstone	21	7.0	87.0	360
C8192 Kichakasimba	MZ	Weathered Sandstone	80	22.2	150.0	480
C8188 Bshu Maendeleo	MZ	Weathered Sandstone	64	8.4	57.0	4500
C8191 Lukore Sec. Sch.	MZ	Weathered Sandstone	74	20.1	200.0	1200
C7271 Kirewe	MZ	Sands	8	2.0	242.0	300
C4824 Mkomba	MZ	Fractured Shale	140	30.5	217.0	600
C7364 Lira Mkatisya	MZ	Weathered Siltstone	38	6.8	70.0	2700
C4773 Tiribe	MZ	Weathered Sandstone	150	14.0	183.4	256
C4572 Mkongani	MZ	Weathered Sandstone	130	23.0	200.0	430
C6721 Kivuleni	MU	Loose Sands	40	0.8	33.3	3180
C5768 Kigombero	MU	Weathered Sandstone	33	24.5	100.0	720
C6670 Kikoneni Vibalani	MU	Weathered Sandstone	57	5.3	83.3	5700
C6723 Mrima Camp	MU	Weathered Sandstone	40	17.2	73.3	2430
C6771 Kikoneni Dispensary	MU	Weathered Sandstone	81	13.2	125.0	4387
C6733 Marenje II	MU	Weathered Sandstone	18	4.0	90.0	600
C7091 Marenje I	MU	Clay Sandstone	50	19.0	125.0	3420
C7093 Ganda	MU	Loose Sands	20	2.9	50.0	750
C7096 Mangwei	MU	Loose Sands	18	7.0	57.0	300

Table 4: Cont.

Legend

MYCU	-	Maji ya ChumviAquifer/Formation
MZ	-	Mazeras Sandstone & Shimba Grifts Aquifer/Formation
MU	-	Magarini Sands Aquifer/Formation
L/h	-	Litres per hour
M	-	Meters

3.2.1. The Duruma Sandstone Aquifers

The Duruma sandstone series form the main water bearing formation outcropping in nearly the whole project area, except for a small portion in the south. These formations, composed exclusively of sandstones, shales, siltstone, and grits are thought to have been deposited between the Upper Carboniferous and the Upper Triassic periods. Caswell, (1953 and 1956), Miller (1952) and Saggerson (1952) observes that these rocks are products of denudation of the basement system and laid down under fluviatile, lacutrine, deltaic and neritic conditions in a climate which alternated between arid and pluvial. It is also noted that the mineralogical composition of these rocks tend to be similar to those of the Precambrian rocks which are mostly quartzose, feldspathic and arkosic. The geochemistry of these rocks has great bearing on the chemical quality of the groundwater found in these regions. In the study area the three main divisions of the sandstone series comprise the Mazeras sandstone and Shimba grit, the Mariakani sandstone formation and the Maji ya Chumvi beds all of which form the consolidated aquifers in the area. Each of the three divisions have hydrogeological features which have an important control on their potential for development of useful water supplies.

The occurrence of groundwater in regions underlain by these rocks is determined by the presence of geological structures, in addition to the permeability and porosity of the rock formation. In the course of their deposition the sediments comprising these aquifers were gently folded and there was extensive complex faulting close to their contact with the basement rocks Miller (1952). Therefore, these rocks are important water bearers, and for most part where they are exposed they form local recharge zones. Another important factor controlling the amount of groundwater resources available in these rocks is their geographical location. As such the Mazeras sandstone and Shimba grit and some sections of the Maji ya Chumvi beds in the south are found in relatively wet zone with relatively positive groundwater potential. The Mariakani sandstones and a large section of the Maji ya Chumvi rocks outcrop in marginal areas of relatively little rainfall and, therefore, limited groundwater recharge, thus resulting in poor yields of boreholes sunk in these rocks despite their fairly good permeability.

3.2.1.1. Maji ya Chumvi Sandstone Aquifers

The upper formation of the Maji ya Chumvi beds outcropping in the area is composed of soft sandstones and hard quartzitic layers intercalated with soft micaceous shales. A marine intercalation is known to form a horizon within the upper strata of this formation hence greatly modifying the quality of the water found in these rocks. The entire Maji ya Chumvi series is thought to comprise of coarse sediments, mainly quartzose pebbles and is less consolidated than the Mariakani sandstones. Caswell (1953) and Miller (1952) noted that the Mariakani sandstone formation is an alternative of well jointed sandstones and shales, hence where climates favourable each jointed sandstone bed is a potential aquifer. Local recharge occurs throughout the whole region where permeable zones are exposed. Unlike other formations of the Duruma sandstone series, the Maji ya Chumvi beds are in general poorly jointed, fractured and are rarely faulted, except at their contact with other formations (Fig. 3, in pocket). This explains their relatively poor groundwater potential compared to other sandstone formations, and due to the marine horizon intercalation found in the succession their yield are of low quality.

The water bearing zones of the Maji ya Chumvi formation have been found to be fractured shales and weathered siltstone and sandstones. Some boreholes sunk into the upper Maji ya Chumvi rocks occasionally have high yields of fair quality. However, as it can be observed from the chemical analysis results (Table 7) water obtained from most boreholes drilled into this formation are highly mineralised for general human consumption. Groundwater in these rocks also occur at great depths such that boreholes sunk into these aquifers are among the deepest in the study area.

3.2.1.2. Mariakani Sandstone Aquifers

The Mariakani sandstones are found underlying most of the north western part of the study area. The rocks are composed of fine grained flaggy sandstones, silty shales and siltstone. These rocks are more sandy, massive and are largely made of poorly sorted inequigranular, subangular quartz and feldspar grains, the latter being considerably weathered Caswell (1953). The three successions into which the formation is divided are middle and lower Mariakani sandstones which do occur in this area but the upper strata exists only as inlier remnants within the middle and lower layers, most of it having been eroded away. During a geological survey in the Kwale district area Caswell (1953) and Miller (1952) noted that the whole Mariakani formation is well jointed with widely spaced joints. Many of these joints are, however, filled with secondary crystalline calcite while muscovites common in the bedding place partings is associated with carbonaceous material.

In general the Mariakani sandstones contain unevenly bedded permeable sandstone yielding variable quantities of moderately poor quality however, the quality of the water obtained from these aquifers show considerable variations. Some of the sandstones outcrop in areas of moderate rainfall hence they are more likely to yield successful boreholes as there is more improved groundwater recharge. Generally, groundwater potentials of these sandstone aquifers are good but the amount of water that can be obtained from boreholes drilled into the rocks depends on how well jointed and fractured or faulted the rocks are. The highly fractured and jointed or faulted rocks act as better aquifers. This observation can be exemplified by boreholes sunk at Kirewe and Mkongani (at depth of about 130m) which yielded very little quantities of water probably due to poor fracturing hence low permeability. The fact that a section of the Mariakani sandstone rocks occur in areas with much better conditions of rainfall provide reservoir sites for dams and weirs in the river valleys. With numerous streams flowing over it, regions underlain by these rocks provide better surface water supplies of good quality than groundwater supplies MOWD, (1974) and Norconsult, (1985). Groundwater in the Mariakani sandstones occur in great depths with boreholes drilled into these rocks being among the deepest.

3.2.1.3. The Mazeras Sandstone and Shimba Grit Aquifers

The Mazeras sandstone and Shimba grits consist of massive, cross-bedded quartz feldspathic sandstones and grits with interbedded shales in the lower horizon Caswell, (1953). The coarse Shimba grits which succeed the Mazeras sandstone are highly weathered and frequently kaolinized. These rocks are cemented together by mica, fine feldspar, silica or calcite with the former two as the most common minerals thus resulting in thick succession of loose sand deposits of moderately high porosity hence permeability. The contact between the Mazeras sandstone, Shimba grits and the Mariakani sandstones is often faulted and fractured (Fig. 3 in pocket). This coupled with the weak consolidation nature of these rocks make them very good aquifers with high yields of good quality water. They are also considered as the most likely sites for obtaining reasonable supplies of groundwater among the Duruma sandstone series, Norconsult, (1985).

The Mazeras sandstones and Shimba grits constitute what is often referred to as the Shimba Hills hydrogeological zone Norconsult, (1985) and have been mildly folded and faulted. A major syncline in the West of Kwale town runs in a nearly North South direction in the north-eastern part of the study area (Fig. 3 in pocket) forming a bowl like water basin storing a lot of ground water. Most of this water discharges out of the syncline bowl at Marere springs to the North, among others. The sandstone is also highly fractured and in addition to the numerous joints found in these outcrops induce a fairly high permeability on the formations.

Considering that the area underlain by these rocks receives fairly high amount of rainfall of well over 1000mm annually, a substantial portion of this water percolates into the ground through joints and fractures. Hence, the forest in the Shimba Hills National Reserves and its environs (Fig.2 in pocket) forms very important recharge zone for the Mazeras sandstone aquifers. As a matter of fact all the permanent springs and streams in Kwale district, except the Umba river, originate from the Shimba Hills Norconsult, (1985). The Mazeras sandstone rocks are drained by numerous springs some of which are perennial. Considering the fact that the highly fractured and jointed middle and upper Mazeras sandstone strata are underlain by a relatively less fractured lower succession of sandstones intercalated with shale horizons it appears that these springs occur at the contact between the more permeable upper successions and the less permeable lower layers which form a barrier to any further downward movement of percolating water. This argument can also be supported by the fact that most of these springs are intermittent, flowing only during the wet season when ground water recharge increase.

The seasonal occurrence of the springs can also, as observed earlier, be explained by seasonal variations, of groundwater table.

Groundwater in these formation is found at relatively shallower depth than in the older divisions of the Duruma sandstone series. Borehole yields in these rocks are also fairly high but the amount of groundwater extractable from the aquifers will improve with borehole depth, improved ground water recharge and presence of geological structures. Even though ground water obtained from these rocks is of fairly good quality the content of total dissolved solids is generally high.

3.2.2. The Cainozoic Rock Aquifers

The Cainozoic rocks include a thick series of terrestrial sands and gravels and various subsidiary sandy beds overlying the more consolidated and hard older Duruma sandstones. These rocks are confined to the coastal strip and include representatives of the Pliocene and Recent periods. Of most hydrogeological importance in this area are the Magarini sands which occur in the southern parts abutting the Maji ya Chumvi beds and Mazeras sandstone and Shimba grits. The Magarini sands are essentially of quartzose composition and were derived from the extensive weathering process of the Mazeras sandstones and other members of the older divisions Caswell (1953 and 1956). Intercalated within the sands are lenticular bodies of clay and argillaceous material (clay perticles) are frequently found mixed with sand and sometimes the clay act as cement and binding the sands into weakly coherent sandstones. However most parts of the deposits is unconsolidated, consisting largely of quartz and mostly weathered feldspars.

The Magarini sands have been noted to hold large volumes of particles) groundwater at relatively shallow depths. The large sand and gravel pebbles comprising this formation make them highly porous hence permeable. The sand deposits outcrop in regions of heavy rainfall with the result that a large part of this precipitation leads to local recharge through the highly permeable Magarini sands to become groundwater.

In some places shallow boreholes drilled into these sands yield reliable quantities of good quality groundwater. The borehole at Kivuleni (at altitude of 22m above sea level) was drilled to a depth of 40m below sea level and yet the water extracted has a very low total dissolved solids value. However, boreholes dug deep in such sands may result in tapping mineralised groundwater from the underlying older Duruma sandstones. Such a case is exemplified by other boreholes drilled in the sands.

3.3. Groundwater Recharge and Groundwater Flow

3.3.1. Groundwater Recharge

The groundwater occurrence and distribution in any given water bearing formation in a given area is dependent upon the amount of groundwater recharged into the affected soil/rock formation. The recharge water, together with the nature and characteristics of the aquifer control the volume of water that the rock formation can hold in storage or/and release and in part determine the suitability or potentiality of the aquifer for groundwater development. Generally, infiltrating precipitation is the principal source of groundwater recharge in many areas (Robson and Souza, 1981). The distribution of water recharge is in many cases controlled by topography such that areas of high altitude generally receive more precipation than lower areas. In the study area the topographically high regions of Shimba Hills, Jombo and Mrima Hills and neighbouring areas are the principal zones of groundwater recharge. In the study area closeness to the ocean is one of the factors that control the amount of rainfall, hence the quantity of water recharge into the aquifers.

The entire study area can be considered as a single groundwater basin with the various lithological subdivisions as groundwater sub-basins since all the rock outcrops in the area, except for the igneous intrusions which are potential aquifers. As pointed out earlier in previous sections shallow ground water recharge in this area occurs locally in all regions where rocks of favourable permeability are exposed. The quantity of infiltrating water is also determined by the amount of rainfall received in a given locality. The rocks exposed in the north-western part of the study area receive very little surface recharge and relies largely on subsurface recharge further to the North. This results in longer residence time of the water in the aquifers and subsequent high mineral salt concentrations as observed from the chemical quality data of groundwater recharge in the area. Another possible source of groundwater recharge in the area is percolation of river and stream water below the river or stream bed. However, this phenomenon is only significant during the rain periods (when discharge is high) as most of the streams and rivers in the area are seasonal.

3.3.2. Groundwater Flow

According to proceedings of an advisory group meeting on the interpretation of environmental isotope and hydrochemical data in groundwater hydrology, Vienna (1976) the regional groundwater flow in a given groundwater basin(s) can be defined as the movement of ground water caused by natural potential differences at a rate perceptible on the human time scale and over distances commensurate with common land forms and structures. The influence of topography on groundwater flow is clearly illustrated in this area. Here the subsurface water seem to flow from the high grounds (altitude) at the Shimba Hills areas in the North towards lowland discharge areas in the South and South-east. In general, the groundwater in this area flow in a North-South-Easterly and North-South directions in conformity with the general South-East dip of the formations. However, the igneous intrusions and other geological features and/or structures particularly faults, appear to have a strong controlling effect on the groundwater flow. This effect is depicted in the central and southern parts of the area where the Jombo Hill complex and its subsidiary intrusions and the South-Easterly or sometimes North-South downthrows of the faults, cause a dispersion effect on the general groundwater movement, thus creating modified local flow directions (Fig.5).

Groundwater flow is also dependent upon the amount of local recharge into the aquifers. In the study area water recharge occurs in all regions where rocks of favourable permeability are exposed and precipitation is sufficient to provide enough infiltrating water. As a result, the highly fractured feldspathic agglomerate intrusions, which usually outcrop in areas of heavy rainfall, act as local recharge zones. This can be observed at Mrima Hill and Kiruku intrusions where the groundwater movement in these regions maintain its South-Easterly flow direction.

An understanding of the nature of groundwater movement in drainage basins is a prerequisite to hydrogeological investigation since no satisfactory solution to groundwater exploitation problems can be achieved without knowing the water shed/basin in a region, the distribution of water potential, transmissivity, recharge and discharge zones, (proceedings of an advisory group meeting, Vienna, 1976). A definition of the groundwater flow characteristics of a basin and a distinction of the water recharge and discharge zones are important in groundwater development and planning as reasonable yields from boreholes can be obtained when they are correctly sited.

Boreholes and wells sunk into formations outcropping at or near discharge zones may yield relatively reliable quantities of water supplies.

Groundwater movement studies are also important in hydrochemical mapping in that in many instances the chemical composition of a groundwater body, and even spring and river waters into which the groundwater can be discharged, will be influenced by how effective the groundwater movement is (Ongweny, 1973, Maina, 1982 and Mailu, 1983).

CHAPTER IV

4. METHODOLOGY OF FIELD WORK

4.1. Water Sampling and Field Data Collection

The investigations in the area involved collection of borehole, spring- and river water samples for chemical analysis. Two water holes were also sampled. Hydrochemical data for another twelve boreholes were obtained from achieves so as to permit thorough investigation conclusions on the water chemistry in the area.

The river water was sampled at several locations along the course of Ramisi river and its tributaries Mkanda, Lovu and Maji Moto streams. The water was collected as close to the middle channel as possible. The spring water was collected from flowing springs and close to the discharge point to ensure that the water sampled was representative enough. For non-flowing springs and water holes the samples were collected several centimetres below the surface. The boreholes in the area are all fixed with handpumps and not connected to tanks. Therefore, the water samples were collected just below the pump outlet after the borehole water was allowed to run out for sometime.

Two sets of water samples were taken from each sampling site. The water was collected in half litre pre-cleaned polythene bottles acidified with a few drops of metal free nitric acid. In the field the bottles were rinsed at least twice with the water to be collected before they were filled. A few drops of nitric acid were added to the first set to prevent any bacterial activity or any possible precipitation of metals. The set of water samples collected was stored without treatment.

The untreated water samples were used for the determination of total suspended solids (TSS), measurements of bicarbonate and carbonate ions, alkalinity, hardness and laboratory determination of conductivity at 25°C, which was later used to estimate the total dissolved solids (TDS) content of water. The whole water sampling process was conducted over one period between August and December, 1989. This was meant to avoid any effect of seasonal variations that would grossly affect water chemistry.

Some physical parameters such as the ambient temperature, pH and conductivity of the water were also determined. Dissolved oxygen content of the surface water bodies was also measured. The field investigations also included collection of well log data from the on-going Kwale Water and Sanitation Project at Kwale. Some other data on well logs were obtained at the Drilling Section of the Ministry of Water Development Headquarters. This information was used for subsurface geological study, especially in identification of the various aquifers penetrated by boreholes. Information on water yield data for several borehole was also obtained and used in the discussion of the general groundwater hydraulics of the aquifers. Since there are no opening provisions at the handpump head measurements of water static levels were only obtained from the data bank office in Kwale (SIDA) and Ministry of Water Development headquarters, Nairobi.

4.2. Field and Laboratory Analysis of Water Samples

All the chemical analysis and some physical property determinations of the water samples were carried out using the standard methods for examination of water as stipulated in the American Public Health Association (APHA), American Water Work Association (AWWA) and Water Pollution Control Federation (WPCF 1985), Andrews (1972) and Minear and Keith (1984).

4.2.1. Physical Properties Analysis

Physical water properties determined at the field included dissolved oxygen (D.O.), pH, temperature, total suspended solids (TSS), total dissolved solids

(TDS) and conductivity of water samples. The dissolved oxygen (D.O) content of the surface water was determined insitu using a Syland scientific oxygen meter model GMBH D-6148.

The water pH measurements were taken using a portable Hatch digital pH - meter model 19000. The pH values for surface waters were determined in the field whereas for groundwaters the pH measurements were made immediately after collecting the water, and as such these pH determinations can be considered to be representative of the shallow aquifer and surface water conditions. Water temperatures were taken using the temperature electrode of a portable PCM1 conductivity meter model 128662TG, which was also used to determine the specific electrical conductance of the water at the field conditions. However the electrical conductivity of the water samples was later measured in the laboratory at standard temperatures of 25°C. These conductivity values were used to estimate the total dissolved solids (TDS) concentration of the water by multiplying the former by a factor of 0.6. This was done assuming that the conductivity is proportional to the TDS in water since most dissolved solids impart the ability to conduct electricity to water Andrews, (1972), Bouwer (1978) and Mancy, 1973). Similarly the pH values at which the content of bicarbonate (HCO^-_3 ions were determined were measured in the laboratory since these parameters were determined at a much later date after sampling. The temperatures are in degrees centigrade (°C)while the water conductivity and TDS are reported in microsiemens per centimetre (µs/cm) and ppm, respectively.

Measurements of total suspended solids (TSS) content was not done for groundwater since its content is negligible. The TSS value were determined by filtering a 100 ml volume of each water sample through a dried and pre-weighed filter paper. The residue was dried in an oven at a temperature of about 105°C and allowed to cool, after which it was re-weighed. The difference in weight is due to suspended solids in the sample volume used. The total suspended solids content of the samples, which is expressed in parts per million (ppm), was calculated from the following equation (Andrews, 1972)

$$TSS = \frac{\text{Difference in Weight x 100mg/1}}{\text{ml sample used}} \quad \text{........ eq 1}$$

4.2.2. Total Hardness,Total Alkalinity,Bicarbonate HCO_3^-) and Carbonate (CO_3^{2-})Ions

For the determination of the total hardness of the water the samples were titrated with EDTA titrant. The amount of total hardness was calculated from the volumes of the titre and sample used using the following expression (APHA, AWWA, WPCF, 1985).

$$\text{Total hardness as mgCaCo}_3\text{/1} = \frac{A \times B \times 100}{\text{ml sample}} \quad \text{...... eq. 2.}$$

Where A =ml titre (EDTA)
B = mg $CaCo_3$ equivalent to 100 ml EDTA

Titrimentric method was also used in the determination of total alkalinity. The water samples were titrated with standard indicator. The total alkalinity using methyl orange indicator. The total alkalinity content of the water expressed as mg $CaCo_3$/1 was calculated using the following equation (APHA, AWWA, WPCF, 1985)

$$\text{Alkalinity mg CaCo}_3\text{/1} = \frac{A \times N \times 50{,}000}{\text{ml sample}} \quad \text{..... eq.3.}$$

Where A = Volume of standard acid used
N = normality of standard acid:

Bicarbonate and carbonate ions were determined by titrating the water samples with a standard sulphuric acid solution of 0.01 normality using cresol red and bromocresol green indicators. The carbonate and bicarbonate ion content of the water samples, which was expressed as milligrams calcium carbonate per litre (mg $CaCo_3$/1) were determined from the following relationships:

Results of	OH Alkalinity as $CaCo_3$	CO^{2-}_3 Alkalinity as $CaCo_3$	HCO^-_3 Alkalinity Titration $CaCo_3$
P=0	0	0	M
P=1/2m	0	2P	M-2P
P=1/2m	0	2P	0
P=1/2m	2p-m	2)m-p)	0
P=m	m	0	0

The phenolphthalein and methyl orange alkalinities were calculated in the same way as total alkalinity above. The carbonate (CO_3^{2-}) alkalinity value expressed as mg $CaCo_3/1$ is taken as the carbonate ion content of the water while the HCO_3^- alkalinity values are considered to be equal to the bicarbonate ion concentration when expressed as mg $CaCo_3/1$.

4.2.3. Major Cations and Anions Analysis

The major cations and anions analysed included sodium, potassium, calcium, magnesium, chloride, sulphate, and fluoride ions. The chloride ions concentrations in the water are determined by argentometric method with acidified standard silver nitrate solution of 0.0014 normality as titrant and potassium dichromat (K_2CrO_4) solution as indicator.

$$\mathrm{mgCl^-/1} = \frac{A \times N \times 35.450}{\text{ml sample}} \quad \text{......... eq.4.}$$

Where A = Volume of $AgNO_3$ solution used
N = Normality of $AgNO_3$ solution.

Turbidimentric method was applied in the determination of the sulphate ion content. Barium chloride crystals were added to known volumes of water samples acidified with hydrochloric acid to form barium sulphate turbidity whose absorbance was later measured by a turbidimeter model 2100A. The sulphate ion concentration in the volume of water used was determined by comparison of readings from a standard calibration curve. The fluoride ion concentration determinations were carried out using the Orion Research Specific Fluoride ion electrode model 96 - 09 - 00.

Due to their relatively low excitation potentials and the simplicity of the emission technique (Minear and Keith, 1984) the sodium (Na^+) and potassium (K^+) ion concentrations were determined by flame atomic absorption spectrometry. The Na^+ and K^+ ion concentration are reported in milligrams per litre or ppm. The calcium (Ca^{2+} ion concentration expressed in parts per million (ppm) was determined by titration using Ethlenediamine tetracetic acid (EDTA) titrant at a pH of about 12 to 13. The calcium value was calculated from the following equation:

$$\mathrm{mgCa/1} = \frac{A \times B \times 400.8}{\text{ml sample}} \quad \text{.....eq.5.}$$

A = ml of titrant (EDTA)
B = $mgCaCo_3$ equivalent to 1ml EDTA titrant at the Ca - indicator end point.

Magnesium (mg^{2+}) ion concentrations in parts per million were calculated by determining the difference between total hardness value and calcium ion concentration using the expression;

$$\text{Hardness}\,(\text{mgCaCo}_3/1) = 2.497(\,\text{CA,mg/l})\; 4.118(\,\text{mg,mg/l}\,) \;....\; \text{eq. 6.}$$

4.2.4. Silica, Iron(Fe), Manganese(Mn) and Trace Metal Analysis

Two analytical techniques were used to analyse Iron, Manganese and trace elements concentrations. Pye Unicam Atomic Absorption Spectrophotometer (AAS) model SP191 was used in the determination of iron (Fe), manganese(Mn), copper(Cu), lead(Pb) and zinc(Zn) metals by direct aspiration of filtered water samples (Levinson, 1979).

All the trace metals, including iron and manganese, were also determined separately using XRF MCA machine. The XRF method is a simple, rapid and accurate analytical technique but, unlike AAS, it allows simultaneous determination of trace metals; it permits sensitivity below 0.1. ppm concentration and as low as 200mg/1 (Watanabe, Berman and Russell, 1972). The method has special sensitivity and characteristics over most other techniques in that it has a broad analytical range since an element can be determined from the ppm level up to percentages. It has a good precision and is affected little by concentration. In contract to AAS, it is non destructive and a single paper disc could permit the determination of several elements simultaneously. Its application to multi-elemental qualitative and quantitative analysis, together with and its simplicity, rapidity and high sensitivity has made it one of the methods widely used in trace metal analysis in water.

The concentration of silica ions in the water was not determined. However, for the purpose of this study values of silica content in groundwater for some borehole samples were obtained from the Kwale district water and sanitation project.

4.3. Data Synthesis

The well log data collected has been used in the study of the general subsurface geology , especially in identifying the various lithological units from which the boreholes studies tap their water. The static water levels have been used to construct a water contour map from which the flow direction of the groundwater system in the area has been drawn using the triangular method (Fig.5 page 26) A locational map of the sample sites (Fig.4 in pocket) has been prepared. This has been used to interpret the data in terms of the geology, among other factors.

The chemical analysis data have been tabulated to illustrate the chemistry of ground and surface waters in the study area and for interpretation and discussion of geology and other factors. Correlation coefficient ratios were calculated for the trace elements, major cations and anions determined. The correlation coefficients of the major ions assist in the interpretation of the ground and surface water chemistry in terms of the geology and other variables, and more so, in establishing the possible cause of the obviously high salinity and hardness observed during this investigation.

A comparison between the concentrations for the chemical constituents determined in accordance to potability norms set by the World Health Organisation (WHO) and the Kenya Government. The observed concentrations of the minor elements and major ions has also been studied for evaluation of the suitability of the waters for industrial and agricultural uses besides domestic applications.

The chemical data of Na^+, K^+, Ca^{2+}; Mg^{2+}; So_4^{2-}; Cl^-, Co_3^{2-} and HCO_3^- ions was plotted on a multivariate trilinear piper diagram to ascertain the various types of water in the study area. Several concentration (hydrochemical) maps of all major cations and anions, including salinity (as TDS), alkalinity and total hardness have been drawn to show the water quality variations in the area. Sodium salinity and bicarbonate hazards have been calculated from the chemical results. Sodium absorption ratio (SAR) values were also calculated. This has enabled classification of the water resources of the area for irrigation purposes.

