

**HYDROGEOCHEMISTRY OF GROUNDWATER IN
NAIROBI AREA.**

BY:


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**A THESIS SUBMITTED IN PARTIAL FULFILLMENT FOR THE
DEGREE OF MASTER OF SCIENCE (GEOLOGY) AT THE
UNIVERSITY OF NAIROBI,
COLLEGE OF BIOLOGICAL AND PHYSICAL SCIENCES, FACULTY
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OCTOBER 2003

Declaration

This is my original work and has not been