CHAPTER V

5. HYDROGEOCHEMISTRY

5.1. Introduction

The chemical composition of water is a result of the spectacular characteristic of its ability to dissolve a greater range of substances (Johnson, 1972). This excellent solvent property of water in addition to the relative ease with which a mineral or rock material is dissolved, biological activities taking place in the near surface soil, prolonged contact between percolating groundwater and the solid phases through which water flows, subsurface temperature and other physio-chemical phenomena are responsible for the chemical composition of a given groundwater system. Surface waters are also charged with chemical substances in solution, including suspension picked up by the water as it flows in the drainage channels and from the rock and soil materials over which it flows as surface runoff. Thus, in general, the chemical composition of water is a reflection of the geological environment of its occurrence, climatic, biologic, hydrologic, and geochemical processes operative in the given environment (Ongweny, 1973 and 1975). In addition to geologic hydrological and hydrogeological (both "ancient and modern") factors, the quality of water resources can be greatly influenced by human activities through disposal of domestic, municipal, industrial and agricultural wastes.

The chemical composition of most springs deriving water from the subsurface is generally similar to that of the groundwater since they are likely to tap water from the same geological formations and their quality will vary with season depending on variations in the groundwater recharge.

In this chapter a general consideration of the quantitative and qualitative analyses of the various water characteristics controlling the uses into which the water can be put into is given.

5.2. Quantitative Analysis of Chemical and Physical Constituents

5.2.1. Physical Properties

5.2.1.1. Dissolved Oxygen (D.O.)

The factors that determine the amount of dissolved oxygen in a given water body include salinity, barometric pressure, the nature and degree of activity of organisms and pollutants present (Klein, 1971 and Andrews, 1972). The concentration of dissolved oxygen is an important index in water purity as it is one of the first indications of the presence of organic pollution, particularly river water. The concentration of dissolved oxygen in water should not be less than 5 ppm. However this limiting value varies greatly depending on the above factors.

Dissolved oxygen contents were determined insitu for river, waterholes, and spring water only. From the values obtained (table 5) it can be noted that the amount of dissolved oxygen in the water is very much dependent upon the ambient water temperature. Waters with higher surface temperatures recorded less amount of dissolved oxygen. The concentration of dissolved oxygen in the water in the study area varies between 0.5ppm for the thermal Kitoni springs (with discharge surface temperatures of about 49.7°C) to a maximum value of about 6.9 ppm at 21.9°C water temperature. The surface waters have an average dissolved oxygen content of about 4.9 ppm.

5.2.1.2. Total Suspended Solids (TSS)

Unlike surface waters, groundwater in thw studt area contain negligible quantities of suspended matter. The nature or type of this suspended matter vary widely and may include living or dead micro-organic flora and fauna, human, plant and animal wastes, silt and clay and a variety of industrial waste

(Andrews, 1972). As such it has been found rather difficult to set acceptable standard for the content of total suspended solids for drinking water. Suspended matter is very objectionable in rivers and other open surface water systems because it may introduce pathogenic organisms, cause putrefaction and a diminished dissolved oxygen content (Klein, 1971). The mineral and organic matter in a channel may lead to silting, and by blanketting the stream it can cause destruction of flora and fauna in the stream or river. In addition presence of grit material can have abrasive action which can cause physical harm to aquatic life. In general, water with suspended matter may be aesthetically objectionable. The waterhole at Kirewe have the highest TSS value of 333 ppm while thermal Kitoni springs and Majimoto river have the lowest TSS values of 10 ppm and 13 ppm, respectively.

Surface water in the study area have very low contents of suspended matter (Table 6). the water hole at Kirewe have the highest total suspended value of 333 ppm while the thermal Kitoni springs and Maji Moto river have the lowest total suspended solids of 10 ppm and 13 ppm, respectively.

5.2.1.3. Conductivity

The specific electrical conductance of a water sample is taken as a measure of its ability to conduct electric current and is generally related to the water temperature and concentrations of dissolved mineral salts or ions (Great Britain Department of Environment 1972; Matthess, 1982). Standard conductivity measurements are carried out at 25°C so that any variations in this property are taken as a function of concentration and the type of dissolved ions only. Thus conductivity values can permit a rapid evaluation of the chemical quality of water.

Table 5: Field Data

Sample No. Location/ Name	Aquifer/ Formation	Dissolved Oxygen, (ppm) Temperature (°C)	Conductivity (µs/cm) at Field Temperature	Water Temperature (°C)
C7265 Henzamwenye	MYCU	ND	2520	28.0
C7356 Mamba	MYCU	ND	1627	27.2
C7100 Makambani I	MYCU	ND	1982	28.0
C8178 Voyamulungu	MYCU	ND	950	28.6
C7369 Lira Majimoto	MYCU	ND	2060	30.1
C856 Ndavaya	MYCU	ND	7030	22.9
C8180 Mwananyamala	MYCU	ND	876	24.3
C7354 Mrima Mabovu	MYCU	ND	940	25.4
C7368 Lira Godoma	MYCU	ND	1432	24.6
C8192 Kichaka Simba (not in map)	MZ	ND	146	26.1
C8188 Eshu Maendeleo	MZ	ND	101	27.6
C7271 Kirewe	MZ	ND	1050	22.7
C4824 Mkomba	MZ	ND	2988	23.8
C6721 Kivuleni	MU	ND	256	27.2
C5768 Kigombero	MU	ND	114	26.7
C6670 Kikoneni Vibalani	MU	ND	973	27.9
C6723 Mrima Camp	MU	ND	839	26.7
C6733 Marenje	MU	ND	1494	22.4
C6671 Kikoneni Dispensary	MU	ND	497	23.1
Wh_1 Mkongani Waterhole	NA	4.6;26.0	318	23.0
Wh_2 Kirewe Waterhole	NA	5.6;25.0	641	22.8
S_1 Kitoni Spring	NA	0.5;59.7	7230	59.4
S_2 Kivuleni Spring	NA	4.9;23.3	63	22.1
S_3 Munyala spring	NA			

Table 5:Cont.

Sample No. Location/ Name	Aquifer/ Formation	Dissolved Oxygen, (ppm) Temperature (°C)	Conductivity (μs/cm) at Field Temperature	Water Temperature (°C)
S_3 Munyala Spring	NA	3.4;23.2	98	21.9
S_4 Mwaniki Spring	NA	6.2;22.1	330	22.6
S_5 Shilingi Tupu Spring	NA	4.8;26.6	176	27.3
S_6 Githinji Spring	NA	5.6;23.7	295	24.4
r_1 Majimoto river	NA	4.6;31.2	7100	32.0
r_2 Ramisi river	NA	4.9;29.4	1630	28.9
r_3 Ramisi river	NA	4.8;23.0	1127	23.0
r_4 Lovu river	NA	4.9;26.0	1553	24.6
r_5 Mkanda river	NA	6.8;21.9	329	22.4
r_6 Ramisi river	NA	6.4;25.3	1495	23.4
r_7 Mkanda river	NA	5.7;25.9	346	26.4
r_8 Ramisi river	NA	4.9;26.9	1230	23.6

MYCU - Maji ya Chumvi Aquifer/Formation

MZ - Mazeras Sandstone and Shimba Grit Aquifer/Formation

MU - Magarini Sands Aquifer/Formation

ND - Not Determined

NA - Not Applicable

Wh_n - Water hole sample
S_n - Spring water
R_n - River water

Table 6: Total Suspended Solids (TSS)

Sample No.	Location/Name	TSS(ppm)
r_1	Majimoto -river	12
r_2	Ramisi - river	52
r_3	Ramisi - river	85
r_4	Lovu - river	123
r_5	Mkanda - river	91
r_6	Ramisi -river	172
r_7	Mkanda - river	74
r_8	Ramisi - river	183
Wh_1	Mkongani - waterhole	65
Wh_2	Kirewe - waterhole	333
S_1	Kitoni (Majimoto) spring	10
S_2	Kivuleni - spring	67
S_3	Munyala - spring	243
S_4	Mwaniki - spring	63
S_5	Shilingi Tupu - spring	143
S_6	Githinji - spring	94

According to the American Water Works Association (1971) conductivity measurements can usually be used to established the degree of mineralisation of the water, to assess the effect of the total concentration of ions on chemical equilibria and physiological effects on flora and fauna, corrosive rate, etc. Conductivity values can also be used to assess the degree of mineralisation of distilled and deionised water, evaluation of variations in dissolved mineral concentration of raw or waste water and to estimate total dissolved solids in a sample by multiplying conductivity by an empirical factor. The conductivity of the water resources in the Ndavaya-Mrima area is relatively high with values ranging from 93µs/cm to 8900 µs/cm. With an exception of Kitoni spring and Maji Moto river into which the spring discharges its waters, rivers and spring water resources have relatively low conductivity than borehole water. The boreholes at Masimbani (C6731), Kivuleni (C6721), Kichakasimba (C8192) (not in map), Kigombero (C5768) and Mwaluvangaeshu Maendeleo (C8188) have exceptionally low conductivities.

.2.1.4. Total Dissolved Solids (TDS)

The total dissolved solids (TDS) of surface and groundwater is a measure of the total ions carried in solution by the water. Water of high dissolved solids are generally of inferior potability and may induce an unfavourable physiological reactions to the consumer. Highly mineralised waters are also unsuitable for many industrial and practically all agricultural applications (AWWA, 1971). Recommended maximum TDS limit for drinking water is 500mg/l (Andrews, 1972). Most groundwaters in the study area and the geothermal Kitoni spring and Maji Moto river have high TDS values. The total dissolved values for boreholes, springs and rivers vary from 50 to 5340 ppm. Groundwater from Mazeras sandstones and Magarini sands are relatively less mineralised.

.2.1.5. pH and Temperature

The geochemical and biological factors which control the quality of water are influenced by the acidity or basicity and temperatures of the water. The hydrogen potential (pH) is a measure of the acidity or basicity of a water resource, further i.e. determines the solvent ability of the water to dissolve mineral salts from rock minerals. pH determinations carried out in the field show little variations from those measured in the laboratory (table 7). The laboratory pH values vary form 5.4. to 8.3, while those pH values taken at the field range from 5.0 to 8.1. The water resources in the study area have pH values within the range 5.0 to 8.0 with an average pH of 6.98.

Table 7: Water Quality Data (Concentration in ppm)

Sample No.	Location/ Name	Aquifer/ Formation	Na	K	Ca	Mg	SiO_2	SO_4	Cl	F	TDS	HCO_3	Cond. (µs/cm at 25°C)	Total Alkal- inity as $CaCo_3$	Total Hardness as $CaCo_3$
C7265	Henzamwenye	MYCU	294	9.8	225	145	30	70	950	1.3	1140	437	1700	412	1156
C7356	Mamba	MYCU	158	9.2	102	73	20	73	350	0.3	1187	128	1978	316	556
C7100	Makambani I	MYCU	221	3.7	103	113	30	39	523	0.1	1441	184	2402	484	720
C8178	Voyamulungu	MYCU	199	6.1	59	57	60	35	263	0.1	1017	236	1696	366	382
C7369	L. Majimoto	MYCU	154	4.7	106	48	50	51	410	0.7	1356	167	2261	570	460
C856	Ndavaya	MYCU	1985	6.2	4.8	453	20	20	3750	2.0	5340	591	8900	428	1876
C8180	Mwananyamala	MYCU	99	4.3	61	6.5	40	18	113	0.2	602	216	1003	382	146
C7354	Mrima Mabovu	MYCU	200	6.2	71	48	50	46	300	0.5	1017	118	1696	130	374
C7368	L. Godoma	MYCU	66	4.6	47	111	40	63	373	0.1	1102	131	1837	304	574
C7279	Mkuduru III	MYCU	360	4.5	210	210	20	176	910	0.7	2100	324	3500	-	-
6731	Masimbani	MYCU	31	3	3	2	80	5	22	0.5	138	52	230	-	-
C6732	Kikonde	MYCU	360	11	292	252	80	370	1235	0.9	3000	14	5000	-	-
C7101	Makambani	MYCU	240	5	114	6	45	58	452	0.7	1200	412	200	-	-
C7355	Dzuni	MYCU	120	20	79	72	50	176	206	2.0	1020	490	1700	-	-
C7273	Mkuduru II	MYCU	360	4	93	70	50	75	614	0.6	1500	302	890	124	-
C8192	Kichakasimba	MZ	13	4.1	4	6.3	20	14	28	0.4	88	236	148	46	95
C8188	Bshu Maendeleo	MZ	18	2.1	11	7.8	20	4.4	120	0.2	300	24	500	49	64
C8191	Lukore Sec. Sch.	MZ	106	9.7	26	25	50	18	132	0.2	432	117	720	210	342
C7271	Kirewe	MZ	179	1.3	16	14	30	75	230	0.1	652	45	1088	44	98
C4824	Mkomba	MZ	305	15	160	204	80	96	980	0.1	2289	49	3815	294	1240
C7364	L. Mkatisya	MZ	190	5	2.4	89	60	75	18	0.8	660	402	1100	-	-
C4773	Tiribe	MZ	400	13	50	70	16	75	614	0.6	1500	258	2500	-	-
C4572	Mkongani	MZ	130	4	98	137	50	220	664	0.3	1800	390	3000	-	-
C6721	Kivuleni	MU	35	3.7	7.6	8.5	20	19	25	0.2	195	67	235	38	54
C5768	Kigombero	MU	21	2.5	4	2.4	30	4.5	50	0.6	119	23	198	24	20
C6670	Kikoneni Vibalani	MU	150	8.4	51	6.0	40	69	123	0.1	763	350	1273	480	372
C6723	Mrima Camp	MU	199	6.7	47	33	50	53	153	0.3	627	159	1046	150	253

C6771	Kikoneni Dispensary	MU	55	5.7	49	41	30	11	54	0.1	280	24	466	56	82
C6733	Marenje I	MU	210	5.7	42	43	10	43	342	0.4	1017	343	1696	142	282
C7091	Marenje II	MU	216	4.3	86	38.4	60	49	345	0.7	960	398	1600	-	-
C7093	Ganda	MU	390	6	43	24.5	30	30	642	1.2	1200	100	2000	-	-
C7096	Mangwei	MU	590	14.5	196	183	20	180	1700	0.1	3720	188	6200	-	-

Table 7: cont.

Sample No.	Location/ Name	Aquifer/ Formation	Na	K	Ca	Mg	SiO_2	SO_4	Cl	F	TDS	HCO_3	Cond. (µs/cm at 25°C)	Total Alkalinity as $CaCo_3$	Total Hardness as $CaCo_3$
Wh_1	Mkongani Waterhole		157	3.4	11	14	-	55	180	0.1	534	27	749	10	68
Wb_2	Kirewe Waterhole		103	3.4	6.4	16	-	25	233	0.3	449	10	749	18	82
S_1	Kitoni (Majimoto) Spring		1632	63	35	13	-	1.2	2443	1.3	5090	590	8480	360	142
S_2	Kivuleni Spring		110	5.3	10	5.3	-	3.6	95	0.3	251	16	418	16	71
S_3	Munyala Spring		15	6.7	4	10	-	3.3	53	0.5	260	2.6	93	6	52
S_4	Mwaniki Spring		38	4.4	1.6	5.8	-	5	30	0.5	161	12	268	10	28
S_5	Shilingi Tupu Spring		26	3.6	0.3	1.6	-	0.3	30	0.4	119	11	198	8	22
S_6	Githinji Spring		38	3.6	8	4.4	-	6	93	0.3	203	41	339	36	38
r_1	Majimoto river		1029	46	33	19	-	21	1900	0.8	3985	309	6641	484	162
r_2	Ramisi river		60	13	8	7.8	-	0.3	123	0.0	280	53	466	60	52
r_3	Ramisi river		347	15	31	16	-	9.3	603	0.0	1356	107	2261	180	140
r_4	Lovu river		18	1.4	7.2	4.4	-	0.3	51	0.0	110	31	184	36	36
r_5	Mkanda river		38	4.4	10	6.8	-	6.8	103	0.0	187	39	311	54	54
r_6	Ramisi river		42	15	13	11	-	6.7	183	0.0	348	36	579	28	78
r_7	Mkanda river		22	8.4	22	1.9	-	2.5	63	0.0	102	16	170	14	32
r_8	Ramisi river		147	9.2	16	1.7	-	6.7	210	0.0	593	76	989	80	108

Legend:
MYCU - Maji ya Chumvi Aquifer/Formation
MZ - Mazeras Sandstone and Shimba Grits Aquifer/Formation
MU - Magarini Sands Aquifer/Formation
Wh_n - Water hole
R_n - River Water
S_n - Spring

Temperatures also an important controlling factor in the dissolution of minerals. In general, most geochemical reactions and biological activities are temperature dependant. Except for the Kitoni spring with surface Temperature discharge temperature of about 59.4°C and the Maji moto river with surface temperature of about 32°C, the water temperatures vary from 21.9°C to 30.1°C, which generally correspond to the atmospheric temperature (table 5).

5.2.2. Total Alkalinity and Total Hardness

5.2.2.1. Total Alkalinity

The total alkalinity of water sample is a measure of its capability to neutralize acid and is caused by anionus or molecular types of weak, incompletely dissociated acids (Matthess, 1982; Andrews, 1972). Nearly all the alkalinity of natural waters is produced by carbonate and bicarbonate (and sometimes to a lesser extent hydroxide ions), commonly of sodium, calcium and magnesium.

Alkalinity measurements are used in the interpretation and control of water and waste water treatment processes and in determining the suitability of a water resource for irrigation (ALPHA, WPCF and AWWA, 1985). Borehole water in the study area have alkalinity values ranging from 24-570 ppm while surface water have alkalinity contents varying from 6-484 ppm.

5.2.2.2. Total Hardness

Total hardness is the soap consuming property of water and is generally caused by the concentration bicarbonate (HCO^{-}_{3}) and carbonate (CO^{2-}_{3}) ions and other soluble salts of calcium and magnesium. Water hardness caused by the presence of bicarbonate and carbonate ions is referred to as carbonate (temporary) hardness and can easily be treated by heating. Non carbonate (permanent) hardness of water is caused by the presence of chlorides, nitrates, phosphates and other soluble salts. Hardness is most undesirable in river water used for fish raising and for most industrial purposes. In domestic water supply high hardness in water is objectionable because it consumes a lot of soap and forms boiler scales on heating appliances. Hardness problems are not common in river water except in cases where the rivers drain dolomitic or limestone rich rocks. Hardness in surface water can also be increased by pollution and contamination by acid leachates from mine spoils, garbage disposal areas and other sources (Bouwer, 1978). Water is classified on the basis of the degree of hardness into soft and hard water.

Table 8:**Classification of Water Based on Degree of Hardness**

(Source: Andrews, 1972)

Category	Hardness as $CaCo_3$ ppm
Soft	0 - 60
Moderately Hard	61 - 120
Hard	121 - 180
Very Hard	> 180

Drinking water should not contain total hardness greater than 80 ppm. However, where no soft water is available total hardness values below 250 ppm are considered acceptable but total hardness values above 500 ppm is hazardous to human health (Andrews, 1972). Most groundwater in the study area have total hardness values in excess of 350 ppm with Ndavaya (C856), Mkomba (C7356), Henzamwenye (C7265) and Makambani (C7100) borehole water having hardness concentrations of 1876 ppm, 1240 ppm, 1156 ppm and 720 ppm respectively.

5.2.3. Major Chemical Constituents

5.2.3.1. Sodium, Na^+

Sodium is a major constituent of igneous and sedimentary rocks and is present in most natural waters in sedimentary rocks Sodium occurs in argillites (shales and clays) and resistates (such as sandstone) either as a constituents of unweathered mineral grains, cementing material or as a crystalline residium of pore solutions (Matthess, 1982). The sodium ion is released from rocks during weathering and dissolution. Other sources of sodium in water include cyclic salting in coastal areas, leachate and as a bio-element present in most chemicals used by man.

Sodium is the dominant cation in most mineralised groundwater, except for gypsiferous and calcium bicarbonate waters. In the Ndavaya-Mrima area sodium is the most common and dominant cation in both ground and surface waters with concentrations ranging from 13 to 1985 ppm in groundwater and 15 to 1632 ppm in surface waters (Table 7). Boreholes with abnormally high sodium content are Ndavaya (1985 ppm), Mangwei (590 ppm) and Tiribe (400 ppm) while Maji moto river (1029 ppm) and Kitoni spring (1732 ppm) are surface waters with high sodium concentrations.

5.2.3.2. Potassium, K^+

Potassium is another common element in both igneous and sedimentary rocks. However, because of the low solubility of potash silicates and its low geochemical mobility, potassium occur in low concentration in most groundwaters. Potassium salts are highly soluble and are widely used as agricultural fertilisers. Hence potassium can be introduced in ground and surface waters through surface runoff from cultivated areas and also as a result of human pollution.

In Ndavaya-Mrima area generally the water resources have potassium concentrations below 10ppm (Table 7). High values are found in Kitoni spring (63 ppm,) and boreholes at Dzuni (C7355) (20 ppm,), Mkomba (C4824) (15ppm), Mangivei (C7096) (14.5 ppm,) and Tiribe (C4773) 13ppm).

5.2.3.3. Calcium, Ca^{2+}

Calcium is one of the principal cations in groundwater. The predominant sources of calcium in water are igneous minerals such as silicates, ferromagnesian minerals and feldspars (Bouwer, 1978).

In sedimentary rocks calcium occurs in argillite and fine grained rocks, as carbonate, dolomite, calcite and calcium fluoride and other calcareous deposits. Groundwater from limestone and other calcareous rocks is generally hard due to high contents of calcium which are usually accompanied by high carbonate and bicarbonate ions. Calcium can also be introduced in water as cyclic salts from seawater, from terrestrial dust and industrial emissions. The low solubility of calcic minerals and the resistance to weathering of the igneous and metamorphic parent rocks are the causes of the low calcium content in ground and surface water from these terrains. Significantly high Ca^{2+}ion contents are observed in mineralised calcium chloride waters. High calcium concentration in water is objectionable because of its association with high hardness.

With an exception of few occurrences the calcium content in both surface and groundwater in the area investigated is generally low. The calcium content in groundwater range from 2.4 ppm to 292 ppm while surface waters have calcium concentrations between 0.3 ppm and 35 ppm (Table 7).

2.3.4. Magnesium, Mg^{2+}

Magnesium ions in waters from igneous and metamorphic and other altered rocks, are derived primarily from ferromagnesium minerals and their alteration products. In sedimentary rocks the elements occur in magnesite and other carbonate rocks, as a constituent of clay minerals and other argillite and salt deposits of marine origin and terrestrial evaporates. Due to its low geochemical mobility, magnesium occurs in water in concentrations generally below that of calcium, except in magnesium rich aquifers (Matthess, 1982). High magnesium concentrations are objectionable because it contributes to water hardness, results in scales in boilers and can cause carthatic and diuretic effects to consumers.

Groundwater in the study area have significant concentration of magnesium ranging from 2 to 453 ppm. The surface waters in the study area have very low concentrations of magnesium ion, with contents varying from 1.6 ppm to 17ppm (Table 7).

.3.5. Silica, SiO_2

Silicon is present in most water resources as silica (SiO_2) and mostly originates from the weathering of silicates and other silicate containing rocks, and to lesser extent, amorphous silica. According to the APHA, AWWA and WPCF (1985) silica in water is undesirable for a number of industrial uses because it forms difficult-to-remove silica and silicate scales in equipments, especially on high pressure steam turbines and blades. Silica contents of surface waters are usually low.

Silica occurrences in water resources of the study area are notably high ranging from 10 ppm to about 80ppm.

5.2.3.6. Chloride, Cl^-

Chloride is one of the most common and major inorganic ions in water and waste water. However, Chloride is not a common element in most rocks. The primary source of chloride ions in groundwater are evaporite rocks, salty connate waters (for deep aquifers) and saline sea water intrusion into fresh water aquifers in coastal regions. Chloride can also find its way into water from leachate (in dry climates), argillite and other fine grained rocks and sediments, as a man made airborne pollution in the atmosphere and as sea spray, terrestrial dust in the atmosphere and as dry fall out on the land or earth surface in coastal regions (Talsma and Phillip, 1971; Drever, 1982). In general, groundwater containing significant amounts of chloride also tend to have high amounts of sodium thus indicating the possibility of contact with waters of marine origin (Bouwer, 1978). High chloride concentration in water are objectionable to taste as it results in a bitter salty taste. A high amount of salt harm metallic pipes and structures as well as growing plants. Such waters are therefore, undesirable in irrigation, drinking and most industrial purposes.

Both surface and groundwater in the Ndavaya-Mrima area have generally high concentrations of chloride which has led to saline conditions for most groundwaters. The chloride concentration in groundwater range from 18 to 3750 ppm. Except for Kitoni springs (2543 ppm), Majimoto river (1900 ppm) and a section of Ramisi river (603 ppm), surface waters in the study area have relatively low chloride concentrations, generally below 200 ppm (Table 7).

5.2.3.7. **Sulphate, SO_4^{2-}**

Sulphur, as an element, is in itself only a relatively minor constituent of igneous and sedimentary rocks but occur as metal sulphide and polysulphides (Matthess, 1982).

In addition to sulphide, other sources of sulphate in water resources include sedimentary evaporate deposits (both terrestrial and marine), cementing material or sulphate enclosed within layers or cracks in sedimentary rocks, decomposing organic matter, leachate from fertilizers, industrial wastes and (cyclic salting and oxidation of hydrogen sulphate from coastal marshes in coastal areas.

High concentration of sulphate should be discouraged as it can exert carthatic action on human beings (Johnson, 1972). Groundwater in the study area have relatively low sulphate concentrations generally below 100 ppm. The high occurrences of sulphate in the groundwater are observed in boreholes at Marenje (C7091)(345ppm), Ganda (C7093 ppm) (642ppm), Mangwei (C7096) (180 ppm, Mkunduru (C7279) (176ppm), Dzuni (C7355) (176 ppm), Kikonde (C6732) (370 ppm) and Mkongani (C4572) (220ppm). Surface water studied have very low concentrations of sulphate ion generally below 10ppm, except for river Majimoto (21ppm) and water holes at Kirewe (25ppm) and Mkongani (55ppm).

5.2.3.8. **Bicarbonate (HCO^-_3) and Carbonate (CO_3^{2-})**

The carbon dioxide produced by the biota of the soil or other bacterial activities in deeper formations is the major source of the notably high bicarbonate concentrations observed in some groundwaters from non-carbonaceous or calcareous rocks (Bouwer, 1978). Otherwise the principal source of high bicarbonate concentrations in both surface and groundwater are the various carbonate rocks and minerals which occurs as cementing materials in sedimentary rocks and in sedimentary evaporite deposits.

Groundwater in the study area have a high bicarbonate content and practically no carbonate ions. The bicarbonate ion concentrations in the groundwater range from 14 ppm to 450 ppm. Surface water in the study area have low contents of bicarbonate ion generally below 50 ppm, except for Kitoni spring (590 ppm), Majimoto river (309 ppm) and a sample from Ramisi river (107 ppm).

5.2.3.9. Fluoride, F^-

Fluoride is a very important ion in medical geology and is usually found in low concentrations in ground and surface waters, generally below 1 ppm. The primary source of fluoride in groundwater from igneous terrains is fluorite the minerals apatite and mica, and certain amphiboles and cryolite. In sedimentary rocks, mica and fluorspar are the main sources of fluoride in water, besides weathering products of the above minerals.

Borehole water in the study area have substantial concentrations of fluoride (0.1-1.3 ppm) but generally below 1.5 ppm (Table 7). While spring and waterhole waters in the study area have similar concentrations of fluoride the river waters analyzed have no fluoride concentrations below detection limit.

5.2.4. Trace (Minor) Metals

Most minor metals are, in their trace amounts, essential for biological systems. Natural sources of trace metals in water are weathering of rocks, or else, they may also be introduced into the atmosphere and hydrosphere by human activities (Drever, 1982). The proportion of a particular trace metal that goes into solution is dependent upon the nature and solubility properties of the host minerals in which it is incorporated, the geochemical mobility of the individual metal and on the intensity of chemical weathering and other processes which help to release it into the hydrologic environment. Many of these metals occur in very low concentrations in water partly because they are very rare in the earth crust rocks. However, a majority of these trace metals occur in association with other metallic sulphides which are widely distributed in the earth crust. In such cases weathering of these rocks can result in localised higher concentrationsof dissolved trace metals. Groundwater generally contain higher amounts of these minor metals than surface water. In many rivers and lakes, it has been found that the human input of trace metals is many times high than the natural input.

The water resources of the study area analysed have recorded very low concentrations of these trace elements generally below 2 ppm (Table 9.) Iron (Fe) and Manganese (Mn) are the most common and dominant minor metals in both ground and surface water resources in the Ndavaya-Mrima Area.

The other trace metals analysed for are lead (Pb), copper (Cu), zinc (Zn), selenium (Se), Arsenic (As), Nickel (Ni), cobalt (Co), chromium (Cr), and cadmium (Cd).

Table 9: Concentration of Minor (Trace) Element in the Groundwater and Surface Water in the Study Area (Concentration in ppm)

Sample No.	Location/ Name	Aquifer/ Formation	Fe	Mn	Zn	Pb	Cu	Ni	As	Se	Co	Cr	Ba	Cd
C7265	Henzamwenye	MYCU	1.650	0.070	0.200	0.000	0.040	0.010	0.002	0.003	0.000	0.030	0.040	0.200
C7356	Mamba	MYCU	0.100	0.09	0.400	0.002	0.010	0.000	0.001	0.000	0.030	0.010	0.000	0.000
C7100	Makambani I	MYCU	0.200	0.030	0.050	0.000	0.010	0.003	0.005	0.003	0.000	0.010	0.000	0.000
C8178	Voyamulunga	MYCU	0.100	0.100	0.500	0.006	0.005	0.000	0.005	0.001	0.010	0.005	0.000	0.000
C7369	L. Majimoto	MYCU	0.800	0.100	2.200	0.030	0.010	0.100	0.000	0.005	0.040	0.040	0.000	0.380
C856	Ndavaya	MYCU	0.400	0.300	0.900	0.030	0.010	0.006	0.000	0.004	0.010	0.010	0.000	0.000
C8180	Mwananyamala	MYCU	0.030	0.200	0.060	0.001	0.040	0.000	0.000	0.001	0.000	0.000	0.000	0.000
C7354	Mrima Mabovu	MYCU	0.100	0.030	0.010	0.004	0.020	0.000	0.000	0.000	0.030	0.030	0.000	0.000
C7368	L. Godoma	MYCU	0.500	0.200	0.040	0.071	0.002	0.004	0.000	0.000	0.000	0.000	0.000	0.000

8192	Kichakasimba (not in map)	MZ	1.100	0.060	0.300	0.670	0.020	0.010	0.001	0.001	0.001	0.004	0.000	0.000
C8188	Eshu Maendeleo	MZ	1.500	0.020	3.300	0.006	0.020	0.010	0.002	0.000	0.020	0.020	0.000	0.000
C8191	Lukore Sec.	MZ	0.600	0.010	0.700	0.003	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000
C7271	Kirewe	MZ	0.500	0.040	0.100	0.020	0.008	0.004	0.000	0.000	0.000	0.002	0.000	0.000
C4824	Mkomba	MZ	2.200	0.100	1.000	0.500	0.001	0.010	0.003	0.010	0.000	0.000	0.000	0.000
C6721	Kivuleni	MU	0.600	0.060	0.200	0.006	0.020	0.006	0.000	0.000	0.000	0.003	0.000	0.000
C5768	Kigombero	MU	2.900	0.030	0.200	0.005	0.050	0.006	0.004	0.001	0.000	0.010	0.000	0.000
C6670	Kikoneni Vibalani	MU	2.030	0.070	0.100	0.002	0.008	0.010	0.006	0.000	0.000	0.010	0.000	0.000
C6723	Mrima Camp	MU	0.100	0.030	0.600	0.002	0.010	0.006	0.000	0.003	0.002	0.020	0.004	0.000
C6771	Kikoneni Dispensary	MU	0.300	0.010	0.080	0.010	0.003	0.000	0.000	0.000	0.000	0.002	0.000	0.000
C7091	Marenje I	MU	0.200	0.010	0.030	0.002	0.006	0.000	0.020	0.002	0.000	0.000	0.000	0.000
Wh_1	Mkongani Waterhole		0.000	0.030	0.020	0.003	0.010	0.004	0.002	0.000	0.000	0.001	0.000	0.000
Wh_2	Kirewe Waterhole		0.800	0.010	0.030	0.020	0.005	0.002	0.000	0.000	0.000	0.001	0.000	0.000
S_1	Kitono(Majimoto)		0.200	0.060	0.020	0.003	0.020	0.001	0.000	0.003	0.000	0.006	0.000	0.000
S_3	Munyala Spring		0.300	0.100	0.050	0.070	0.040	0.030	0.000	0.004	0.003	0.030	0.000	0.000
S_4	Mwaniki Spring		0.600	0.010	2.020	0.060	0.003	0.030	0.000	0.001	0.000	0.002	0.000	0.000
S_5	Shilingi Tupu Spring Spring		0.070	0.200	0.010	0.020	0.006	0.010	0.000	0.000	0.000	0.010	0.000	0.000
S_6	Githinji Spring		0.100	0.070	0.020	0.030	0.003	0.002	0.000	0.000	0.001	0.003	0.000	0.000
r_1	Majimoto river		0.500	0.020	0.010	0.020	0.020	0.003	0.000	0.000	0.030	0.007	0.000	0.000
r_2	Ramisi river		2.000	0.300	0.050	0.060	0.040	0.020	0.000	0.001	0.003	0.000	0.000	0.000
r_3	Ramisi river		1.300	0.100	0.010	0.040	0.005	0.020	0.020	0.000	0.000	0.090	0.000	0.000

r_4 Lovu river	2.900	0.200	3.030	0.050	0.010	0.010	0.000	0.000	0.000	0.010	0.000	0.000
r_5 Mkanda river	0.900	0.300	0.030	0.010	0.005	0.000	0.000	0.000	0.000	0.010	0.000	0.000
r_6 Ramisi river	2.600	0.200	0.030	0.030	0.010	0.004	0.000	0.000	0.000	0.020	0.000	0.000
r_7 Mkanda river	8.200	0.400	1.020	0.030	0.050	0.001	0.000	0.000	0.003	0.000	0.000	0.000
r_8 Ramisi river	4.200	0.010	0.040	0.001	0.007	0.010	0.000	0.000	0.000	0.000	0.000	0.000

Ledend: MYCU - Maji ya Chumvi Aquifer/Formation
MZ - Mazeras Sandstone & Shimba Grits Aquifer/Formation
MU - Magarini Sands Aquifer/Formation
Wh_n - Water hole
S_n - Spring
R_n - River water

5.3 Qualitative Analysis

The hydrogeochemical data obtained from hydrochemical surveys can only be important in water development programmes if interpreted in relation to the mineralogical and hydraulic properties of an aquifer, groundwater recharge, drainage gradient and hydrologic characteristics (Talsma and Phillip, 1971; Matthess, 1982 and Llyod 1985). To achieve a better interpretation good presentation of the chemical data is necessary. Many methods of presentation of hydrogeochemical data are widely used at present. In this study the chemical data has been presented in multivariate trilinear piper diagrams and hyrdochemical concentration maps. The data has also been subjected to statistical analysis.

5.3.1. Piper Diagrams and Concentration Maps

Piper diagrams have been used successfully to classify various chemical water types in groundwater basins (Llyod 1985). In the piper diagram the major ions are plotted as cations and anions milliequivalents per litre in two base rectangles (Figures 11 and 12) (pages 101 and 102). In addition to permitting comparison the trilinear diagrams can also be used to show the effect of mixing between waters since mixtures of two types of groundwater plot on a straight line in each of the three fields.

Classification of the various chemical types of water resources in an area is done by plotting of the chemical data in certain subareas of the diamond shaped field (Maina, 1982).

Concentration maps are important in the interpretation of groundwater chemistry in relation to flow direction, flow experience, geology and geological structures, among other hydrological influences. The concentration of the dominant cations and anions, total hardness, total alkalinity silica content and total dissolved solids (salinity) in the groundwaters investigated were plotted and concentration maps drawn (figure 8-1 to 8-13).

5.3.2. Statistical Analysis

Another important approach to understanding the chemistry of natural waters is to investigate statistical associations among dissolved constituents and environmental parameters such as lithology, climate, relief, and population (Drever, 1982). Such statistical associations generally do not establish any cause-and-effect relationships but instead it represents data in such a way that cause-and effect relationships can be deduced. A better way of demonstrating statistically such relationship is by simple correlation and factor analysis.

In correlation analysis co-efficients are calculated for all possible pairs of variables which may include geological variables such as percentage of gypsum in the drainage basin (Drever, 1982, and Levinson, 1979). The correlation coefficients are considered to express numerically the extent to which two variables are associated statistically. For instance Drever (1982) observed that a value of +1 indicates that the two variables are perfectly correlated; a value of 0 indicates that the variables have no correlation at all (i.e. they are completely independent) while a value of -1 indicate that they are perfectly negatively correlated.

The correlation coefficients of all the major cations and anions (Table 10) and of all trace metals (Table 11) common in the water resources of the study area were determined.

Table 10: Correlation Coefficient for major Chemical Constituents in the Water Resources of the Study Area

Na										
K	+0.593									
Ca	+0.082	+0.572								
Mg	+0.542	-0.008	+0.499							
Si	+0.471	+0.339	+0.334	+0.239						
SO_4	-0.042	+0.014	+0.703	+0.558	+0.396					
Cl	+0.998	+0.597	+0.303	+0.779	+0.485	-0.584				
HCO_3	+0.583	+0.363	+0.256	+0.456	+0.332	+0.240	+0.651			
TA	-0.454	-0.006	+0.773	-0.517	+0.014	-0.621	-0.520	+0.782		
TH	+0.414	+0.022	+0.647	+0.597	+0.083	+0.312	+0.746	+0.490	-0.713	
	Na	K	Ca	Mg	Si	SO_4	Cl	HCO_3	TA	TH

Table 11: Correlation Coefficients for some Trace Elements in the Water Resources of the Study Area

Fe						
Mn	+0.166					
Zn	-0.130	-0126				
Pb	+0.291	+0.221	-0.115			
Cu	+0.438	+0.327	-0.036	+0.186		
Ni	+0.226	+0.901	+0.082	+0.555	+0.744	
	Fe	Mn	Zn	Pb	Cu	Ni

. **Factors Influencing Water Chemistry and Quality**

.1. Geological Influence on Water Quality

The chemistry of surface and ground water is influenced considerably by the nature of the earth crust and the aerial distribution of the different rock types (Holden, 1970). Therefore, the water chemistry will reflect the mineralogical composition of the rocks which is an indication of the climatic influences during deposition, other depositional conditions and subsequent modifications resulting from the interaction between rainwater, rocks/soils and other physical and geochemical processes.

Falling rain water dissolve substances in the atmosphere and dry fall out settled on the land surface. The chemistry of these elements has significant influence on the ultimate composition of groundwater. Water has great solvent properties and therefore, tends to dissolve and disintegrate by weathering process materials it comes into contact with (Nordell, 1951; Johnson, 1972). The extent of this dissolution, weathering and the amount of minerals taken up in solution is depended upon the solubility, textural and structural properties of the rocks/soils and soil material such that the quality of the water tend to reflect the chemical composition of the aquifer independent of climatic and hydrological conditions (Talsma and Phillip), 1971). Hence different aquifer will yield waters of varying chemical quality even in the same environment.

The geological factors influencing the quality of ground and surface waters include geohydrologic characteristics, geological structures, the mineralogical composition, texture and other lithological properties of the rocks. Fine textured rock formations such as clays and shales, and volcanic rocks are characterised by groundwater of high mineral content due to their low permeability. Similarly massive metamorphic, igneous rocks and firmly consolidated sedimentary rocks may act as semipermeable systems which retard groundwater movement resulting in increased mineral dissolution and concentration. Irrespective of the mineralogical composition water from such lithological formations is usually characterised by relatively high contents of dissolved salts. Depending on the mineralogical composition of the aquifer the groundwater can be of high alkalinity and moderate to high hardness. On the contrary loose or unconsolidated coarse textured, fractured or heavily jointed aquifers allow active groundwater movement and are generally characterised by low mineral salt contents.

Aquifer rocks are generally composed of different rock forming minerals. Most sedimentary rocks are composed of relatively more soluble minerals and are likely to hold low mineralised water than igneous and metamorphic rocks. Among sedimentary rocks most fresh water is located in siliceous sands and sandstones (Talsma and Phillip, 1971). Pure siliceous material without soluble cement leads to groundwater of very low dissolved solids. Sandstones with soluble cement materials contain appreciable amounts of salts, mainly sulphate, chloride, sodium, calcium and magnesium with high contents of bicarbonate ions. Presence of carbonate salt horizons and argillaceous lenses can result in marked differences in the mineral components in the ground water. Groundwater in contact with evaporite deposits are characterised by high mineral salt contents chiefly composed of sulphate, chloride, calcium and magnesium or sodium ions depending on the cations present. Calcareous rocks especially limestone, are characterised by slightly alkaline carbonate rich waters which are low in total solids. Shales and ferruginous (clayey) rocks, in general, yield highly mineralised water enriched in iron, fluoride and sulphate minerals (Matthess, 1982; Bouwer, 1978).

Due to their notable resistance to weathering and dissolution processes igneous and crystalline rocks are characterised by waters of low salt concentrations. Groundwater from these rocks including that from metamorphic and volcanic rocks which contain high bicarbonate and silica contents. Sodium is also found in higher amounts than in sedimentary rocks. However its concentration in groundwater from volcanic rocks is less that of calcium and magnesium.

The chemical composition of sub-surface water undergoes marked changes and as it flows down through the soil and rock zone into deep aquifers as a result of geochemical processes. These geochemical reactions include dissolution, hydrolysis, precipitation, absorption, ion exchange, oxidation and reduction (Matthess, 1982; Drever, 1982; Talsma and Phillip, 1971). Groundwater of similar age from similar rock masses in the same region are expected to have similar quality. But due to the geochemical phenomena, biological activities and other factors water from one rock type can exhibit greater or less degree of variation in quality (Matthess, 1982; Robson and Saulnier, 1981).

Eventhough surface water is characterised by low dissolved mineral salt content the chemical composition and the variation trend in quality is similar to that of groundwater in the same area since they all reflect the lithological properties of the region and the entire catchment environment.

5.4.2. Other Factors Influencing Water Quality

In addition to geological factors several other processes are responsible for the quality of surface-and ground water resources. Of significant importance in this respect are climatic, biologic and hydrologic factors active in the environment (Ongweny, 1973 and 1975) and human activities. The initial chemistry of meteric water, main source of water both surface and underground, has great influence on the ultimate quality of water resources. As the rain falls it dissolves substances in the atmosphere, such as salt spray from the ocean, gaseous emissions from industries and other pollution and dust particulate and washes them down into the ground water system.

Geomorphic and hydrological factors also contribute significantly to the chemistry of water. The concentration of chemical constituents in water increase with flow rates, hence the longer it stays in contact with aquifer rocks and the longer distance it flows/moves in the sub-surface thw water dissolves more minerals and thus higher concentration value. Similarly groundwater generally moves from high to lowgradient subsurfaces. Therefore, water in aquifers at high altitudes have low mineral salts and the concentration increases towards discharge points (Lloyd, 1985) Groundwater in aquifers outcropping in regions of high rainfall and increased ground water recharge is characterised by low concentrations of salts.

Areas with little rainfall are accompanied by little groundwater recharge resulting in concentration of mineral salts in the rocks. Such areas experience high evaporation rates which results in extraction of water from the ground and surface water resources leaving high mineralised water. Evapotranspiration of soil/vegetation water at the earth's surface results in significant salt concentrations which are usually leached away by infiltrating rain water and eventually reach groundwater systems leading to considerable amounts of salts in the groundwater resources.

Besides geology, the major single controlling factor on water quality is human activities. The intensive use of natural resources by man and the large production of wastes often pose a threat to quality of both surface and ground waters (Bouwer, 1973). Agricultural wastes, industrial and domestic wastes including urban runoff are the three main ways through which man activities can modify the chemical characteristics of water resources. The quantity and quality of these wastes vary widely but the major quality concerns from domestic wastes ore pathogenic organisms introduced into the waters, oxygen demand of organic system, nutrients and total solids (Hann, 1972). Domestic wastes and industrial wastes enter water systems through direct disposal and through urban runoff after a rainstorm.

A variety of chemicals and fertilisers used in agriculture can cause substantial water quality degradation in many aquatic systems if discharged in significant amounts. Other sources of agricultural wastes are animal wastes, crop residues and processing wastes. Percolation of irrigation water may also introduce high mineral salt contents to groundwater. Industrial wastes may be detrimental to the quality of water in many ways ranging from toxicity, oxygen demand, sludge deposits, surface films and thermal effects, etc (Hann, 1972).

The quality of groundwater can be influenced by encroachment of sea water into inland fresh water aquifers and near shore river water courses. This invasion of saline sea water is common in coastal aquifers due to overpumping of borehole water or in certain cases where the fresh water aquifer are underlain by saline waters. The chemical composition of water can also be modified by interfering with the hydrologic, physical, chemical and biological processes without necessarily adding substances into the water bodies. By interfering with the soil structure through cultivation, the content of carbon dioxide in groundwater increases considerably as a result of increased solvent ability of percolating water for calcareous rocks. This culminates in high concentration of calcium and magnesium in the groundwater. Similarly human activities causing changes in groundwater temperature affect the chemical quality of the groundwater through temperature dependent chemical processes. Areas with enhanced biological activities are characterised by water resources rich in bicarbonate and carbonate ions and relatively high contents of alkaline earth elements.

5.5. Water Quality Criteria and Use

The desirable quality of a water resource is determined by its chemical and biological constituents, Physical properties and sediment content. The quality criteria and standards are generally based on specific chemical requirements necessary for these applications. Water is classified according to intended use into public water supply (domestic), recreational, agricultural and industrial use.

.5.1. Water for Domestic and Recreational use (Potable Water)

According to the American Water Works Association (AWWA, 1971) a potable water is one which may be consumed in any desired amount without concern for adverse effects on the health of the user. Water for drinking must meet high standards of physical, chemical and biological purity i.e. it must be free from pathogenic organisms, minerals and substances capable of producing adverse physiological effects. Water for recreational use must be aesthetically acceptable i.e. should be free from apparent turbdility, colourless, odourless and free from objectionable taste. Potable water should be of reasonable temperature and have pH close to 7.0.

The main standards used for determining the suitability of water for both household and recreational use are those recommended by the world health organisation (WHO) (Table 12-1). The standards are liable to change with time and vary from county to country, depending upon the economic prosperity, experience, climate and geographic location (Llyod, 1985).

The quality standards for surface water are and generally applicable to relatively unpolluted waters. Groundwater is generally considered potable in regard to bacteriological characteristics, toxic substances and constituents affecting tastes and odour. The Kenyan Government water laws governing the quality of drinking and recreational waters are those standards set by WHO.

Drinking water can also be classified on the basis of the content of total dissolved solids (TDS) and the level of hardness (Table 12-2).

Table 12-1: WHO Standards for Drinking Water Quality, 1982
(Source, Tebbutt, 1983)

Chemical Constituent	Permissible Limit (ppm)
Sodium	200
Calcium	75
Magnesium	50
Chloride	250
Sulphate	400
Fluoride	1.5
Iron	0.3
Manganese	0.1
Lead	0.05
Zinc	5.0
Copper	1.0
Nickel	0.1
Arsenic	0.05
Selenium	0.01
Cadmium	0.005
Chromium	0.05
Hardness, as $CaCo_3$	500
Total dissolved solids (TDS)	1000
pH	6.5 - 8.5
Colour	Not objectionable to 90% of consumers
Turbidity	5 NTU
Coliforms	Absent in 100ml

use they are rather relatively too hard and high alkaline for many industrial applications. The groundwater resources in particular, are also highly saline with high concentrationsof iron and manganese. (Table 7 and 9).

Table 12-3 General Quality Tolerances for Industrial Process of Water

Industry	Turbidity NTU	Colour TCU	Hardness (ppm) as $CaCo_3$	Alkalinity (ppm) as $CaCo_3$	Fe+Mn (ppm)	TDS (ppm)	Others
Food Product							
Baked Goods	10	10	SHD	-	0.2	-	a
Beer	10	-	-	75-150	9.0	500-1000	a,b
Canned Foods	10	-	25-75	-	0.2	-	a
Confetionary	-	-	-	-	0.2	100	a
Ice	5	5	-	30-50	0.2	300	a,c
Laundering	-	-	50	-	0.2	-	c
Manufactured Products							
Leather	20	10-100	50-135	135	0.4	-	-
Paper	5	5	50	-	0.1	200	d
Paper Pulp	15-20	10-20	100-180	-	0.1	200-	e
Plastic, Clear	2	2	-	-	1.0	300	
Textiles, dying	5	5-20	20	-	0.2	200	-
Textiles, general					0.25	-	f
	5	20	20	-	0.5	-	

legend

SHD	-	Some hardness desirable
a	-	Must conform to standards for potable water
b	-	NaCL-275ppm
c	-	SiO_2 Ca - and Mg - HCO_3 are troublesome; Sulphate and Chlorides for Na, 4Ca, Mg each - 300 ppm
d	-	No slime formation
e	-	Noncorrosive
f	-	Constant compositions, residual aluminium no more than 0.5 ppm

5.5.3. Agriculture Water

The largest single agricultural use of water is for irrigation (Camp, 1963). In the agricultural sector water can also be used for watering and caring of livestock and poultry and for cleansing and other general purposes.

Water quality standards for livestock are not readily available so that for most part potable standards for human water use are fundamentally applied. Farm animals can, however, drink water with moderately high dissolved solids when sodium is the chief constituent, but such water should have a TDS content less than 5000 ppm (Llyod, 1985; Matthess, 1982). The water quality standards for farm animals vary depending upon the types of stock, the size or age and feeding habits. Specific ion concentrations recommended for farm animals are given in the following tables: 12-4A and 12-4B below.

Table 12-4A: Quality Criteria for Drinking Water for Farm Animals (Livestock)
(Source: AWWA, 1971; Bouwer, 1978)

Quality Characteristics	Permissible Level, ppm (1963)	Maximum Limiting Concentration ppm 1963	1972
Total Dissolved Solids (TDS)	2500	5000	3000
Aluminium	–	–	5
Arsenic	1	–	0.2
Boron	–	–	5
Cadmium	5	–	0.05
Chromium	–	–	1
Cobalt	–	–	1
Copper	–	–	1
Lead	–	–	0.1
Mercury	–	–	0.01
Nitrate	200	400	100
Nitrite	None	None	10
Selenium	–	–	0.05
Vanadium	–	–	0.01
Zinc	–	–	25
Sodium	1000	2000	
Calcium	500	1000	
Magnesium	250	500	
Chloride	1500	3000	–
Sulphate	500	1000	–
Fluoride	1	6	2
Bicarbonate	500	500	–
pH	6.0–8.5	5.6–9.0	–

Table 12-4B: Quality Standard for Water Used for Livestock (Source: AWWA, 1971)

Farm Animals	Permissible Salinity (TDS) Concentration (ppm)
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle, dairy	7,150
Cattle, Beef	10,000
Adult dry Sheep	12,900

Young animals and pregnant or lactating animals are less resistant to high salt levels than older animals. With an exception of very few chemical constituents the water resources in the study area are generally suitable for use in the livestock industry and can be used to water virtually all farm animals.

The quality requirements of irrigation water vary between crop types and drainability of soils and climate. Water constraints in irrigation can be examined using a number of empirical indices which can provide a good practical guide to water suitability for irrigation uses (camp, 1963; Bouwer 1978 and Lloyd 1985). The parameters that govern the quality of irrigation water include:-

i) TDS - total salt concentration affects crop yield through osmotic effects

ii) The concentration of cations that can cause deflocculation of the clay in the soil and resulting damage to soil structure and decline in infiltration rates. Of particular interest here is the concentration of sodium and its proportion in the water to other cations mainly calcium and magnesium.

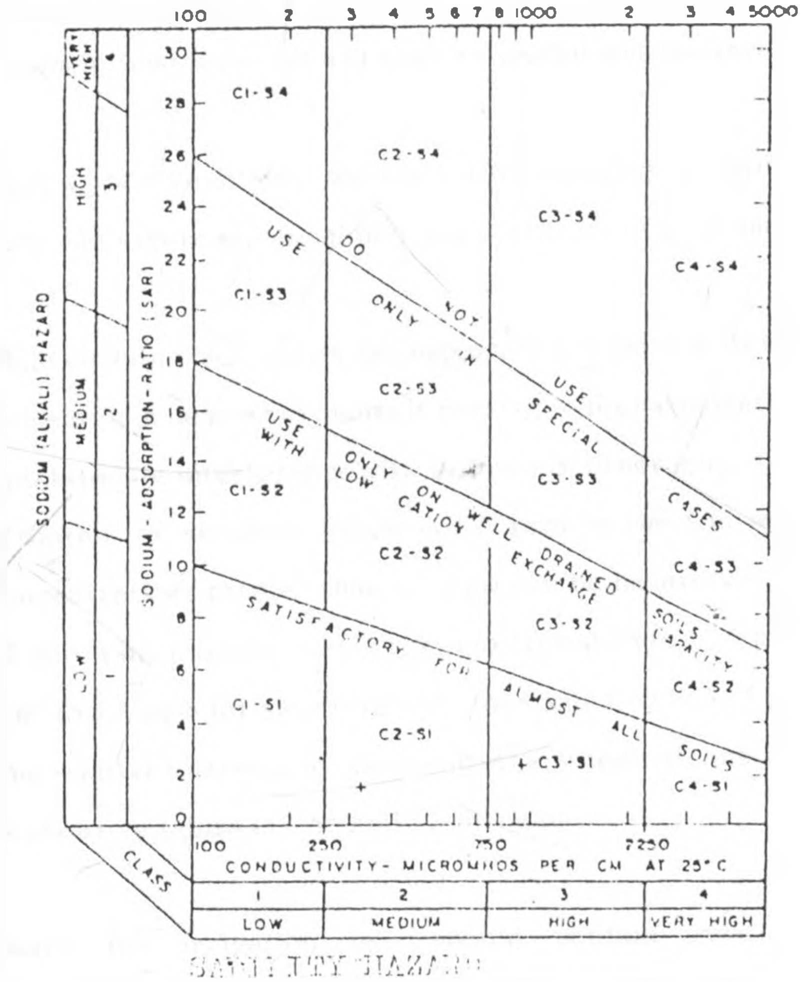
iii) The concentration of bicarbonate ion as related to the content of calcium and magnesium

iv) The occurrence of boron and other specific (minor or trace elements) ions in concentrations that are toxic to plants or that have unfavourable effects on crop quality.

Salinity and toxicity are the main water quality problems experienced in irrigation waters (Johnson, 1972). Salinity, which is a measure of the total salt concentration (TDS) is generally determined in terms of the specific electrical conductance of water, usually measured at 25°C and expressed as micromhos per centimetre. Depending on the drainage, leaching conditions and management of the soil under irrigation, waters with conductivity as high as 2250/μmhos/cm can be used satisfactorily without adversely affecting the crop yield. But excessive prolonged use of such salinities can result in accumulation of soluble salts in the soil with consequent decrease in crop yield (Camp, 1963; American Year Book of Agriculture, 1955). Except for salt sensitive plants water of relatively low salt concentrations and conductivities of between 250 and 750 μmho/cm or even less are the most satisfactory for irrigation. Figure 7 illustrates the various categories of irrigation waters classified on basis of the total salt content (TDS or salinity) expressed as conductivity and sodium absorption ratio (SAR).

Soils of high alkalinity with excessive exchangeable sodium are generally characterised by poor filth and low permeability. The alkalinity hazard of irrigation waters is commonly measured in terms of the relative proportion of sodium to calcium and magnesium ions in the water, commonly referred to as sodium absorption ratio (SAR). The index SAR has been used to classify water resources for irrigation into four classes:

Class 1, S1: Low sodium water, can be used on almost all soils; sodium sensitive crops may accumulate injurious concentrations of sodium unless some gypsum is added



Fig; 6. Diagram for classification of irrigation waters (after camp, 1963).

Legend:

Class 1,S_1 : Low sodium water
Class 2,S_2 : Medium sodium water
Class 3,S_3 : High sodium water
Class 4,S_4 : Very high sodium water

Class 2, S2: Medium sodium water, will present an appreciable sodium hazard in fine texture soils having high cation exchange capacity, especially under low leaching conditions unless gypsum is present in the soil; can be used on coarse textured or organic soils with good permeability.

Class 3, S3: High sodium water. May produce harmful levels of exchangeable sodium in most soils and will require special soil management.

Class 4, S4: Very high sodium water, generally unsatisfactory for irrigation purposes except at low salinity where the use of gypsum may be effective.

While certain trace metals are important for plant growth many other ions and elements can be toxic to plants if present in high concentrations either by direct uptake or by interference with mobility of other ions. Generally, the safe limit of boron for sensitive crops is 0.7 ppm in the soil water after extract and concentrations greater than 1.5 ppm can be hazardous. The permissible limits of boron in irrigation waters ranges from 0.33 to 1.25 ppm for sensitive crops, 0.67 to 2.5 ppm for semi torelant crops and 1.00 to 3.75 ppm for terelant crops. The relative tolerance to boron and other chemical constituents of certain plants is shown in tables (12-5A and 12-5B below.

Water for irrigation use should contain relatively low bicarbonate concentrations. The bicarbonate quality index is based on residual sodium carbonate which is a measure of the excess bicarbonate. Like SAR and total salt concentration (salinity hazards indices) this parameter can also be used to identify or define the suitability of a water resource for irrigation purposes. Water with residual sodium carbonate values exceeding 2.5 ppm are marginal, while those containing less than 1.25 ppm residual sodium carbonate are likely to be safe for irrigation.

Table 12-5A: Recommended Maximum Limits (ppm) for Trace Elements in Irrigation Water

(Source: Bouwer, 1972)

Element	Permanent Irrigation of all Soils
Alluminium	5
Arsenic	0.1
Beryllium	0.1
Boron - Sensitive Crops	0.75
Boron - Torelant Crops	2
Boron - Semitolerant Crops	1
Cadmium	0.01
Chromium	0.1
Cobalt	0.05
Copper	0.2
Fluoride	0.1
Iron	5
Lead	5
Lithium - Citrus	0.075
Lithium - Other Crops	2.5
Manganese	0.5
Molybdenum	0.01
Nickel	0.2
Selenium	0.02
Vanadium	0.1
Zinc	2

Table 12-5A: Recommended Maximum Limits (ppm) for Trace Elements in Irrigation Water

(Source: Bouwer, 1972)

Element	Permanent Irrigation of all Soils
Alluminium	5
Arsenic	0.1
Beryllium	0.1
Boron - Sensitive Crops	0.75
Boron - Torelant Crops	2
Boron - Semitolerant Crops	1
Cadmium	0.01
Chromium	0.1
Cobalt	0.05
Copper	0.2
Fluoride	0.1
Iron	5
Lead	5
Lithium - Citrus	0.075
Lithium - Other Crops	2.5
Manganese	0.5
Molybdenum	0.01
Nickel	0.2
Selenium	0.02
Vanadium	0.1
Zinc	2

Table 12-5B: Relative Tolerance of Plants to Boron, Listed in Decreasing Order of Tolerance.
(Source: Bouwer, 1978)

Tolerant	Semi-Torelant	Sensitive
Athel	Sunflower	Pecan
Asparagus	Potato	Black Walnut
Palm	Acala Cotton	Persian (English) Walnut
Sugar beet	Tomato	Jerusalem Artictic
Mangel	Sweet Pea	Kales
Garden beet	Radish	Navy Bean
Alflfa	Field Pea	American elm
Gladidus	Ragged Robibrose	Plum
Broad bean	Olive	Pear
Onion	Barley	Apple
Turnip	Wheat	Grape
Cabbage	Corn	Kadota fig
Letucce	Milo	Persimmon
Carrot	Oat	Cherry
	Zinia	Peach
	Pumpkin	Apricot
	Bell pepper	Thornless Blackberry
	Sweet potato	Orange
	Lima bean	Ovacado
		Grapefruit
		Lemon

Figure 9-1, 9-2, and 9 show the SAR and TDS (salinity) plotting of the river, spring and ground water resources of the study area. Except for a few cases of groundwater the water resources in the Ndavaya-Mrima area are suitable for irrigation and can be used with most soils.

CHAPTER VI

6. INTERPRETATION AND DISCUSSION

In addition to ascertaining the potability, hydro-geochemistry offers important data area. As pointed out earlier the chemical composition of natural waters is largely dependant upon the geology of the environment of its occurrence, particularly the mineralogical composition of various water bearing formations.

The rocks underlying the study area are erosional products of the basement system and are exclusively composed of quartz, feldspars and mica (muscovite) minerals with minor inclusions of hornblende, pyroxenes, heavy mineral and other ferromagnesian minerals (Caswell, 19953 and Miller, 1952). Accordingly these minerals are bound together by ferruginous material, calcite, limonite, chlorite and other iron oxides. The Magarini sands, which are erosional and weathering products of the Duruma sandstones, are also quartzose and feldspathic since they are composed of quartz and feldspar sediments, pebbles and gravels of similar composition. The rocks of the study area also consist siltstone and shale layers which constitute major intercalations within the sandstones. These shales and siltstones are made of ferruginous clay minerals and other fine grained minerals with enrichments of ferromagnesian minerals. Shales and other fine grained rocks are known to have localised enrichments of alkali and alkali earth elements and chlorides. Thus the chemical composition of these rocks is the main cause of the various chemical constituents in the area. Whilst the mineralogical composition of the respective aquifer rocks is the primary source of high mineral salt concentrations the variations in the groundwater salinity (TDS) in the area seem to be controlled largely by how active the groundwater recharge is. Similar trends can also be observed with most of the respective individual chemical constituents. Except for boreholes at Ndavaya and Mkomba, the groundwater salinity tends to decrease from North-west to South-west with flow direction. The total dissolved solids, however, show a general increase from North to South with flow direction, except for a few localised high concentrations. The observed variation trends of the TDS values can be explained by differences in the groundwater recharge over the area. The Eastern and Southern parts of the project area receive relatively higher rainfall fairly distributed over the year than the Western regions. Therefore, areas in the Eastern part receive higher groundwater recharge which most probably increase groundwater movement consequently causing dilution effects on the waters. In the Western area, the aquifers receive diminished groundwater replenishment due to low intermittent precipitation. In addition to the high evaporation rates, long residence time and long travel (flow) distance, the shallow groundwaters in these parts of the area experience pronounced concentration of salts, thus the high total solids. On the contrary any attempt of salts to accumulate in the groundwater on the Eastern parts is rapidly checked by the enhanced groundwater recharge and flow. The high permeability and porosity of the weakly consolidated Magarini sands result in greatly improved groundwater movement and explain the generally low mineral salt content in the water.

6.1.2. Electrical Conductivity Values in Relation to Major Constituents

The electrical conductivity of water is a measure of the ease with which it can conduct electric current and is dependent upon the amount and kind of dissolved ions. Therefore, water with high concentration of dissolved ions (i.e. TDS) have high conductivity. Sodium, chloride and sulphate ions are more conducting and, therefore, waters with high concentration of these ions are characterised by high conductivity values. In the study area those water resources with high sodium and chloride ion concentrations are highly mineralised with correspondingly high conductivity. The conductivity values of the shallow groundwater resources range from 93 to 8900 ppm and most boreholes have conductivities above 100 ppm. The general decrease of conductivity eastwards (Fig.8-2) can be explained by flushing and dilution effects on the Eastern region of the study area caused by enhanced groundwater recharge and flow.

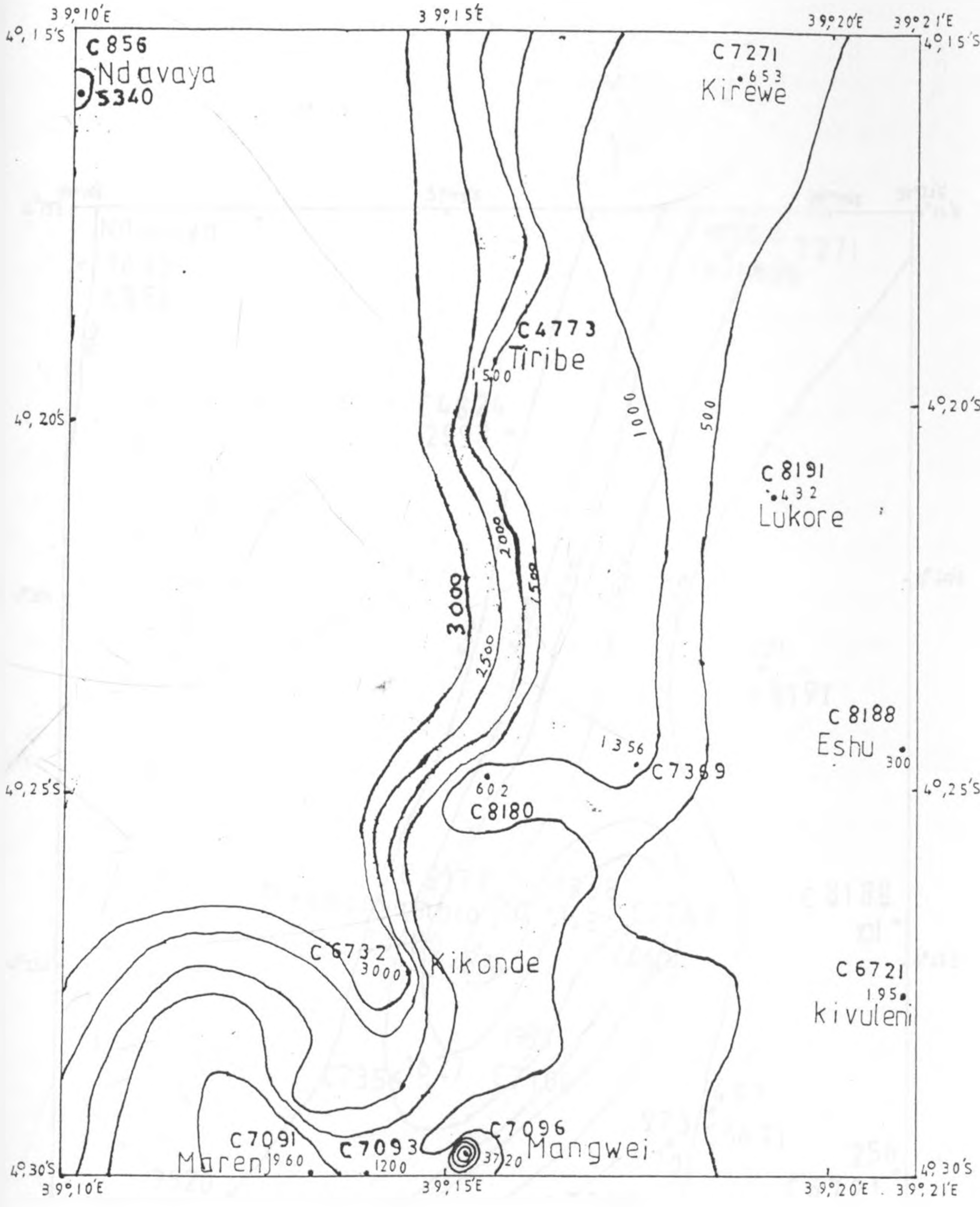


Fig.7-1 TDS Concentration Map in the Study Area

C7091 - Borehole number

1500 - Concentration contour line

1200 - Concentration in ppm

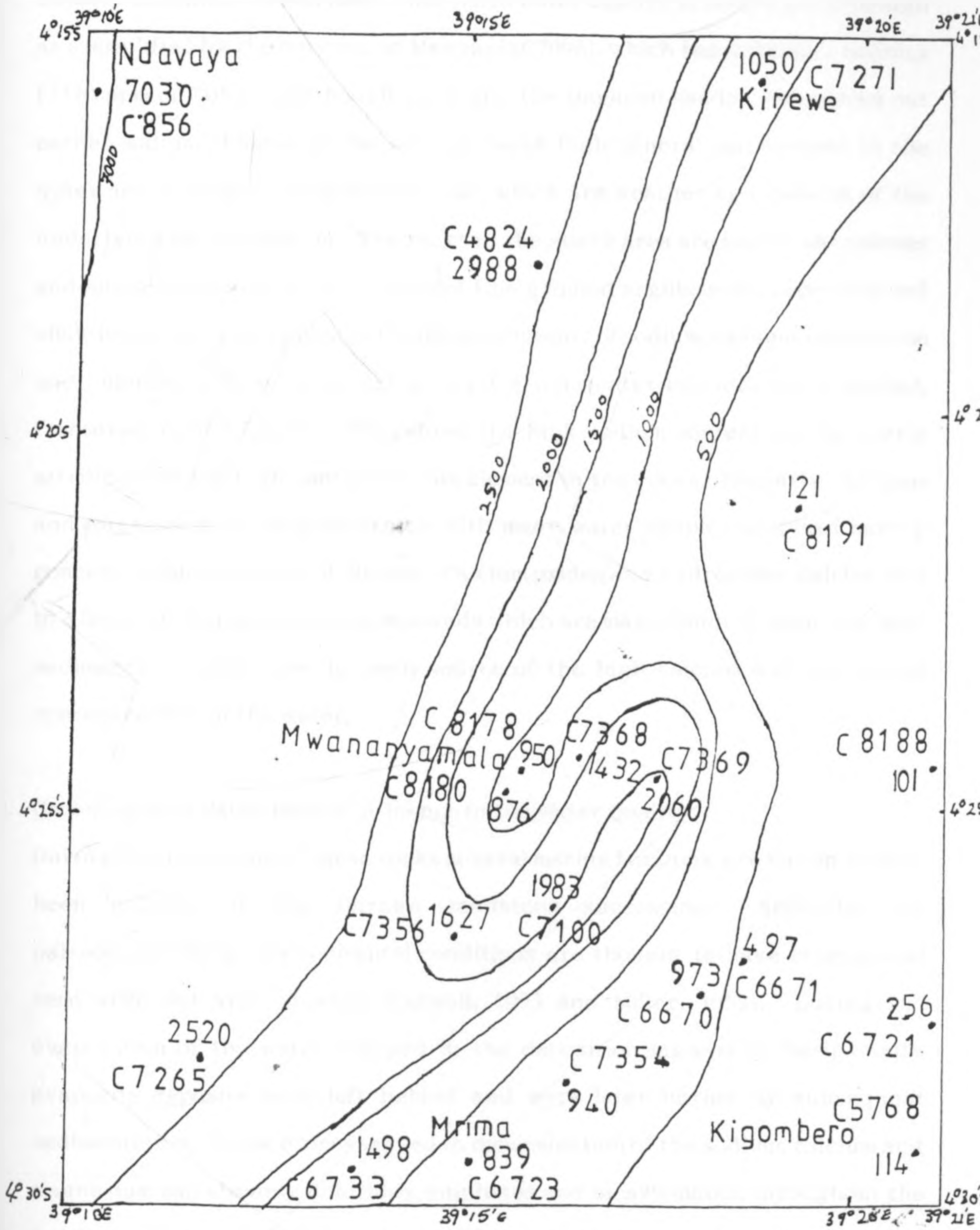


Fig.7-2 Distribution Map for Conductivity in the Study Area

C6723 - Borehole Number

876 - Conductivity in µs/cm

1000 - Conductivity contour line

The main cause of the high sodium and chloride concentrations in the water resources is geologic and not "Modern" sea water intrusion phenomena. Minor cases of seawater encroachment into fresh water aquifer is taking place though as exemplified by the borehole at Mangwei (C7096), which has very high salinity (3720 ppm of TDS) even though sunk into the Magarini sands. As pointed out earlier sodium chloride is the main cause of high mineral salt content in the water and is largely derived from soils which are weathering products of the underlying rock formation. The rocks in the study area are mainly sandstones and siltstones which contain lenses of fine grained argillaceous, claystone and shale intercalations (Appendix I) with enrichments of sodium, calcium, magnesium and chloride. These rocks act as good groundwater carriers when jointed, fractured or/and faulted. Therefore, the high sodium content can be partly attributed to the high content of this element in the rocks. Similarly, calcium and magnesium are relatively high with many water samples analysed having concentrations in excess of 50 ppm. Calcium oxides and hydroxides, calcite, and to a lesser extent magnesium compounds which are major binding agents of most sedimentary rocks are the main source of the high calcium and magnesium concentrations in the water.

6.1.3. Geological and Paleoclimatic Influence in the Water Quality

During the deposition of these rocks several marine horizons are known to have been included in the Duruma sandstone succession. Similarly, the palaeodepositional environmental conditions are thought to have experienced semi arid and arid climates (Caswell, 1953 and Miller, 1952). During the evaporation of the water trapped in the deposition lagoons or basins salty evaporite deposits were left behind and were later buried by subsequent sedimentation. These processes led to dissemination of the sodium, calcium and magnesium salts, mainly chlorides, sulphates and bicarbonates, throughout the sandstone series so that in most parts the rocks of the area are generally salty.

As rain water infiltrates the rocks through the pores, joints and fractures they redissolve and wash down these salts into the groundwater environments. The precipitation and concentration of salts is higher the longer the infiltration process, the higher the evaporation rates and the slower the groundwater movement and recharge. These "ancient" salts are the main cause of high salinities noticed in the groundwater resources in the Ndavaya-Mrima area.

According to Talsma and Phillip (1971) and Yasushi Kitano (1975) nearly all the chloride found in water originates from the ocean mostly as sea spray salting. Due to its nearness to the ocean sea spray contributions on the chloride concentrations in the water resources of the study area are expected to be significant. However, while this may be taking place some of the boreholes closest to the ocean seem to have very low salt concentrations implying minimal contribution from this source. Kivuleni (C6721), Mwaluvanga Eshu (C8188), Kigombero (C5768), Marenje (C7091), Ganda (C7093) and even Kichakasimba (C8192) are the boreholes most close to the ocean and yet their TDS contents are, 195 ppm, 300 ppm, 119 ppm, 960 ppm, 120 ppm and 148 ppm and their chloride values, 25 ppm, 120 ppm, 50ppm, 345ppm, 642 ppm and 25 ppm respectively are among the lowest in the area. Boreholes at Kivuleni (40m deep) and Eshu (64m deep) are drilled below sea water level but are relatively very low mineralised. This suggests that little seawater intrusion in the area do occur and that seaspray salting (cyclic salting) plays a minor role in the contribution of the chloride ions in the total mineral content. Therefore, geology and particularly paceo-deposition environmental conditions play a major role in contributing to the total salt concentration in the groung waters. The main origin of sodium chloride, the major contributor to high water salinity are the salts disseminated within the succession.

Surface waters in the area are relatively low mineralised except for the thermal spring at Kitoni and Maji Moto river and a section of Ramisi river down stream its confluence with Maji Moto river, which are highly mineralised. All the river and spring waters show low TDS values and low concentrations of sodium, calcium, magnesium, sulphate and chloride ions. However, the two water holes at Mkongani (Wh_1) and Kirewe (Wh_2) are slightly mineralised. The waterholes probably tap their waters from the groundwater in the area thus the relatively high concentrations of chemical constituents. A case of seaspray effects on the chemical quality of surface water is demonstrated by Ramisi river whose salt content increases downstream towards the ocean.

6.1.4. Potassium Concentration in the Waters

Potassium content is generally low in all ground and surface water resources. Very few cases of potassium concentrations above 10 ppm are observed. The low content of potassium in the water can be attributed to the low solubility of potassium minerals present in the rocks and its usually low concentration in the cyclic salts. It may seem that potassium salts are very low among the mineral salts disseminated within the geological successions during the deposition of these sediments.

6.1.5. Silica Concentration in the Waters

On the other hand silica is generally relatively high in the groundwater of the study area. With an exception of boreholes at Mkunduru (C7273) (16ppm of Sio_2), Tiribe (C4773)(16 ppm of Sio_2) and Marenje (C6733)(10ppm of Sio_2) all groundwater resources analysed have more than 20 ppm silica. Though silica is difficult to dissolve, the prolonged contact between most of these waters and the rock forming minerals in the aquifers could account for enhanced dissolution of silica. The concentration map (fig. 8-3) show that the silica concentration in the groundwater resources increase with flow direction and distance from the source. However, this is only true for groundwater obtained from the Duruma sandstone aquifers (except for Mazeras sandstone) and just before the water enters the Magarini sands. Otherwise the concentration of silica decrease eastward from here. Therefore, a central zone of silica concentration can be observed from this distribution map, such that the concentration of silica increases towards the central position of the area from all directions. The low silica content in the water from Mazeras sandstones and Magarini sands can be explained by improved groundwater recharge, favourably high porosity hence permeability of these sands which results in enhanced free and faster movement of groundwater and dilution effects.

From the correlation coefficient analysis (table 10) silica is positively correlated with the four major cations, sodium, potassium, calcium and magnesium. This association can be explained by the fact that most of the minerals forming the rocks of this study area, are generally quartzose and in fact weathering products of the silicate minerals of the precambrian basement system rocks. Therefore, such a relationship can be used to suggest that silicate minerals are partly the source of these cations in the water. The similarly positive correlation between silica and the three dominant anions, sulphate, chloride and bicarbonate is as a result of the corresponding positive relationship between silica and the cations.

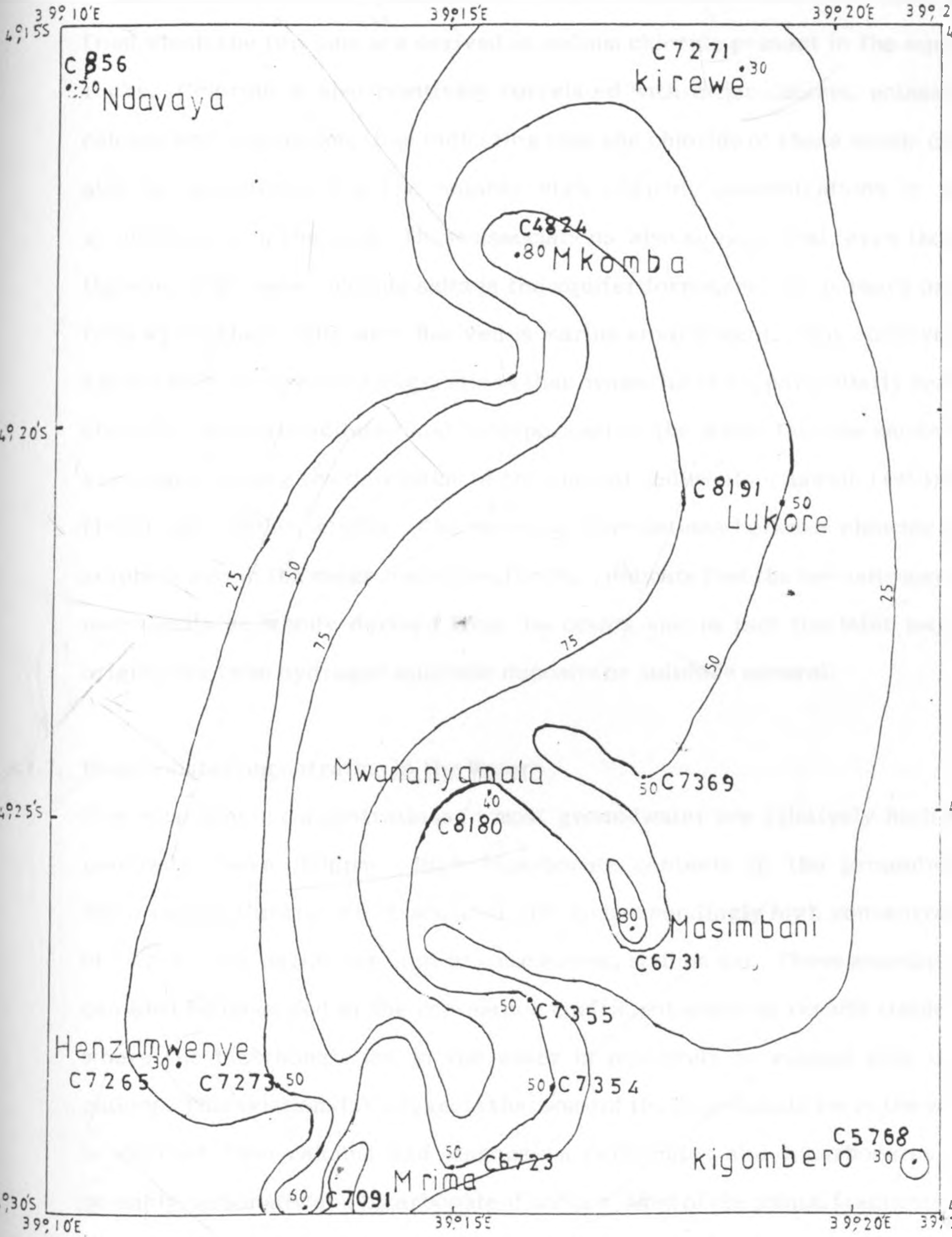


Fig. 7-3 Silica Concentration Map in the Study Area

C7091 - Borehole Number
30 - Concentration in ppm
75 - Concentration Contour line

6.1.6 Chloride Concentration in the Waters

Chloride ions show very positive correlation with sodium hence the main salt from which the two ions are derived is sodium chloride present in the aquifer rocks. Chloride is also positively correlated with other cations, potassium, calcium and magnesium, thus indicating that the chloride of these metals could also be responsible for the notably high chloride concentrations in most groundwaters in the area. These associations also suggest that, even though the source of these chloride salts is the aquifer formations the primary origin from which these salts were derived is marine environment. This observation agrees with the previous suggestions that evaporite salts, particularly sodium chloride, were precipitated and incorporated in the whole Duruma sandstone succession during the deposition of the ancient sediments Caswell, (1953) and (1956) and Miller, (1952). The negative correlations between chloride and sulphate ions in the water resources, further, indicate that the two salts may not necessarily be wholly derived from the ocean, and in fact the later may be originating from hydrogen sulphide deposits or sulphide mineral.

6.1.7. Bicarbonate Concentration in the Waters

The bicarbonate concentrations in most groundwater are relatively high and generally above 100ppm. High bicarbonate contents in the groundwater resources in the area are associated with correspondingly high concentration of calcium and magnesium, and to some extent, sodium ion. These associations can also be observed in the correlation coefficient analysis results (table 10) where the bicarbonate ion in the water is positively correlated with these cations. This relationship suggests that some of the bicarbonate ion in the water is derived from calcium and magnesium carbonates and bicarbonates and possibly carbonates and bicarbonate of sodium. Most of the joints, fractures and fault partings or planes in the sandstones and the rocks in the area are filled with mica and enriched carbonaceous material, Caswell, (1953) and (1956). Furthermore, calcic and ferruginous materials, in addition to other oxides and hydroxides, probably of magnesium are the major cementing or binding materials of these rocks. Thus the high content of bicarbonate ions in the groundwater corresponding to high calcium and magnesium concentrations can be partly attributed to these carbonaceous materials incorporated in the geological formations which act as aquifers. Therefore, like most other chemical constituents, the geology in this area is responsible for most bicarbonate ion dissolved in the water.

The Eastern and Southern part of the study area, as observed during the field study is heavily covered by vegetation, and even in the cultivated regions huge amounts of decaying plant residues are a common occurrence. Considering that these decaying vegetation produce high contents of carbon dioxide gas which is quickly dissolved into infiltrating rain water, a significant contribution of the bicarbonate in the water is as a result of the increased dissolution ability by infiltrating water of carbonate bearing rocks and mineral phases. But since most of the carbon dioxide dissolved in groundwater is derived from microbial activities, Matthess, (1982) and Bouwer, (1978). This environmental modification on water quality can also explain the relatively small positive correlation between calcium and magnesium and the bicarbonate ion (table 10). In the concentration map Fig. 8-4 it can be observed that bicarbonate ion concentrations decrease eastward but increase South-South-Eastward, with a major concentration zone in the central-southern part of the area. Groundwater from the Magarini sands and the Mazeras sandstone and Shimba grits have relatively low bicarbonate values. With an exception of Kitoni springs and Maji Moto river, surface water resources have relatively low bicarbonate concentrations.

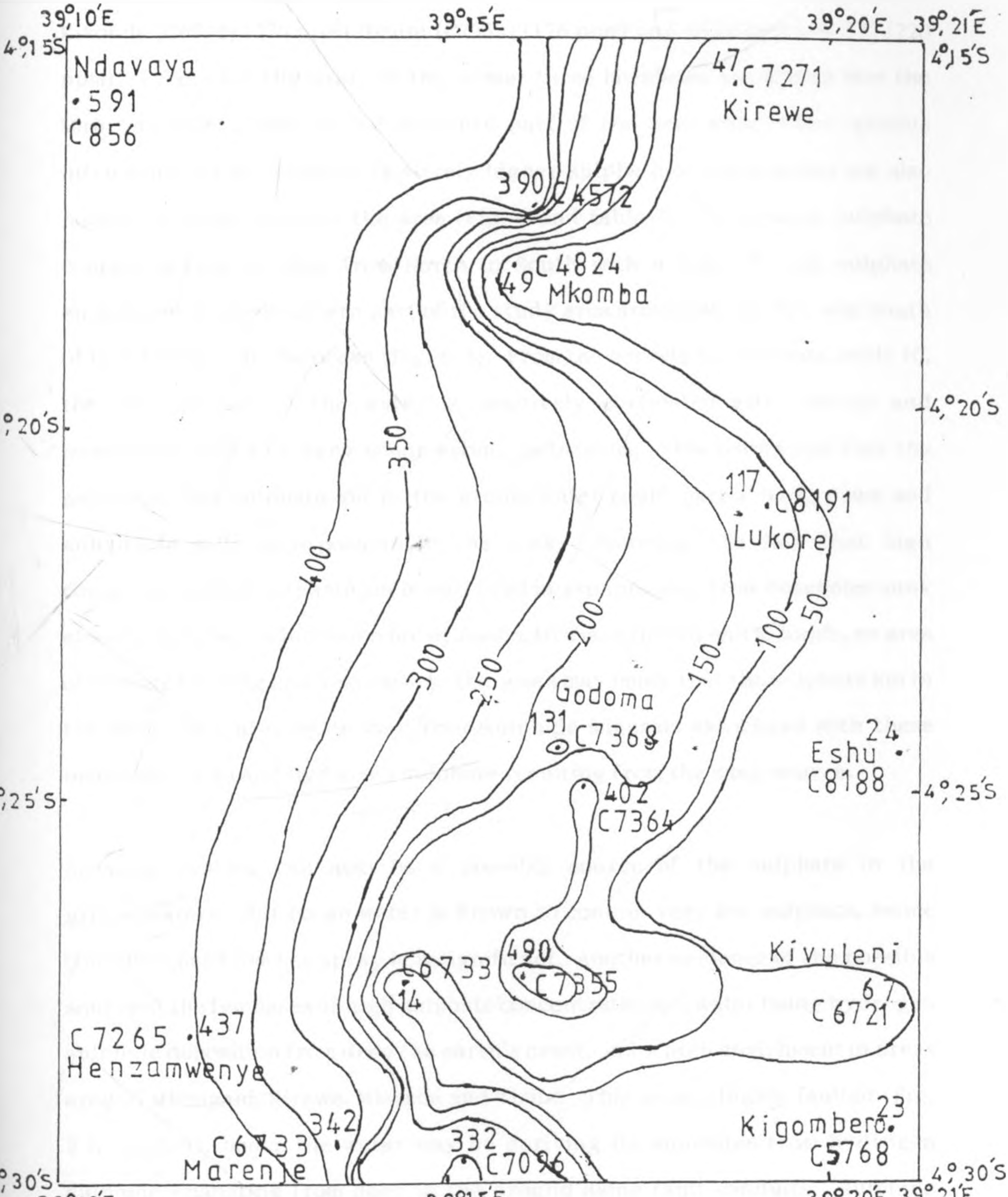


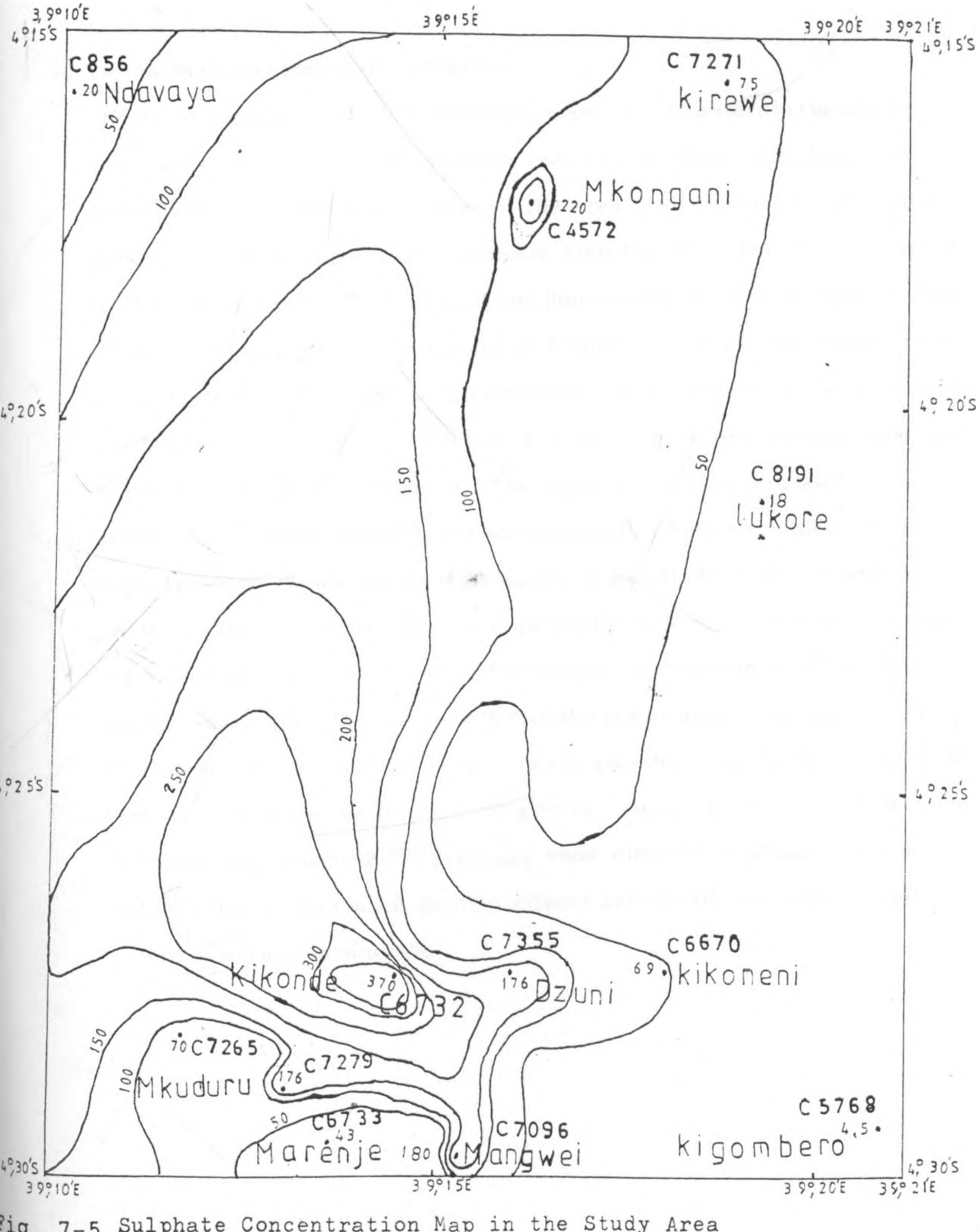
Fig. 7-4 Bicarbonate Concentration Map in the Study Area

C6733 - Borehole Number
342 - Concentration in ppm
200 - Concentration Contour line

6.1.8. Sulphate Concentration in the Waters

The sulphate ion concentrations in the groundwater are relatively low, well below 96 ppm. Exceptions are noted for boreholes at Mkuduru (C7279) (176 ppm), Kikonde (C6732) (370 ppm), Dzuni (C7355) (176 ppm) and Mkongani (C4752) (220 ppm). Except for the later, all the former three boreholes are drilled into the Maji ya Chumvi beds in the Southern part of the area around the igneous intrusions. Other cases of relatively higher sulphate concentrations are also notable in these parts of the area (Fig. 4 and table 7). In general, sulphate concentrations increase from North to South with a zone of high sulphate enrichment in the Southern part of the study area around Mrima hill, and South of this hill close to the ocean (Fig. 8-5). From the correlation analysis, table 10, the sulphate ion in the water is positively correlated with calcium and magnesium, and to a very minor extent, potassium. This points out that the source of this sulphate ion in the groundwater could partly be gypsum and anhydride salts incorporated in the rock. However, the fact that high concentrations of sulphate ion is observed in groundwater from boreholes sunk close to the igneous intrusion hill at Jombo, Mrima, Nguluku and Kikonde, an area of intense faulting and also close to the ocean may imply that the sulphate ion in the water may also be derived from sulphide minerals associated with these intrusive rocks and hydrogen sulphide resulting from the same source.

Seaspray salting can also be a possible source of the sulphate in the groundwaters. But ocean water is known to contain very low sulphate, hence contributions from sea spray is insignificant. Another evidence of the possible source of the few cases of high sulphate concentrations in water being hydrogen sulphide deposition from deep the earth's crust, is its high enrichment in areas around Mkongani, Kirewe, Mkomba and Tiribe. This area is highly faulted (Fig. 3 in pocket), hence the water may be deriving its sulphates from hydrogen sulphide emanating from deep in the ground along fault conduits. Sulphide deposits must have formed along the fault partings. On the contrary surface waters have relatively low sulphate concentrations. Most surface waters, except



ig. 7-5 Sulphate Concentration Map in the Study Area

C7279 - Borehole Number

176 - Concentration in ppn

250 - Concentration contour line

for the Maji Moto river (21 ppm of SO_4) and the two water holes at Mkongani (55 ppm of SO_4) and Kirewe (25 ppm of SO_4) have sulphate contents below 10 ppm.

6.1.9. Floride in Concentration in the Waters

The fluoride concentrations in both surface and groundwaters in the study area are low. Except for a few isolated cases of localised enrichment in the groundwater, the water resources in the area have fluoride concentrations generally below 0.9 ppm. Occurrences of high fluoride contents are Ndavaya (C856) (2ppm), Dzuni (C7355) (2 ppm) and Henzamwenye (C7265) (1.3ppm), Ganda (C7093) 1.2 ppm) and Kitoni spring (1.3 ppm). Spring water show similar concentrations of fluoride as groundwater. River waters in the area have particularly no fluoride in solution and all river water samples analysed registered zero values (table 7). The high fluoride concentrations in some groundwater obtained from Duruma sandstones have been attributed to localised high contents of mica minerals in the aquifer rocks Mailu, (1983). Furthermore, the Mariakani sandstone formation is generally micaceous Caswell, (1953) and (1956) and Miller, (1952) and mica minerals are very common in all rock forming minerals in the area. With an exception of the few localised high concentrations the fluoride content in groundwaters in the area decrease Eastward, but show a general increase Southwards (Fig.8-11). Magarini sands and Mazeras sandstone and Shimba grits generally show diminished contents of fluoride probably due to increased dilution effects and partly because of their low content of micaceous minerals.

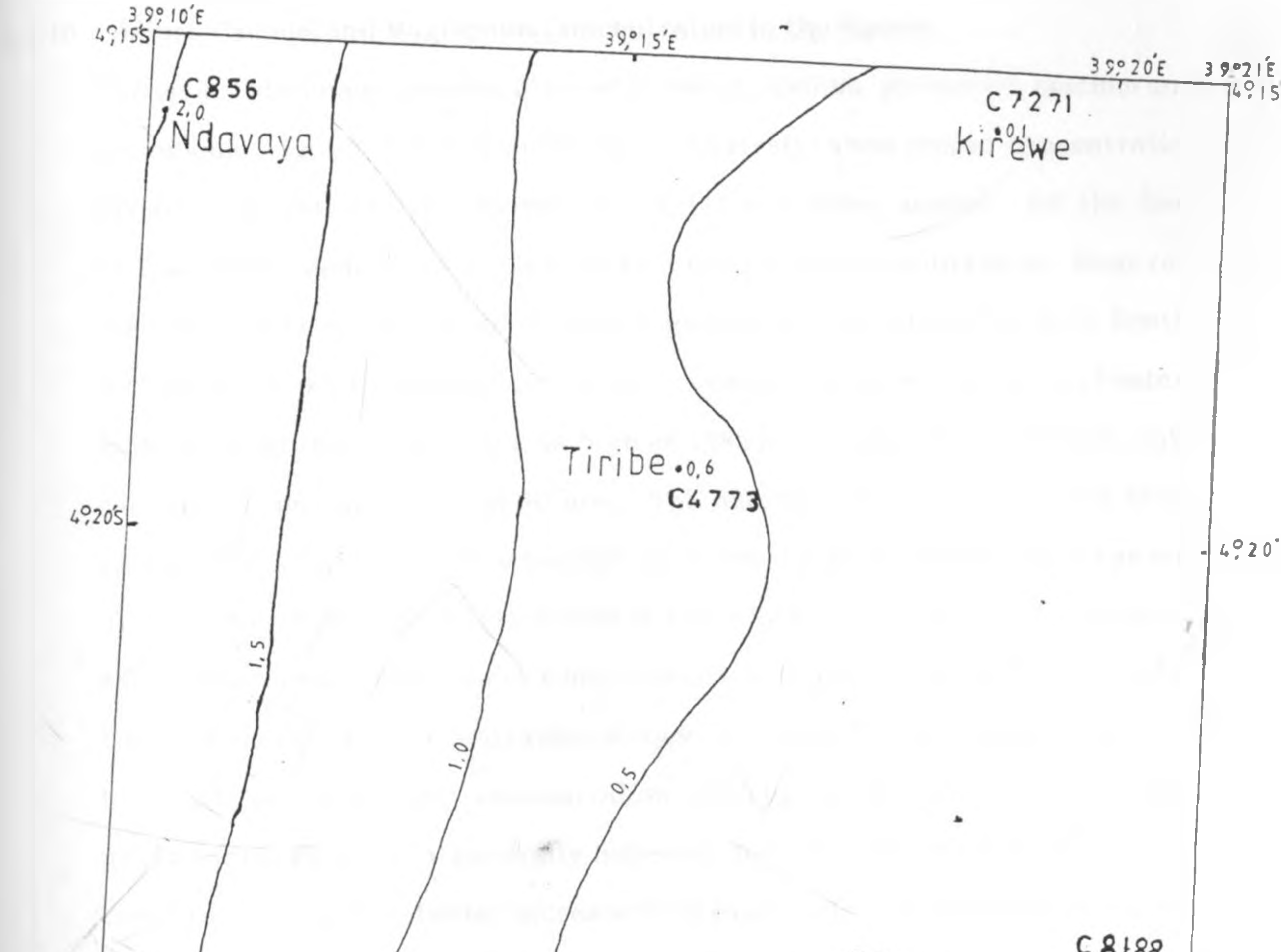


Fig. 7-6 Flouride Concentration Map in the study area

C8188 - Borehole number

1.3 - Concentration in ppm

0.5 - Concentration contour line

6.1.10 Sodium, Calcium and Magnesium Concentration in the Waters

The major (dominant) cations present in water, sodium, potassium, calcium and magnesium (Fig.8-7, 8-8, 8-9 and 8-10, respectively) show similar concentration distribution patterns as chloride (Fig.8-11) and other anions. All the four cations show a general decrease from West to East with flow direction. However, the contents of cations in water show a general increase from North to South. Sodium is the most dominant cation with concentrations in most groundwaters being greater than 15 ppm and as high as 1985 ppm. Some groundwaters, have calcium concentrations below 50 ppm. The decrease in concentration of these cations, like anions, can be explained by increased groundwater recharge and groundwater flow in the eastern side of the study area underlain by Magarini sands and Mazeras sandstones which results in dilution effects. On the other hand the increase in concentration of these ions with flow direction from north to south is caused by concentration effects of the mineral salts with groundwater flow. It is generally believed that the concentration of chemical constituents in groundwater increase from high hydraulic gradient to low and from high topography to low with flow experience and direction (Lloyd, 1985). It has also been observed that groundwaters in the discharge areas register higher contents of chemical constituents than in recharge areas. The increase in concentrations of the chemical ions in groundwater in the study area from North to South is in agreement with these observations. In the study area this change of concentration from that noted West to East is a clear effect of structural geology which modify the groundwater flow in the southern part of the area. From the correlation coefficient, table 10, it can be noted that sodium is positively associated with all the other three cations. Potassium is positively associated with sodium but negatively correlated with calcium and magnesium. Calcium show close association with magnesium. These relationships show the association or differences in their possible origins as explained earlier.

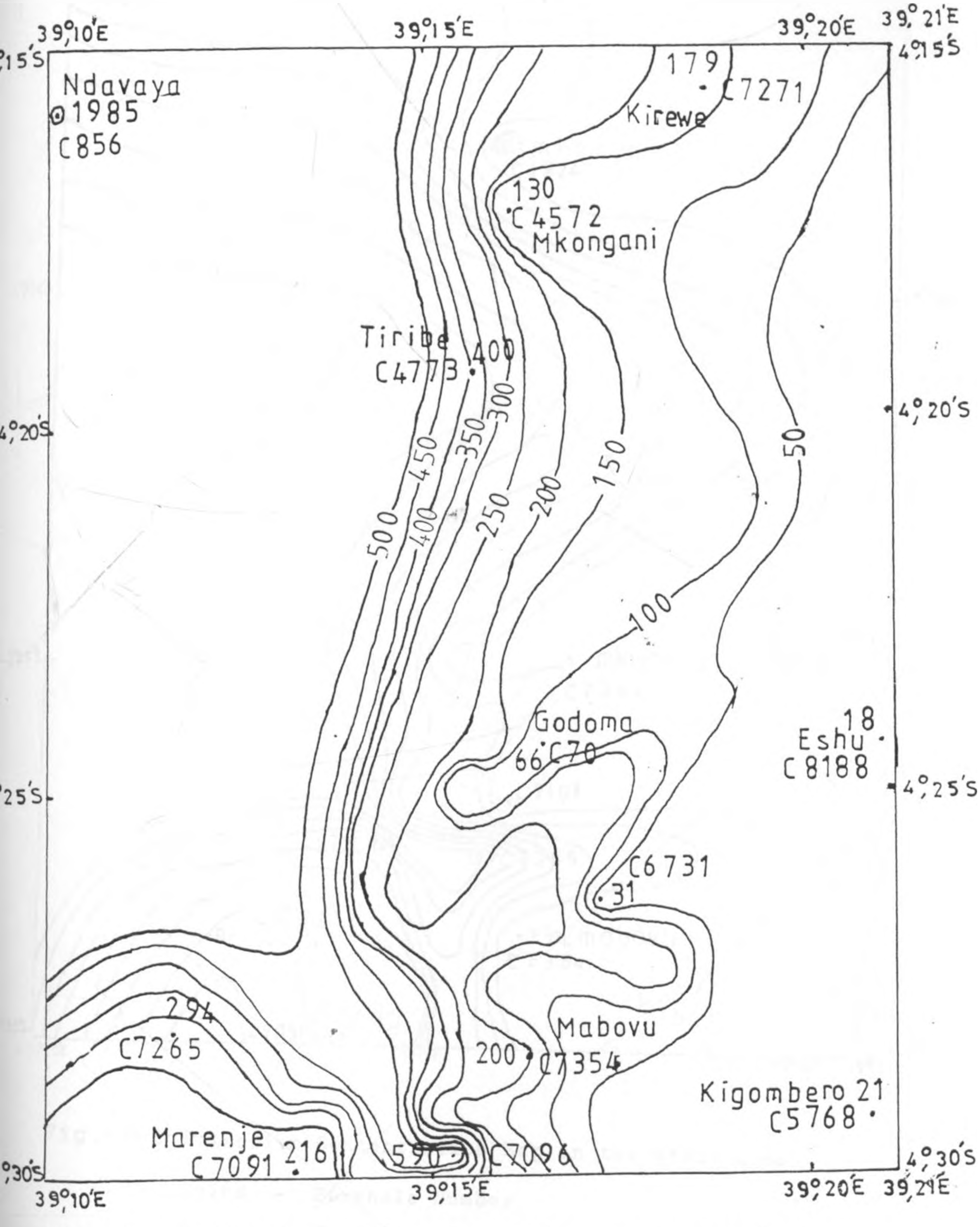


Fig. 7-7 Sodium Concentration Map in the Study Area.

C7091 - Borehole Number

216 - Concentration in ppm

400 - Concentration contour line

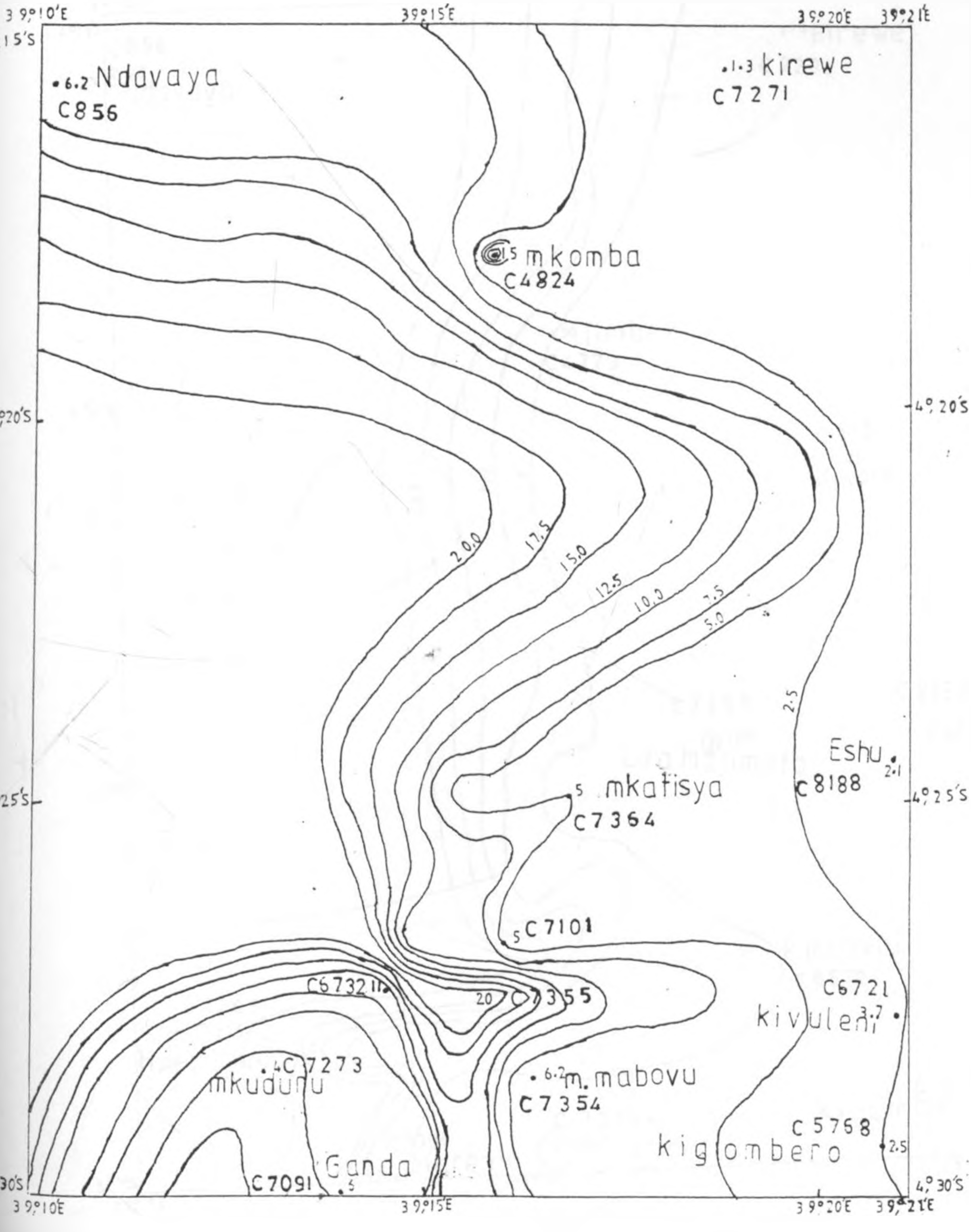


Fig. 7-8 Potassium Concentration Map in the Study Area

C5768 - Borehole Number
6 - Concentration in ppm
5 - Concentration Contour line

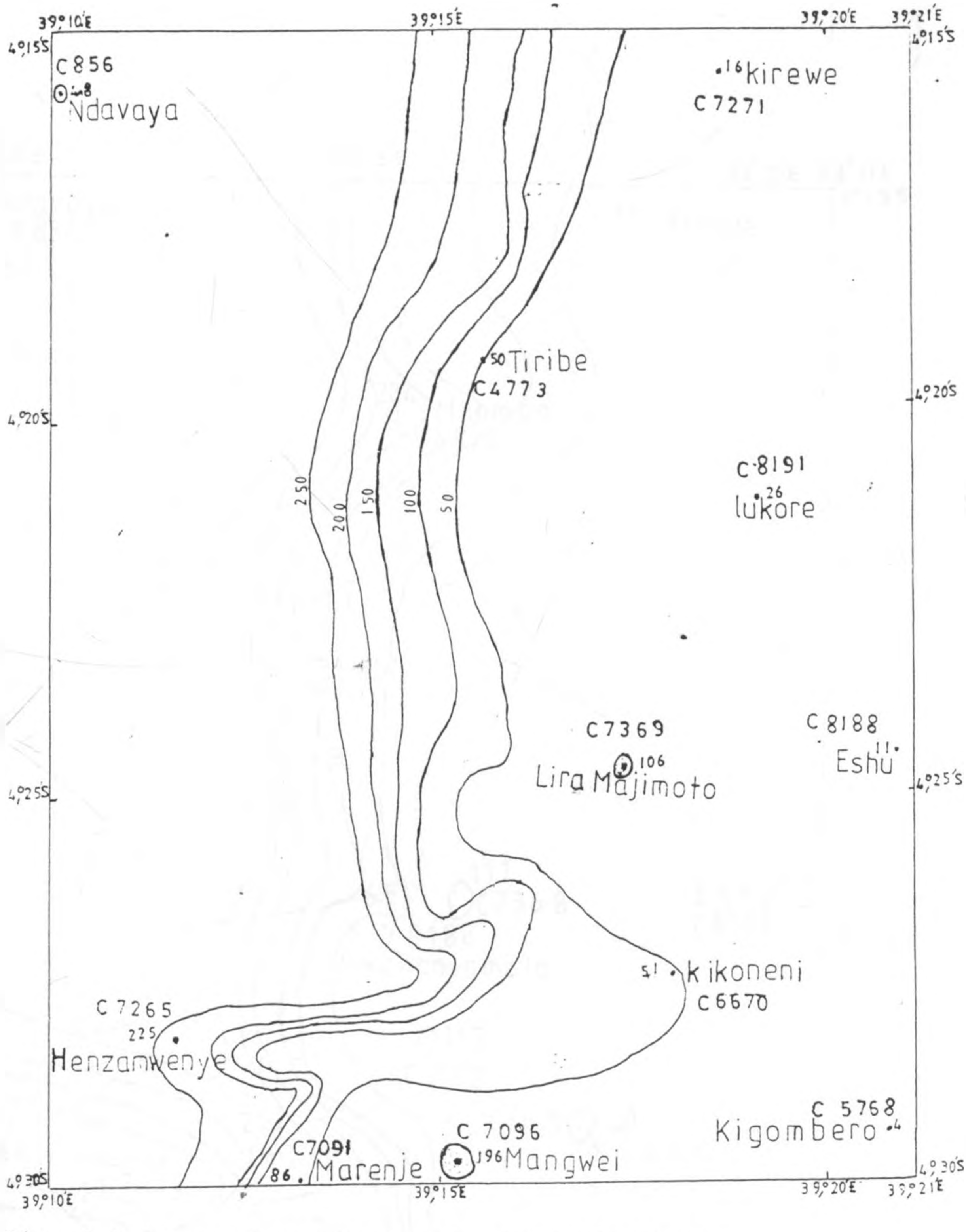


Fig. 7-9 Calcium Concentration Map in the Study Area

C7369 - Borehole number

86 - Concentration in ppm

100 - Concentration contour line

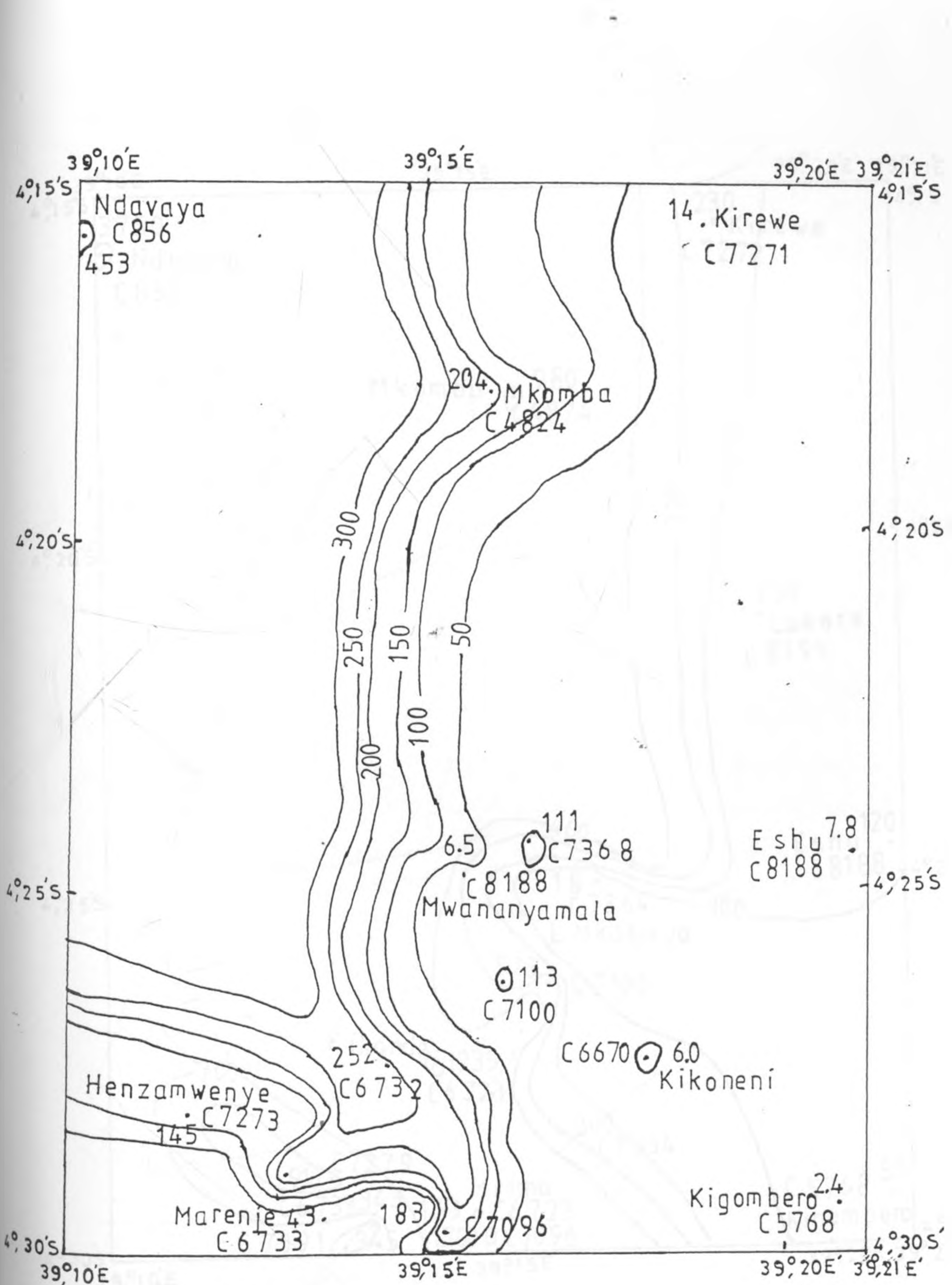


Fig.7-10 Magnesium Concentration Map in the Study Area

C7100 - Borehole Number

252 - Concentration in ppm

50 - Concentration contour line

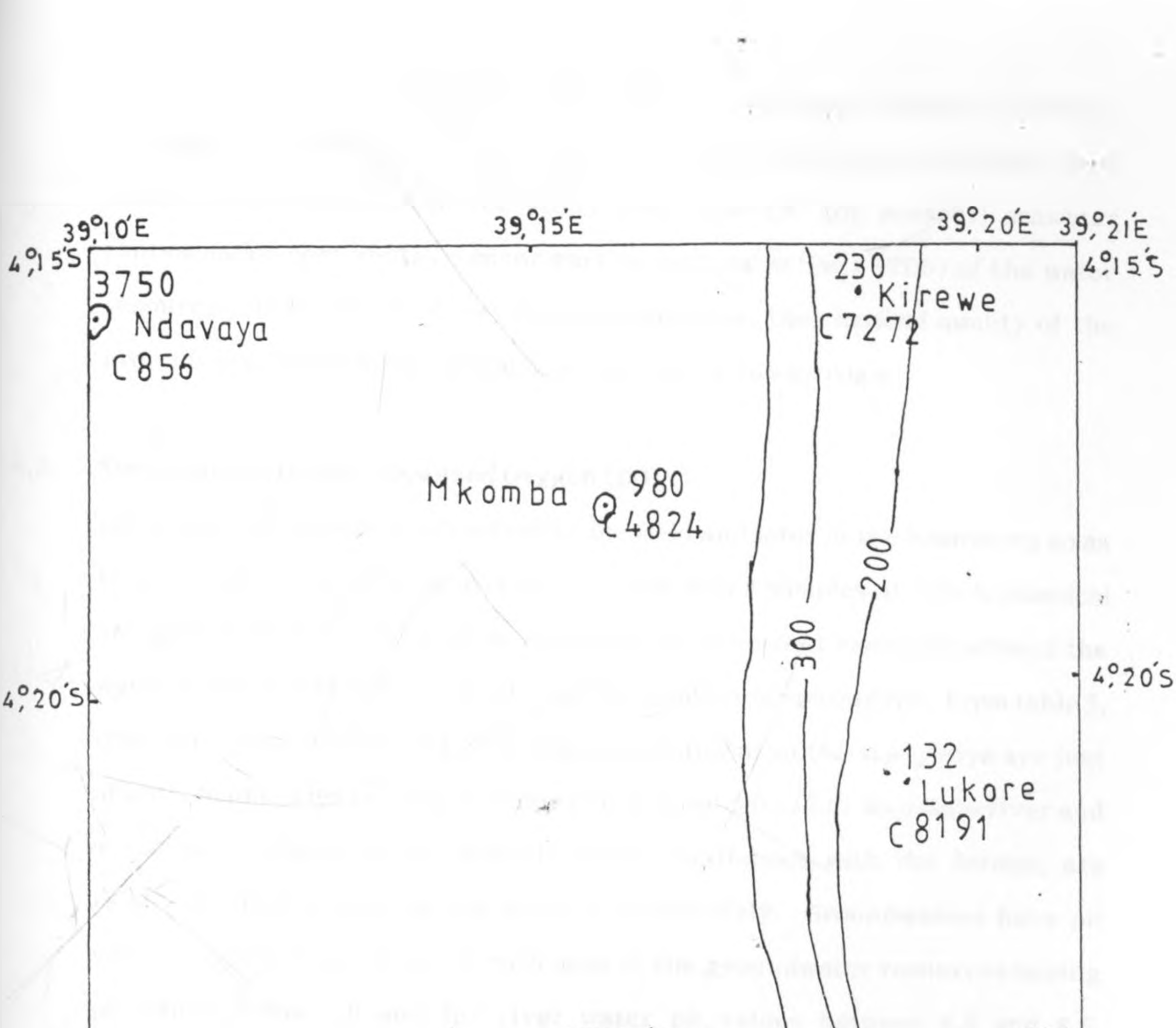


Fig. 7-11 Chloride Concentration map in the Study Area

C6723 - Borehole number

343 - Concentration in ppm

700 - Concentration contour line

The above discussion points out clearly that, even though "ancient" seawater could have been the source of most of the these high mineral salt concentrations in the water resources in the study area "modern" (or present) seawater contamination contributes a minor part to the total salinity (TDS) of the water resources. Hence these observations suggest that the chemical quality of the groundwater in the area is greatly influenced by the geology.

6.2. Temperature, pH and Dissolved Oxygen (DO)

pH determinations were carried out at the field and later in the laboratory so as to ascertain the acidity or alkalinity of the water samples at which chemical analyses were done. Field pH measurements are the most representative of the water conditions as they were taken at the ambient temperatures. From table 5, therefore, both surface and groundwater conditions in the study area are just slightly acidic, with pH values ranging from about 5.0 to 8.0. Maji Moto river and a section of Ramisi river, downstream its confluence with the former, are relatively alkaline with pH 8.6 and 8.1 respectively. Groundwaters have pH values ranging from 5.6 to 7.6, with most of the groundwater resources having pH values below 7.0 and for river water pH values between 6.8 and 8.6. Therefore, the water resources in the area are generally neutral except for some river water samples which are slightly alkaline. This pH range fall within those generally found in most natural waters, therefore, indicating very little human influence on the water quality.

The temperatures of both surface and groundwater in the area close to those of the atmosphere. The surface water temperatures for springs and rivers are generally lower than groundwater temperatures. The waters have temperatures varying between 22°C and 30°C except the thermal spring waters which have discharge temperature (at the field determination) of 59.4°C and Maji Moto river, into which this spring discharge its water, with surface discharge temperature of 32°C. A section of Ramisi river, immediately downstream its confluence with Maji Moto stream has a temperature of 28.9°C.

The amount of dissolved oxygen (DO) in water is dependent upon the surface temperatures of the water bodies. This is demonstrated by the dissolved oxygen values in the area (table 5). The following variations in oxygen solubility with water temperature were confirmed by Tebbutt (1983).

Table 13: Temperature Dependence of Dissolved Oxygen in Water (Source: (Tebbutt, 1983)

Temperature (°C)	0	10	20 30
D.O. mg/1	14.6	11.3	9.1 7.6

Kitoni spring with a surface discharge temperature of 59.4°C has the least amount of dissolved oxygen (0.5ppm). While many factors may be responsible for the amount of dissolved oxygen the surface water resources have generally slightly diminished content of dissolved oxygen. The relatively high salt concentrations (TDS) can partly contribute to the low dissolved oxygen values. In general, the surface waters have concentrations within the 5.0 ppm considered adequate for aquatic life. The dissolved oxygen values ranging from 4.6 ppm to 6.8 ppm may indicate that there is little contamination of these waters. An exceptional case here is shilling Tupu spring with a dissolved oxygen content of about 3.4. ppm at surface temperatures of about 23.2°C. This relatively low dissolved oxygen value may further suggest that some kind of organic contamination of the spring water is taking place. And from both field observations made and the results the possible cause of contamination is bacterial decomposition of plant residues in the waters. In fact this is the common kind of pollution of most surface water resources in the study area.

6.3. Total Alkalinity (TA) and Total Hardness (TH)

Total alkalinity and total hardness of a water resource are the two water properties exclusively caused by the presence of bicarbonate and carbonate ions in the water mainly those of calcium, and magnesium. Groundwater in the area have relatively high values of total hardness and moderate alkalinity contents. From the correlation coefficient analysis (table 10) and the chemical data (table 7) it can be noted that high alkalinity and hardness values are associated with high concentrations of calcium and to a lesser extent magnesium ions in the water. These two properties are also positively correlated with bicarbonate ions, thus implying that the main source of the alkalinity and total hardness in the water is probably calcium and magnesium carbonates and bicarbonates. The negative correlation between total alkalinity and magnesium in the water, however, suggests that magnesium carbonate or bicarbonates contributes very little influence on the water property. It is also possible that sulphates and chlorides of magnesium and calcium are partly responsible for the high hardness of groundwaters.

All groundwater, except Kivuleni (C6721) (54ppm of TH) and Kigombero (C5768)(20 ppm of TH) have total hardness values above 60 ppm, (Table 7). Extreme hardness values are observed at Ndavaya (C856)(1876 ppm). Henzamwenye (C7265)(1156 ppm) and Mkomba (C4824) (1240 ppm) boreholes, all drilled in the middle Duruma sandstones, with the former in Maji ya Chumvi beds and the later one in Mazeras sandstone formation. Most groundwater resources have alkalinity values below 300 ppm but above 50 ppm. In general the groundwaters in the area are very hard for nearly all human and most industrial purposes. Boreholes drilled in the Magarini sands and Mazeras sandstones have soft water with relatively low total hardness values. From the concentration maps (figures 8-12 and 8-13) it can be observed that the total hardness and total alkalinity values in the groundwater decreases Eastward (except for some localised concentrations) with least values in boreholes drilled into Magarini sands. This trend in distribution of the two properties can be

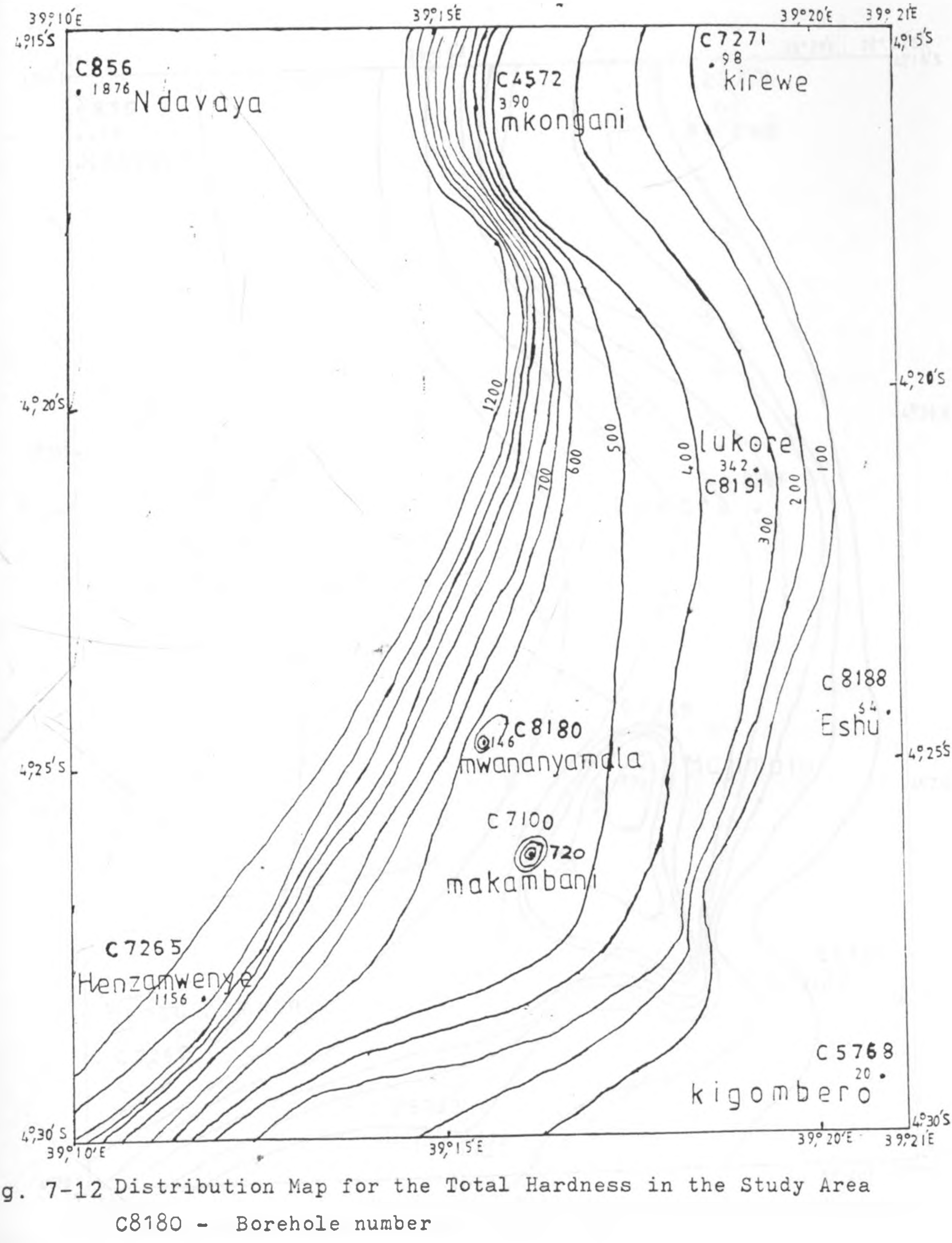


Fig. 7-12 Distribution Map for the Total Hardness in the Study Area

C8180 - Borehole number

1156 - Concentration in ppm

600 - Concentration contour line

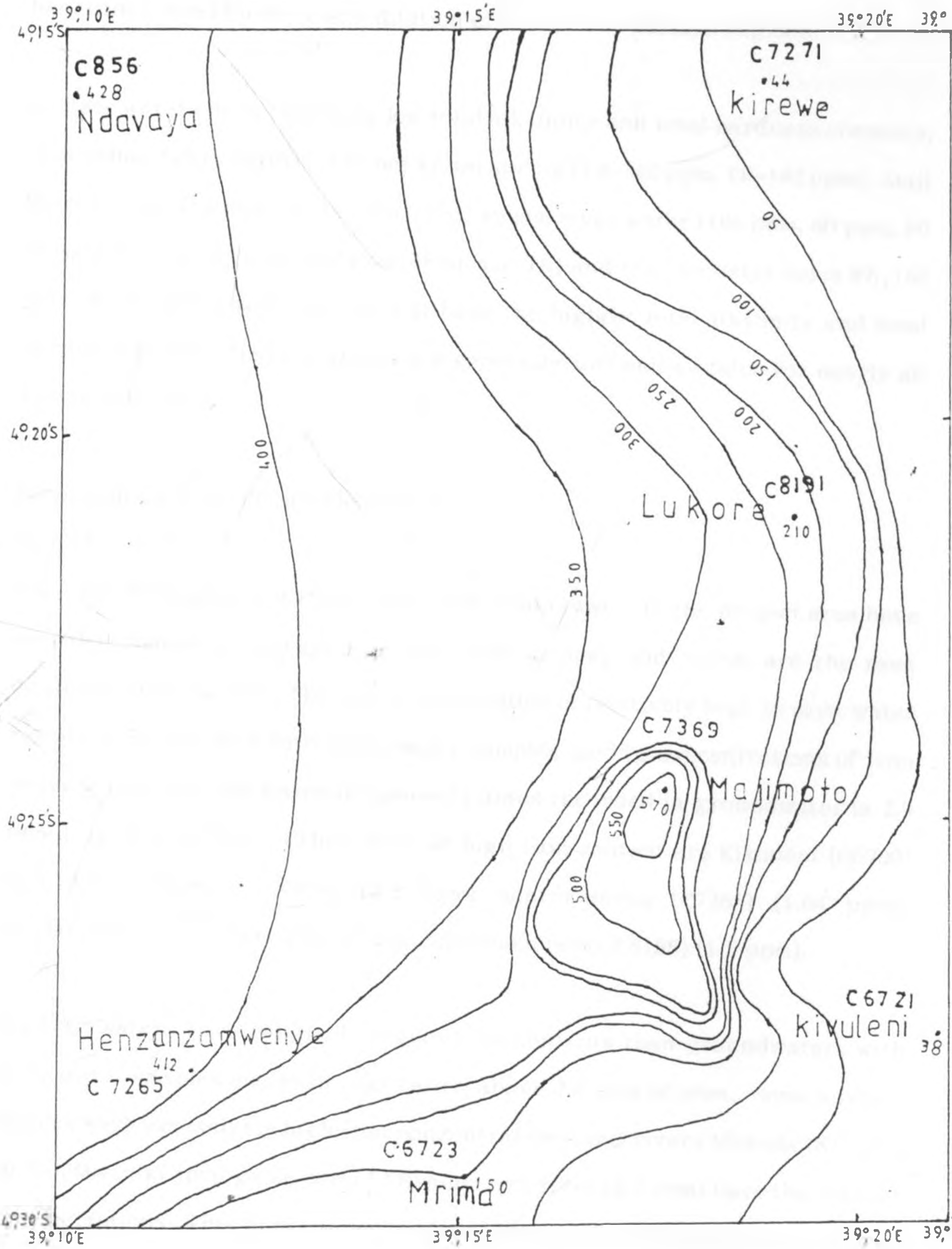


Fig. 7-13 Distribution map for the total alkalinity in the study area

C6721 - Borehole number

150 - Concentration in ppm

30 - Concentration contour line

attributed to enhanced groundwater recharge, activated groundwater flow and hence increased flushing and dilution effects in the eastern regions.

Surface waters have relatively low total alkalinity and total hardness contents, with values below 60 ppm. The hot Kitoni spring (TA-360 ppm, TH-142 ppm). Maji Moto stream (484 ppm TA, 162 ppm, TH), Ramisi river water (180 ppm, 80 ppm, 60 ppm, of TA and 142 ppm, 108 ppm, 78 ppm of TH) and the two water holes Wh_1 (60 ppm of TH) and Wh_2 (82 ppm of TH) have the highest total alkalinity and total hardness levels. Surface waters are generally soft and suitable for nearly all human activities.

6.4. Minor Constituents (Trace Elements)

6.4.1. Iron (Fe)

The chemical analysis of the surface and groundwater in the project area have revealed that iron, manganese, zinc, lead, copper and nickel are the most dominant minor metals. The iron concentration is relatively high in most water resources in the area with many water samples having concentrations of iron above 1 ppm and the maximum concentrations recorded in groundwater is 2.9 ppm (Kigombero(5768). Other cases of high iron content are Kikoneni (C6700) (2.3 ppm), Mkomba (C4824) (2.2 ppm) Henzamwenye (C7265) (1.64 ppm), Kichakasimba (C8192) (1.2 ppm) and Eshu Maendeleo (C8188) (1.5 ppm).

Surface waters have relatively higher iron contents than groundwaters with most water samples analysed registering above 2.0 ppm of iron. Some surface waters have excessively high iron concentrations, and rivers Mkanda (8.2 ppm of Fe), Mwaniki spring (3.6 ppm of FE) and Lovu river (2.9 ppm) have the highest concentrations. This high concentration of iron in the river and spring waters than in groundwater support a suggestion that the occurrences of high iron contents in some borehole waters is not necessarily caused by contamination by the handpump metal equipments but is mostly geological. Most of this iron originates from minerals of the aquifer rock and the near surface rocks and soil over which the rivers flow and from which the springs issue. The main sources here are oxides and hydroxides, and even carbonates, generally common cementing agents and weathering products of the rocks. Ferromagnesium minerals and other iron rich minerals in the rocks contribute the largest amount of this iron. Iron sulphide minerals are also other possible sources of iron in water.

6.4.2. Manganese (Mn)

Manganese is another common metal in the water resources in this area. Many water samples analysed have manganese concentrations above 0.1 ppm. Surface water has relatively higher manganese contents than groundwater, which have concentrations generally below 0.1 ppm. Spring water show similar concentrations of manganese as groundwater while river water has the highest manganese concentrations in the area with values as high as 0.4. ppm. Like iron, the main possible sources of manganese are its oxide and hydroxide compounds in the soil and rock minerals which are released into solution upon weathering. Another possible source of manganese in water is surface runoff from cultivated fields contaminated with fertilizer residues used in treating horticultural crops and bixa trees. Farming of these crops is widely practised in the area and insecticides, fungicides and other chemicals are used, but not extensively. The positive correlation coefficient observed in table 12 between iron and manganese indicate that these two elements are geochemically associated in the rocks of this area.

6.4.3. Zinc, Copper, Lead and Nickel

Zinc is a common trace metal occurring in significant concentrations in groundwater. Groundwater contain relatively high zinc contents than surface waters. All surface waters in the area have very low amounts of zinc in solution generally below 0.05 ppm while nearly all groundwater analysed had zinc concentrations above 0.1 ppm. High concentrations of zinc are found in water from boreholes at Eshu town (C8188)(3.3 ppm), Maji Moto river (2.2 ppm) and

Mkomba (C4824) (1.0 ppm). While there is no specific relationship between the iron and zinc concentrationsin the groundwatersit is a common observation that some of the boreholes having high iron concentrations have correspondingly high zinc contents. However, from table 12 it can be observed that the two elements are negatively correlated. Little contamination could be taking place from the hand pumps and the notably high zinc concentrations in some groundwater is probably derived from zinc minerals in the aquifer rocks and overlying soil layers. Zinc sulphate disseminated in the soil and rocks is most likely to be the main source.

Lead, copper and nickel ions are detected in most groundwater and even surface waters. Their positive correlation with iron could be indicating close association of these metals with iron in the silicate rock forming minerals. It is, therefore, most probably that these trace elements find their way into the water upon weathering of the rocks. Minor cases of artificial contamination by man activities, especially decomposition of domestic metal appliances and detergents, contribution from agricultural chemicals, could contribute to their presence in the water. Only one case of possible livestock chemical contamination of the water resources was noted during the field work at Ndavaya where a borehole is located a few metres from a cattle dip. The chemical effuents from the cattle dip drain to a nearby stream which empty its water into Ramisi river during heavy rainfall spells. Such effluent can also contaminate groundwater. However, the borehole at Ndavaya has one of the lowest, but significant, concentrations of these metals implying that the chemicals from the dip have no effect on the groundwater quality in this particular area.

6.4.4. Selenium, Arsenic, Cobalt, Chromium, Barium and Cadmium

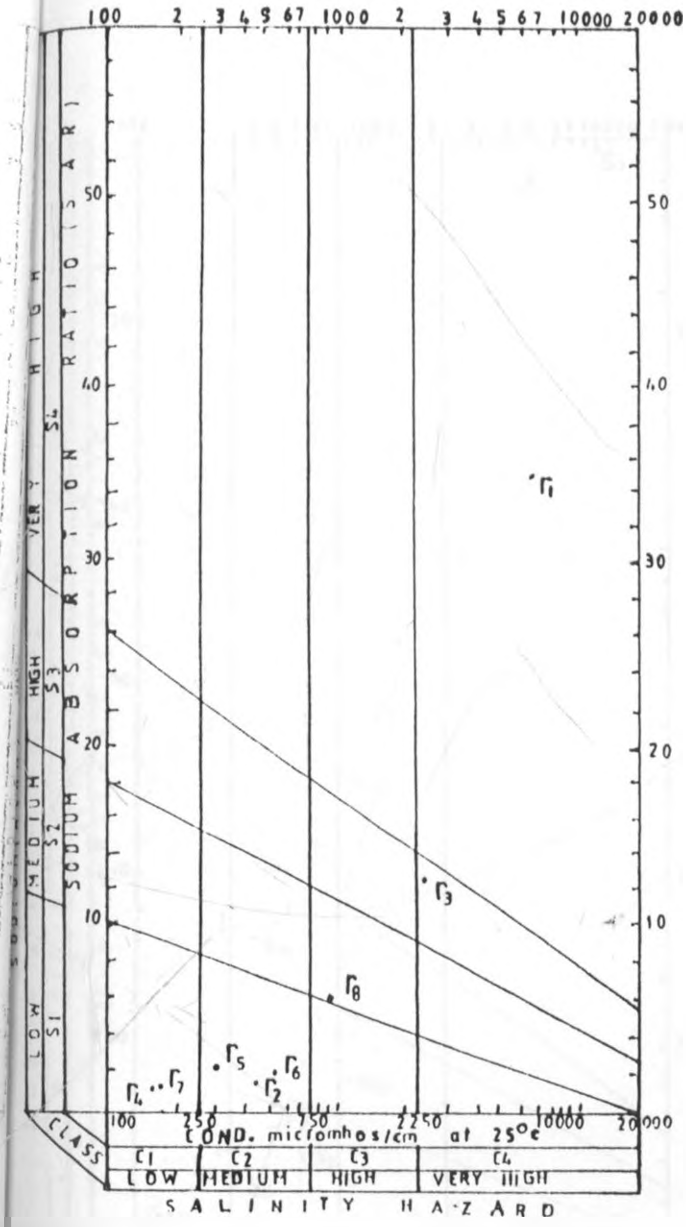
The other trace elements analysed for, selenium (Se), Arsenic(As), cobalt (Co), Chromium (Cr), Barium (Ba) and Cadmuim (Cd) are generally not common occurrences in the water resources of this area. Barium and cadmium are virtually absent while the detected contents of As, Se,Cr and are generally very low. Considering the general scarcity of these elements in the rocks of the earth crust and their relatively low geochemical mobility, Bouwer, (1978) their insignificant concentrations in the water is not a surprise. Hence the main origin of the few occurrences of these metals in the water is geologic and very little, if any, artificial contamination of the water occur.

6.5. Water Quality and Use

A comprehensive account of the quality requirement for most water uses (domestic, industrial and agricultural) was discussed in the preceding chapter. A critical analysis of the chemical data (Table 7) and field data (Table 5) show that most of the groundwater resources in the area have many of the chemical constituents well below the maximum allowable standard levels set by the World Health Organisation (WHO). A comparison of the experimental and field data with the limiting levels for these chemical constituents (Table 12-1) reveal that while some boreholes have sodium, calcium and magnesium ion concentration within the acceptable levels very high contents of these cations, anions and some trace elements are common among the groundwaters. Calcium and in some instances magnesium are especially high. Of particular importance here is the content of sodium ion. Most groundwater have sodium concentrations generally below or within the acceptable level of 200 ppm, but these sodium concentration are associated with very high concentrations of chloride ions, thus rendering most of these waters too saline for most domestic and even industrial applications.

Sulphate and fluoride ion concentrations in the water resources are very much below the 400 ppm and 1.5. ppm maximum acceptable limits for domestic water and farm animals (500 ppm of SO_4 and 2 ppm of F) respectively. The concentration of iron and manganese provide a particular concern because they are relatively high for practically all domestic purposes. The iron concentration, particularly in some surface waters greatly surpass the required 0.3. ppm level, while several groundwater and surface waters have manganese contents above the 0.05 ppm limit. The concentration of these two ions is also generally high for most livestock farming and industry requirements. Lead, copper, zinc, nickel and all the other trace elements analysed for occur in relatively low concentrations in the water, generally for practically all human uses.

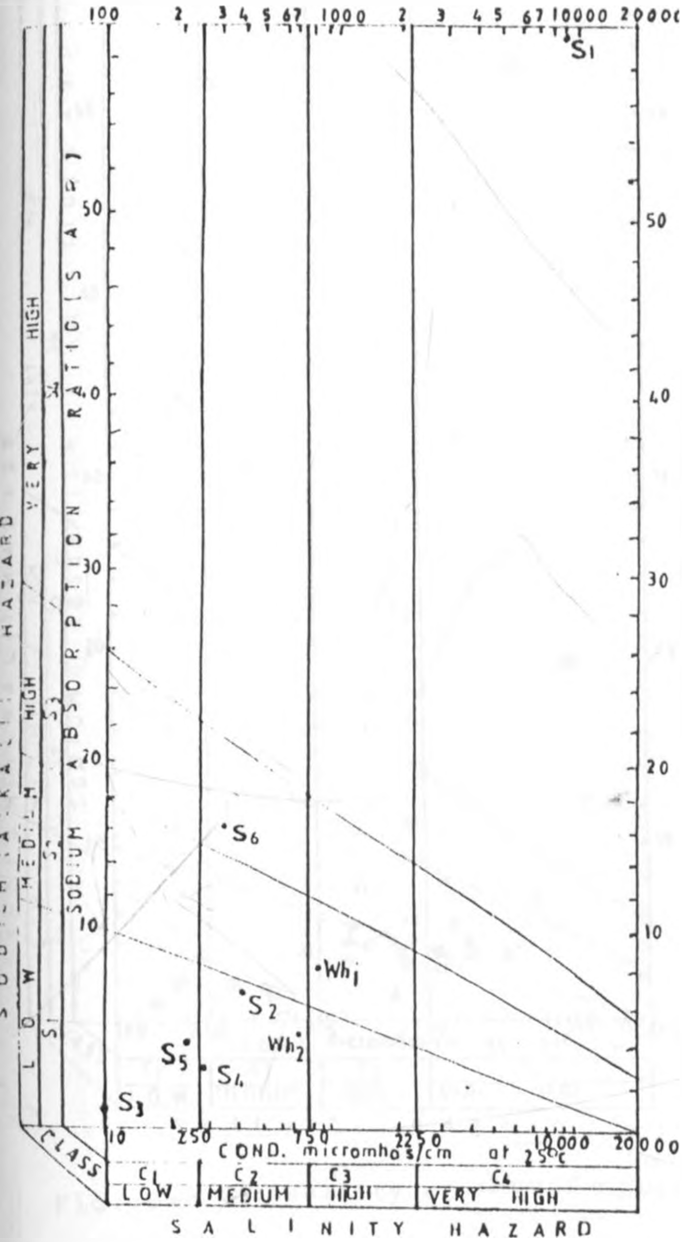
Except for zinc, and some instances of high manganese contents, all the water resources in the area are suitable for irrigation purposes. An overall analysis of figures 9-1, 9-2 and 9-3 show that the water resources in the area, especially surface water resources, are suitable for irrigation with almost all types of soils. However, most groundwaters, though with low sodium absorption ratio (SAR), have notably high salinities (figure 9-1), hence they fall within the high to very high salinity hazard classes. This requires, therefore, that many groundwater resources in the area can only be used under extremely good irrigation management. In general many groundwaters have low sodium (alkalinity) hazards, but quite a substantial quantity of groundwater have moderate to high sodium hazard values . Among groundwaters the boreholes



LEGEND

r_1 Majimbto river water
r_2 Ramisi river water
r_3 Ramisi river water
r_4 Lovu river water
r_5 Mkanda river water
r_6 Ramisi river water
r_7 Mkanda river water
r_8 Ramisi river water

ig. 8-1 Suitability of River waters in the study area for irrigation use.



LEGEND

S_1 Kitoni spring water

S_2 Kivuleni spring water

S_3 Munyala spring water

S_4 Mwaniki spring water

S_5 Shilling Tupu spring water

S_6 Githinji spring water

Wh_1 Mkongani waterhole water

Wh_2 Kirewe water hole

. 8-2 Suitability of Spring waters, Resources in the Study area for irrigarion u

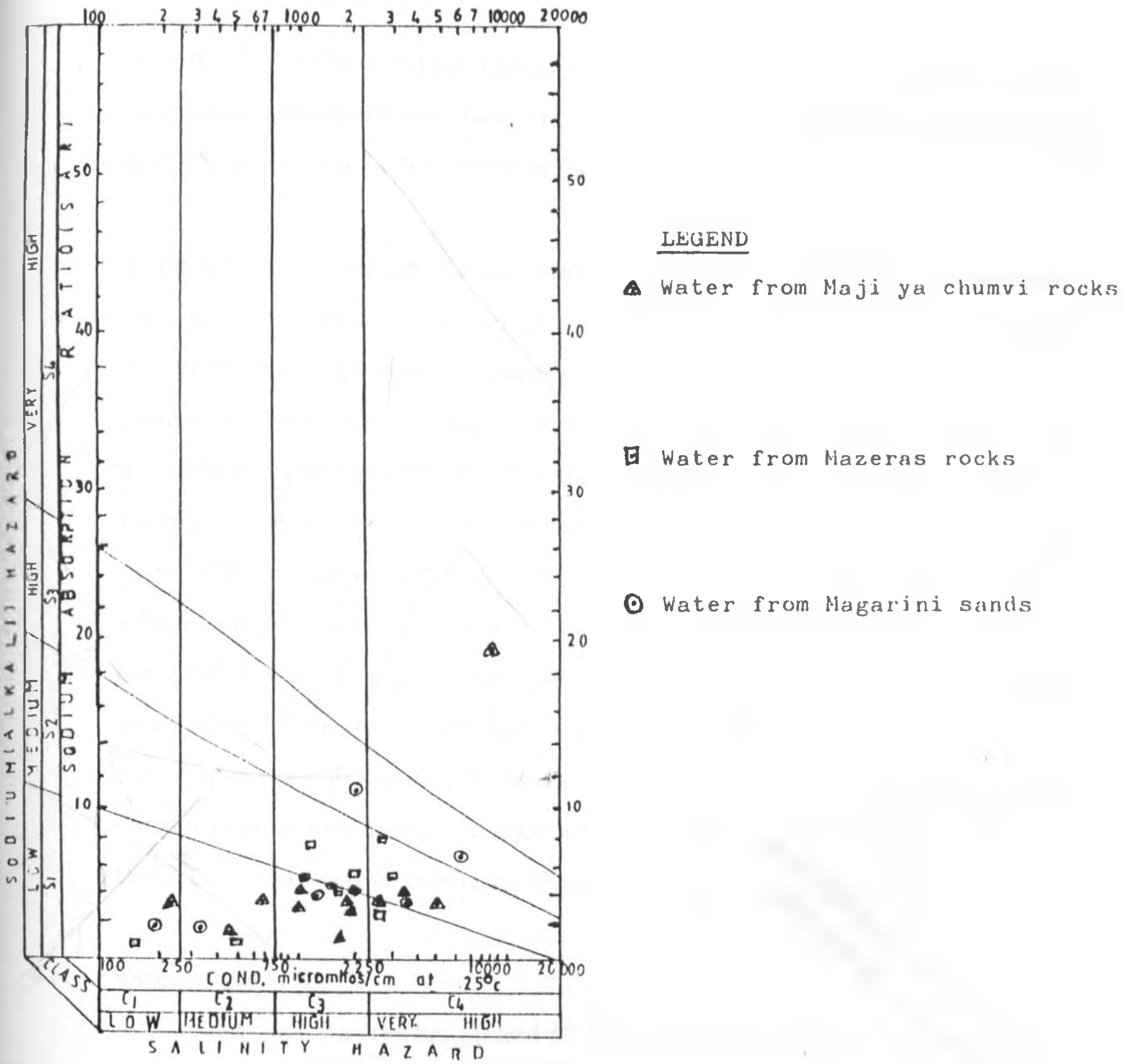


Fig. 8-3 Suitability of Ground waters in the Study Area for irrigation use

Spring water,

at Ndavaya (C856) produce waters of very little use for irrigation. Kitoni springs and Maji Moto river have very high salinity and sodium absorption ratio and, therefore, not fit for any farming activity.

A comparison of the total hardness values (Table 7) and the water classes based on hardness content (Table 8) show that the groundwater resources of this area are generally very hard. However, most of the total hardness values are generally below the acceptable 500 ppmm level for drinking water. The groundwaters also have high contents of total dissolved solids in such that a large number of borehole water investigated have TDS values above the 1000 ppm (WHO recommended level), thus the salty taste noticeable in most groundwater resources in the area. Total hardness of groundwater in the area are generally unsuitable for many industrial purposes. With an exception of the geothermal Kitoni spring and Maji Moto river, surface water resources in the study area are suitable for all human applications. Iron, manganese and zinc concentrations are, however, high while fluoride contents are too low, and therefore, river waters should be treated for these ions before use.

6.6. Water Types

In the diagrams, figures 6A, 6B and 6C (Fig 9 page 109) each subdivision imply the following water types:-

Area 1:	Alkaline earth exceeding alkalis
Area 2:	Have alkali ions exceeding alkali earths
Area 3:	Weak acids (HCO_3^- and CO_3^{2-}) exceed strong acids Spring waters,
Area 4:	Strong acids in water exceed weak acids
Area 5:	Waters with secondary alkalinity (Carbonate hardness greater than 50% usually Ca-mg-HCO_3 waters).
Area 6:	Secondary salinity (non-carbonate hardness) in excess of 50%
Area 7:	Waters with primary salinity exceeding 50% and are Na-K-Cl-SO_{42}- waters (or Na-Cl waters). Most saline waters plot here.
Area 8:	Primary alkalinity exceeding 50%. Waters generally soft.

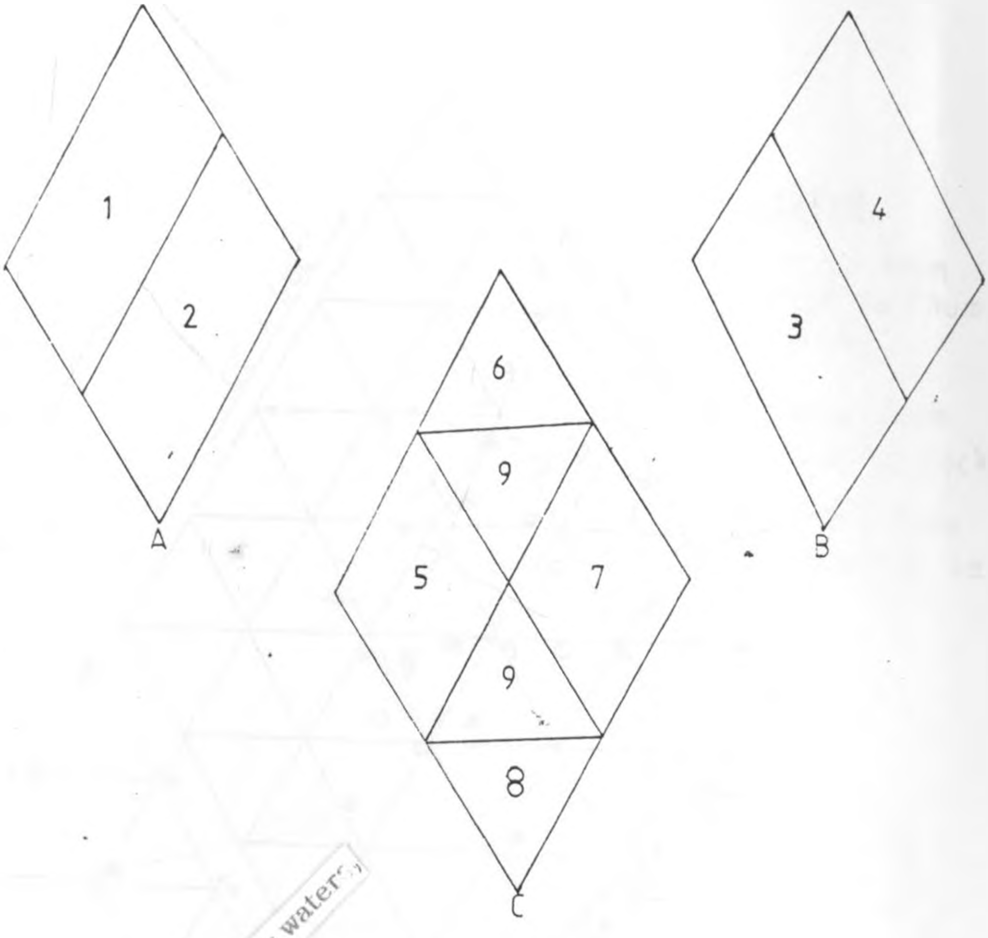
Area 9: None of the cation-anion pairs exceed 50

A correction of figures 6, 10 and 11 indicate that most surface waters in the study area plot within area 7 (figure 9C) and only two plot within area 9 and one water sample falls in field 8. Hence these waters are characterised by high contents of alkali (mg^{2+}and Ca^{2+})ions and strong (Cl^{-}and SO_4^{2-}) acids. Similarly a large number of groundwater analysed plot within subfield 7 with several waters plotting within fields 5 and 9. This implies that several types of groundwater exist in the study area with a majority of the groundwater resources being dominated by alkali elements and strong acids.

The various groundwater and surface water types found in the study area can be realised from the Piper diagrams (figures 10,11 and 12). An interpretation of the diamond shaped trilinear diagram fields, according to Piper, Maina, (1982) is given in the preceeding Chapter (V). In figure 10A it can be observed that surface waters are exclusively composed of alkali ions (Na^{+}, and K^{+}, field 2) with very little alkali earth elements calcium and magnesium. Similarly, these waters also have strong acids dominating weak acids (figure 10) thus implying that the sulphate and chloride concentrations exceed bicarbonate and carbonate ions. Hence, from figure 10C it can be noted that the type of surface water resources found in the Ndavaya-Mrima area is generally sodium-potassium-chloride-sulphate waters plotting on subfield 7. The high domination by strong acids and alkali ions in these waters is mainly caused by sodium and chloride ions rather than potassium and sulphates. Therefore, these waters can be generally Spring waters, grouped as sodium-chloride waters. This is well illustrated in the Piper diagram, figure 12.

Considering figure 11 it show that a mixture of several groundwater types do exist in this area. From figures 10B and 10C, a majority of the groundwater plot in subfield 2 where waters with high concentrations of sodium and potassium plot. Almost an equal number of borehole water also plot in subdivision 1 implying that some groundwater have substantial quantities of calcium and magnesium than the overall sum of sodium and potassium ions. However, on figure 6B it is observed that most of the groundwater plot within subfield 4 thus indicating a dominance by chloride and sulphate ions in the water. Significant groundwater also plot in subfield 3. From the diamond shaped diagrams (figures 6C and 11) it is a general observation that most groundwater plot in area 4 where most saline waters plot. Very few of the groundwater resources plot in subdivision 5, 6 and 9 with none plotting in area 8. It can, therefore, be stated that most groundwater in the area are sodium-chloride waters. The dominant alkaline earth ions in some groundwaters associated with strong acids indicate that calcium-magnesium-chloride-sulphate waters are also present in some parts of the area. Similarly, $Ca-Mg-HCO_3-CO_3$ waters also occur in some regions and only a few cases of groundwater with none of the cations dominating the other are represented.

Spring waters



Spring waters

Fig. 9 Subdivision of [illegible] diamond-shaped field of
Trilinear diagram.
(Source: Maina, 1982)

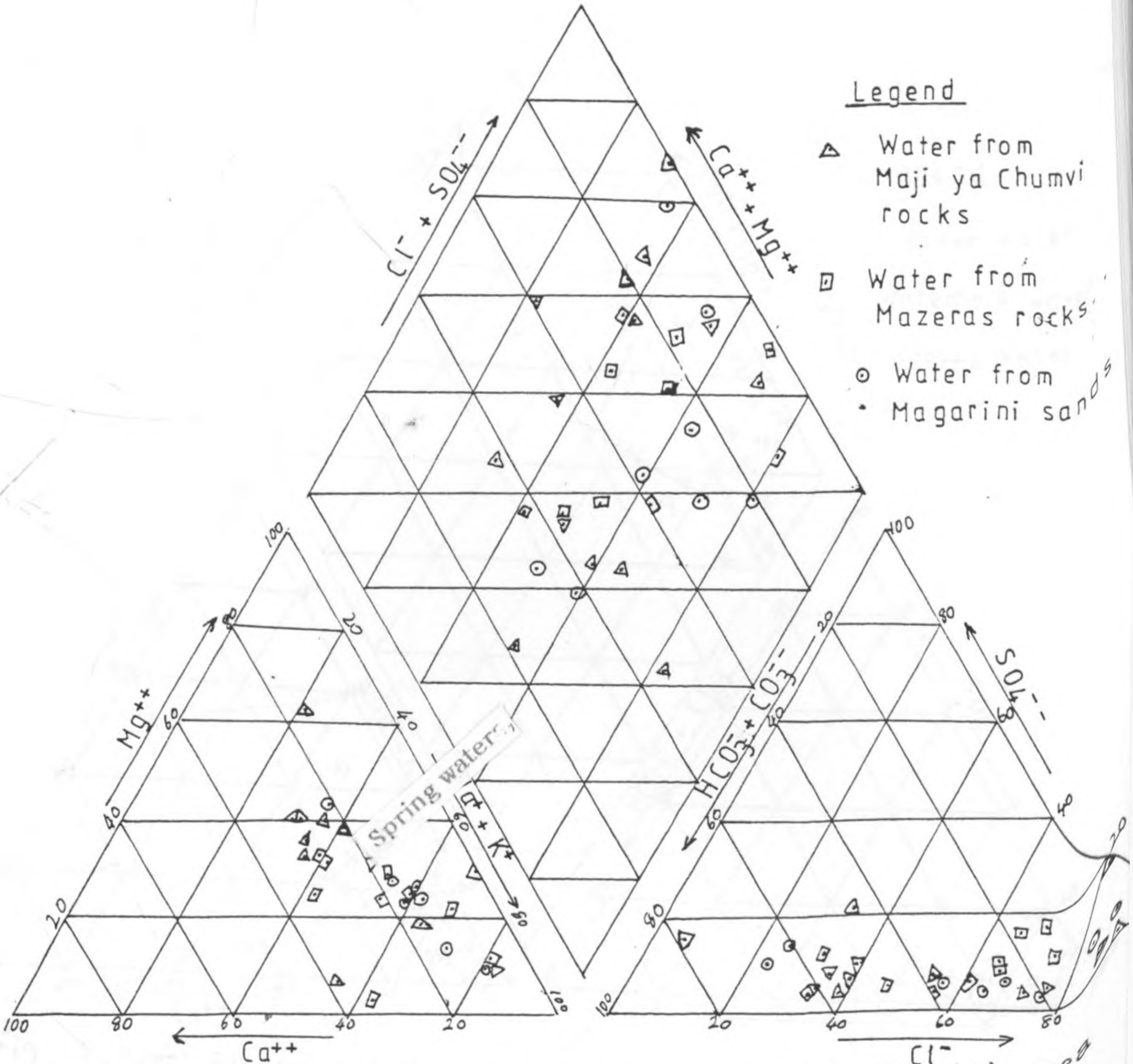


Fig. 10 Piper Digram for Chemical Data for ground water in the study area

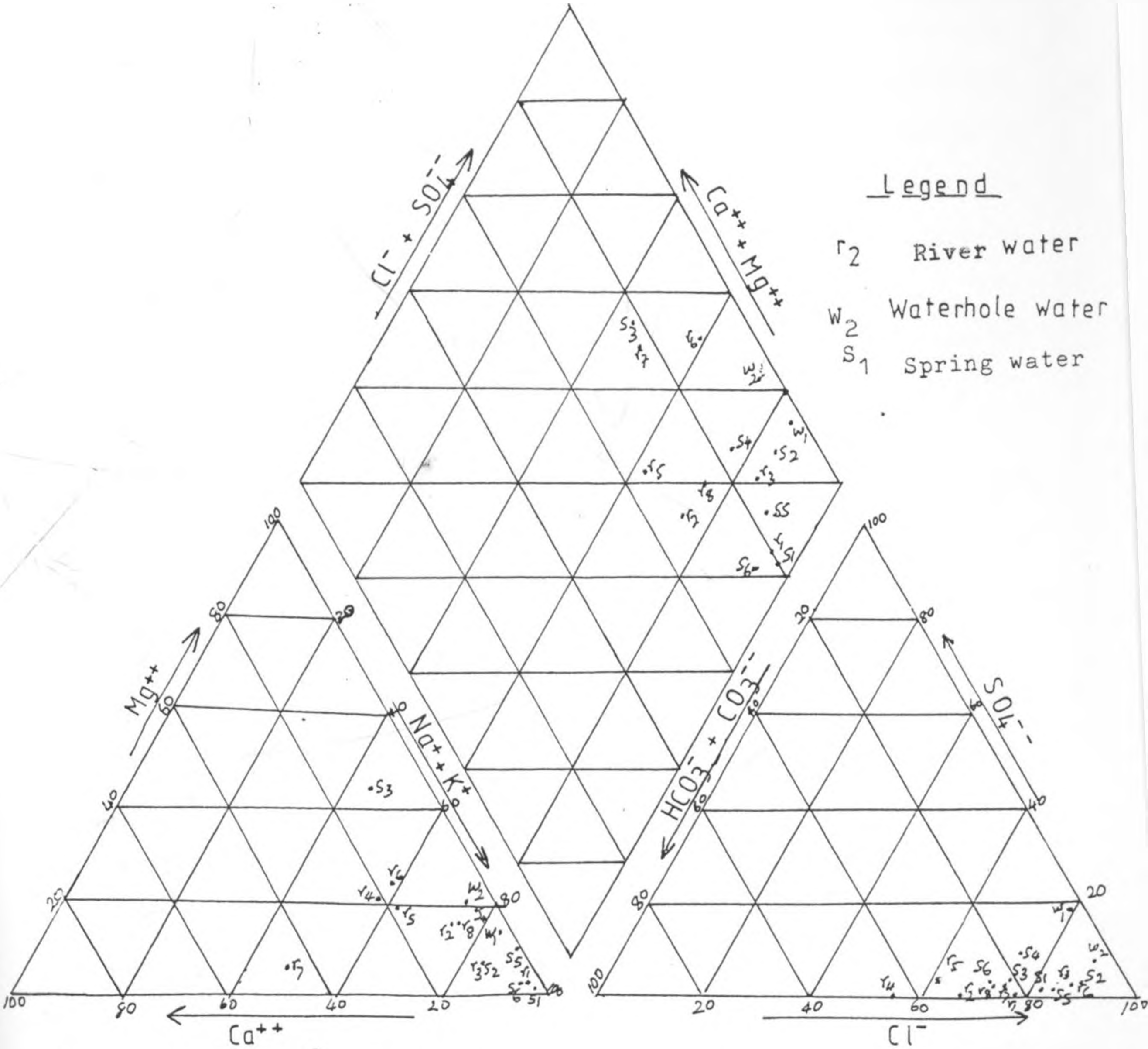


Fig 11 Piper Diagram for Chemical Data for Surface Waters in the Study Area

Mixing of all these groundwater types might be taking place in the area, especially as the water flows from North West to Southeast and North to South.

CHAPTER VII

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

In general, all the sedimentary rocks occurring in this area are potential aquifers. The amount of water held by a given formation is depended upon the amount of groundwater recharge available, the presence of geological structures and the proportion of permeable rock exposed. It has been observed that groundwater recharge occurs locally in all parts of the study area where rocks of favourable permeability outcrop and precipitation is substantial. The lithological properties of an aquifer, especially texture, the degree of compaction and mineralogical composition also determine the amount of water it holds.

Due to their high permeability and exposure in areas of relatively heavy rainfall, the Mazeras sandstone and Shimba grits are known to hold better volumes of groundwater than the Mariakani sandstones and Maji ya Chumvi beds. The weakly consolidated Magarini sands which outcrop in areas of reliable climate are good groundwater carriers and yield large volumes of water than other formations. The Mazeras sandstones and Shimba grits and the poorly sorted Magarini sands offer better sites for groundwater development. Where the rainfall is sufficient the Mariakani sandstones and Maji ya Chumvi beds also yield satisfactory quantities of groundwater.

The igneous intrusions are characterised by intense faulting on their boundaries with the sedimentary formations and act as groundwater recharge zones. The intrusive hills, in addition to the faults, greatly modify the groundwater flow direction in the area.

The depth at which groundwater is found in the aquifers is varied and depends upon the potential for groundwater occurrence in the rock which in turn is determined by formation properties and geological structures. Boreholes in the sandstones (particularly Mariakani sandstones and Maji ya Chumvi beds) are drilled to greater depths for better yields. In the sands significant volumes of water is obtained at relatively shallow depths. Groundwater in the Northern part of the area occur in very deep beds. Though there is no specific observation in the relationship between borehole yields, depth and topography boreholes sunk in the lowland discharge areas generally yield better quantities of water even at shallow depths.

The chemical data was used to construct concentration maps and interpretation of the observed groundwater and surface water quality in terms of geology and other factors. Many of the chemical constituents show a general decrease with flow direction (West to East) most probably because the northwest areas are drier than the eastern parts. However, the concentration of these chemical constituents, except silica and sulphate show a general increase from North to South. Sulphate and silica form a concentration zone in the central part of the study area with concentrations decreasing away from this zone in all directions. The sulphate ion also show localised enrichments around igneous intrusions and faulted areas.

Sodium and chloride are the dominant ions in the water resources of the Ndavaya-Mrima Area and have imparted a salty taste to most of the borehole water. Sodium contents in the water are as high as 1985 ppm while chloride concentrations of up to 3750 ppm have been recorded. Calcium, magnesium and sulphate ion concentrations are also relatively high. Bicarbonate concentration in most groundwaters is high and the water is generally hard. Groundwater from Maji ya Chumvi beds and Mariakani sandstones is more mineralised than water obtained from Mazeras sandstone and Shimba grits. Except for a few cases the Magarini sands have generally soft and relatively low mineralised groundwaters. The few occurrences of high mineralisation in boreholes drilled in the sands is probably caused by sea water intrusion. Surface waters in the area show similar variations in chemical composition and physical parameters as groundwater but are comparatively low mineralised and therefore, fresh. The geothermal Kitoni spring, Maji Moto river into which it discharges its water and a section of Ramisi river are, however, highly mineralised.

The fluoride ion in the water occur in very low concentrations. Most groundwater has fluoride contents below the required level. River waters have virtually no fluoride, with all river water samples analysed registering zero fluoride contents. Silica is another common chemical constituent in the groundwater and occurs in relatively high amounts, probably because of the highly siliceous nature of these aquifers.

The water resources in this area are generally slightly acidic and have pH values ranging from 5.0 to 8.1 with all water samples analysed (except two) having pH value below 7.8 but above 5.0. The dissolved oxygen in the surface waters studied is within the required levels but its contents is slightly diminished. Minor cases of pollution of surface water include decomposing vegetation residues, animal wastes, detergents and human dirt. Agricultural chemicals can also be sited as other possible sources for water quality modification in the study area.

The water chemistry in the area, particularly groundwater, is largely controlled by the geology. The main sources of the chemical constituents in the water are mineral salts disseminated within the geological successions and the aquifer rock forming minerals and also the various cementing materials. Cyclic salting and sea spray are other possible sources of the notably high mineral salt contents in these waters. While "ancient" seawater contamination were responsible for this remarkably high total mineral salt contents current pollution of the groundwaters by sea water encroachment is minimal.

The trace elements Fe,Mn,Zn, Pb, Cu, and Ni are common in water resources. Iron is generally high in the water with most of these waters having concentrations well above the 0.3 ppm (level) limit recommended by WHO. The other trace elements analysed for, Co, Cr, As, Se, Ba and Cd are present in very low concentrations.

The water resources in the area are generally suitable for most human activities including agricultural and industrial purposes, in addition to domestic use. However, most groundwater has too high total dissolved salts hence high salinities, Bicarbonate, silica and iron are generally high for most industrial purposes. Sodium and chloride ions occur in hazardous concentrations in some groundwater. The water have generally low to moderate sodium (alkalinity) hazards and, therefore, suitable for most irrigation purposes. But with the high content of Ca^{2+}, Mg^{2+} and bicarbonate ions these groundwaters cannot be used for long term irrigation purposes unless better irrigation management is applied, including good soil drainability and suitable crops. Iron and manganese contents are also high for drinking waters and should be of concern. Fluoride concentrations in groundwater is within the acceptable levels. Surface waters on the contrary should not be used for drinking without treatment for the notably too low fluoride ion content.

A plot of the concentrations of the major constituents on the Piper trilinear diagrams have revealed that surface waters in the area are generally of sodium-chloride type. Most groundwater is, sodium chloride type. Other possible types of groundwater found in the area are Ca-Mg-Cl-SO_4 waters and Ca-Mg-Co_3-HCo_3 type. Mixing of all these groundwater types might be taking place even though very little evidence of such mixing can be noted from the Piper diagram.

Hydrogeochemical studies are important in hydrogeological investigations since the quality of water resource is important in the planning and exploitation of water resources. Besides ascertaining the suitability of water resources for various human applications (domestic, industrial and agricultural) hydrogeochemicalinvestigationsalso complementother hydrogeological datafor the comparisons of groundwater chemistry in relation to problems of origin, recharge, drainage and distribution.

It is generally believed that sea water encroachment is the major cause of high mineral contents in most groundwaters in Coastal regions. However, in the area studied "modern sea water" intrusion have little influence on the groundwater chemistry. Differences in mineral composition of the aquifer rocks/soils or the existence of geological structures, such as faults, which affect the movement of water and, therefore, flushing, dilution and concentration effects on the contents of the chemical constituents may account for differences in the chemistry of water observed from one place to another.

Some of the important objectives of water analysis are to determine the suitability of the water for its intended use and establish the degree of treatment necessary prior to its use and to provide information on the present quality of stream and rivers and groundwater which can be used to demonstrate future changes in their quality. There is little contamination of the water resources in the area by man's activities but as the area get more urbanized, man interference of the environment will not be inevitable. Therefore, while the chemical composition of the water in the area currently represent that of natural water chemistry the results of this study can be used as a base of information for evaluating future changes in water quality. Such information is important in checking any possible future human interferenceon modification of the water quality.

The water resources in the area are suitable for most agricultural and industrial uses. The waters are suitable for virtually all livestock activities. Except for some cases of high salinities (TDS) in groundwater, the water resources, and in particular river water, are suitable for irrigation purposes. Iron and bicarbonate are however, too high for this enterprise.

7.2. Recommendations

Some chemical constituents in the groundwater occur in excessive amounts. The water should undergo some treatment to reduce the contents of iron to the required levels for drinking water. Fluoride concentrations are in general too low in some water resources, particularly river water. Thorough further chemical investigations should be done to establish the variation of fluoride in the water with time since most surface water resources are used over dry season. Furthermore the use of these waters for drinking should be discouraged unless the water is treated to improve the fluoride content to the required amounts to avoid dental carries in young people. Silica and bicarbonate are generally too high for most industrial purposes. Therefore, any future plan of using this water for industrial developments should take note of this factor.

The study area receives substantial rainfall on only the Southern and Eastern parts. The Western portion receives little precipitation which is poorly distributed over the year and unreliable. During the rain season too much water is wasted as surface runoff. As established during the study of the area the surface water resources are fresh and contain low mineral salt contents, thus suitable for domestic and agricultural utility. Therefore, to alleviate the water shortages during dry season further hydrogeological and hydrological studies should be carried out to find ways of trapping and storing this surface runoff. Construction of surface weirs and roof catchments of rainwater and surface runoff has been practised for quite some time in some parts of the area and should be encouraged. The stored water can be used, with proper treatment, for human consumption in dry season, watering animals and even small scale irrigation of horticultural crops. This would greatly improve the economy of the local community.

Livestock farming (e.g. poultry) and irrigation of suitable salt tolerant crops should also be encouraged, as it has been established in this study that most groundwaters, though generally saline for human consumptions are wholly suitable for agriculture practises. The Ministry of Agriculture and the relevant agricultural research institutions should try to investigate the better irrigation conditions (especially soil salinity, soil drainage characteristics) and help the local community exploit the agricultural potential of the area. Despite the high salinities observed, groundwaters can be used, with proper irrigation management, for growing certain crops. Further, studies on soil fertility and residual carbonate is also necessary to find out possibilities of starting small scale irrigation activities. Research on agrohydrology should further be carried out to ascertain the right crops for the region and Kwale hinterland at large.

The sulphate ions in groundwaters in the area are concentrated in regions intruded by igneous bodies and in faulted areas. This suggests that the sources of the sulphate in the groundwater is most likely the hydrogen sulphide from deep beds which should have reached the crust rocks through fault conduits or were emanated by intrusion activities and disseminated in the aquifer rocks as sulphide minerals.. This may further be indicative of massive sulphide enrichments on the fault planes and dykes and other intrusion veins. Therefore, thorough geochemical exploration activities should be done to ascertain the possibility of sulphide deposits and the nature and quantity of the deposits. This would be of great economic importance if economic exploitable deposits are to be found.

From the study undertaken in the area there exists no specific relationship between borehole yields and depths and topography. In future proper pump tests should be done for all boreholes to determine the actual borehole yields so as to ascertain the true quantity of water these sources can offer. Such tests are necessary in determining the real capacity and distribution of groundwater in the area and the potential of the equifers as sources of water supply to the community. Ascertaining the relationship between boreholes yields and depth to which the respective boreholes are drilled would greatly assist in the monitoring of the performance of the boreholes as reliable sources of water. Such data is similarly important for future development and expansion of the groundwater sources. A known relationship between borehole yields and topography is very important in borehole siting and location.

It has been observed that most boreholes in the study area are concentrated in the Eastern and Southern regions. This has caused difficulties in determining the actual distribution of groundwater resources in the area, and pattern of groundwater flow. In order to facilitate determination of these hydrogeological properties it is necessary that more boreholes should be drilled on the Western part of the study area.

During the study there has been lack of data analysis for deep boreholes, therefore there should be a consideration in the future for such data to ascertain the flow direction, hydrochemistry and their contamination if any.

Lloyd J.W. (1985): Natural Inorganic Hydrogeochemistry.
Oxford University Press, USA. 294p.

Mailu G.B. (1983): The hydrogeology of the Athi River Basin.
Unpublished Msc. Thesis. University of Nairobi,

Maina J.W. (1982): Groundwater Chemistry of the Area to the immediate North of Nairobi Conservation Area.
Unpublished Msc. Thesis. University of Nairobi.

Mancy H.K. (1973): Instrumental Analysis for Water Pollution Control.
Ann Arbor Science Publishers, Inc. USA. 331p.

Matthess G. (1982): The Properties of Groundwater.
John Wiley and Sons. Inc., Canada. 406p.

Miller G.M. (1952): The Geology of the Mariakani-Macknon Road Area.
Geological Survey of Kenya, Nairobi.

Ministry of Water Development (1978): Mkongani Water Supply Project.
Preliminary Design Project MOWD. Nairobi

Ministry of Water Development (1974): Report on the Hinterland of Kwale District and its Water Resources.
MOWD, Nairobi.

Mwangi M.N. (1981): Resistivity Survey for Groundwater in Msambweni Area. Unpublished Msc.
Thesis, University of Nairobi.

National Environmental Secretariat, Ministry of Environment and Natural Resources (1985): Kwale District Environmental Assessment Report. ME&NR, Nairobi.

Norconsult A.S. (1985): Kwale District Community Water Supply and Sanitation Project. Report on Hinterland Groundwater Investigations for Kenya Government and SIDA. MOWD, Nairobi

Norconsult A.S. (1986): Kwale District Community Water Supply and Sanitation Project. Report on Spring Survey in Shimba Hills Area. MOWD, Nairobi.

Nordell E. (1951): Water Treatment for Industrial and Other Uses.
Reihold Publ. Co. USA. 526p.

Ojany F.F. and Ogando R.Br (1973): Kenya. A study in Physical and Human Geography.
Longman (K) Ltd. Nairobi. 228p.

Ongweny G.S.O. (1973): The Geographic and Geologic Background of the Variation of Groundwater Chemistry in Kenya.
Unpublished Msc. Thesis. University of Nairobi

Ongweny G.S.O. (1975): A preliminary Account of the Geologic Background of the Variation of Groundwater

Chemistry in Kenya.
Proceedings, Second World Congress, International Water Resources and Association, New Delhi, India. 1975 Vol. III 225-234p.

Pinta M. (1989): Modern Methods for Trace Element Analysis, Ann Arbor Science Publishers. Inc., USA. 492p.

Robson S.G. and Saulinier Jr. Gj. (1981): Hydrogeochemistry and Simulated Solute Transport. Piceance Basin, North Western Colorado.
Geological Survey Professional Paper 1196 US Government Printing Office

Souza W.R. and Johnson J. S.Y. (1987): Quality of Groundwater in Idaho. USA Geological Survey, Water Supply Paper 2272. US Government Printing Office. 53p.

Sikes (1934): The Underground Water Resources of Kenya Colony. Crown Agents for the Colonies. 4 Millbank Westminister, S.W.I.

Talsma T. and Phillip J.R. (1971): Salinity and Water Use.
National Symposium on Hydrology.
MacMillim Press, Australia.

Tebbutt T.H.Y. (1983): Principles of Water Quality Control. Pergamon Press, Oxford, Britain, 235p.

The Year Book of Agriculture (1955): Water, USA Department of Agriculture, 751p.

Todd D.K. (1967): Groundwater Hydrology. John Wiley and Sons, Inc. USA. 325p.

Tole M.P. (1985): Geochemical Studies of the Geothermal Area East of the Jombo Hill Intrusion, Coast Province, Kenya.
Kenya Journal of Science and Technology Series A (1985)6(2): 91-101pp.

Watanabe H., Bermam S. and Russell D.S. (1972). Trace Metals in Water. Determination of Trace Metals in Water Using X-ray Fluorescence Spectrometry

Williams L.J. (1962): The Geology of the Hadu-Fundi Isa Area, North of Malindi. Geological Survey of Kenya Nairobi.

Vienna (1976): Proceedings of an Advisory Group Meeting on Interpretation of Environmental Isotope and Hydrochemical data in Groundwater Hydrology, Vienna.

APPENDIX I

DRILLER'S (GEOLOGICAL) BOREHOLE LOGS

BH C7265 - HENZAMWENYE

00 - 10m	Slates
10 - 19m	Sandstone
19 - 21m	Weathered Sandstone
AQF	Sandstone/Weathered

BH C8180 - MWANANYAMALA PRIMARY SCHOOL

0 - 8m	Siltstone and Clay
8.- 24m	Compact Siltstone and Sandstone
24 - 36m	Shale and fine Siltstone Weathered/Fractured Shale/Siltstone

BH C8191 - LUKORE SECONDARY SCHOOL

0 - 4m	Brick red topsoil (overbudden)
4 - 12m	Weathered Sandstone with pebbles of quartz
12 - 22m	Sandy Clays
22 - 22m	Clayey sands (minor aquifer)
26 - 28m	Clays
28 - 32m	Clayey sands
32 - 34m	Fine graded sandstone
34 - 36m	Weathered sandstones with shale intercalations
36 - 60m	Clays
40 - 56m	Mudstone
56 - 58m	Medium grained sandstones
58 - 60m	Medium grained sandstone
60 - 64m	Coarse grained unweathered quarzitic sandstone
64 - 74m	Sandstone
AQF	Sandstone/Weathered

BY C7271 - KIREWE

0 - 3m	Fine Sand
3 - 7m	Unconsolidated Sands
7 - 8m	Sandstone
AQF	Sands/Sandstone (0-7m)

BH C7273 – MKUDURU

0 – 3m	Compact Clays
3 – 12m	Weathered Slates
13 – 21m	Weathered Sandstones
AQF	Sandstone (11 – 21m)/Weathered

BH C6733 – MARENJE

0 – 6m	Clayey Sand
6 – 10m	Weathered Sandstone
10 – 14m	Sandstone
14 – 18m	Weathered Sandstone
AQF	Sandstone/Weathered

BH C7818 – MWALUVANGAESHU MAENDELEO

0 – 8m	Clayey Sands (red)
8 – 18m	Clayey Sands (redbrown)
18 – 40m	Clayey Sands (greywhite)
40 – 64m	Sandstone/Weathered
AQF	Sandstone (40 – 64m)/Weathered

BH C7369 – LIRA – MAJIMOTO

0 – 12m	Clay/Siltstone
12 – 22m	Siltstone (fractured)
22 – 32m	Sandstone/Shale
32 – 40m	Shale
AQF	Fractured Siltstone (26 – 28m)

C7368 – LIRA GODOMA

0 – 2m	Sandy Clay
2 – 14m	Silty Sand
14 – 40m	Weathered Sandstone
AQF	Sandstone/Weathered

BH C7364 - LIRA MKATISYA

0 - 36m	Clay with boulders and pebbles
35 - 40m	Weathered Sandstone
AQF	Weathered Sandstone

BH C7091 - MARENJE I

0 - 2m	Sand Soil with gravel
2 - 35m	Sandstone
33 - 35m	Clay
35 - 41m	Sandstone
41 - 43m	Clay
43 - 50m	Hard Sandstone
AQF	Clayely sand (33.41 -35.43m)

BH C6721 - KIVULENI

0 - 10m	Sand
10 - 24m	Sandstone (poorly consolidated)
24 - 40m	Sandstone
AQF	Poorly consolidated sandstone (17 - 24m)

BH C6732 -.KIKONDE

0 -2m	Clay with pebbles
2 - 8m	Soft Sandstone
8 - 24m	sandstone
AQF	Sandstone (6 - 24m)

BH C7354 - MRIMA MABOVU

0 - 20m	Sandstone (weathered)
AQF	Weathered Sandstone (15 - 20m)

BH C5768 – KIGOMBERO

0 – 2m	Sandy Soil (overbudden)
2 – 10m	Clayey Soil
10 – 20m	Clayey Sand
20 – 30m	Fine beach sand
30 – 34m	Weathered sandstone
AQF	Sandstone (30 – 34m)/weathered

BH C4824 – MKOMBA

0 – 20m	Sandy Clay
20 – 50m	Shale
40 – 80m	Shale
80 – 140m	Shale
AQF	Sands and Fractured/weathered shale

BH C7279 – MKUDURU

0 – 20m	Soft Sandstone
15 – 27m	Sandstone/weathered
AQF	Sandstone/weathered(10– 27m)

BH C4773 – TIRIBE

AQF	Coarse sandstone (30 – 40m)

BH C4572 – MKONGANI

AQF	Sandstone (30 – 48m)/weathered

BH C8192 – KICHAKASIMBA

AQF	Sandstone (38 –56m)/weathered

BH C7100 – MAKAMBANI

AQF	Gravel (16 – 18m)

APPENDIX II

pH VALUE AT WHICH HCO_3^- ION CONCENTRATIONS WERE DETERMINED

SAMPLE		pH	Concentration of HCO^-_3
C7265	Henzamwenye	6.7	437
C7356	Mamba	7.4	128
C7100	Makambani I	7.3	184
C8178	Voya Mulungu	7.3	236
C7369	L. Majimoto	7.5	167
C856	Ndavaya	6.4	591
C8180	Mwananyamala	7.7	216
C7354	Mrima Mabovu	7.3	118
C7368	L. Godoma	7.7	131
C7279	Mkuduru III	6.9	324
C6731	Masimbani	6.8	52
C6732	Kikonde	5.9	14
C7101	Makambani II	7.4	412
C7355	Dzuni	7.6	490
C7273	Mkuduru II	7.3	302
C8192	Kichakasimba	6.9	236
C8188	Eshu Maendeleo	6.1	24
C8191	Lukore Sec. School	7.1	117
C7271	Kirewe	6.6	45
C4824	Mkomba	7.6	49
C7364	L. Mkatisya	7.6	402
C4773	Tiribe	6.7	258
C4572	Mkongani	7.2	390
6721	Kivuleni	6.4	67
C5768	Kigombero	6.7	23
C6670	Kikoneni Vibalani	7.5	350
C6723	Mrima	7.4	159
6671	Kikoneni Dispensary	6.4	24
C6733	Marenje I	7.2	343
C7091	Marenje II	7.5	398
C7093	Ganda	6.8	100
C7096	Mangwei	6.9	188
Wh_1	Mkongani Waterhole	6.8	27
	Kirewe Waterhole	6.3	10
Wh_2	Majimoto spring	7.4	590
S_1	Kivuleni spring	6.4	16
S_2	Munyala spring	5.8	2.6
S_3	Mwaniki spring	5.4	12
S_4	Shilingi Tupu spring	5.6	11
S_5	Githinji spring	6.2	41
S_6	Majimoto river	7.8	309
r_1	Ramisi river	7.3	53
r_2	Ramisi river	7.7	107
r_3	Lovu river	6.8	31
r_4	Mkanda river	6.7	39
r_5	Ramisi river	6.9	36
r_6	Mkanda river	7.0	16
r_7	Ramisi river	7.3	76
r_8			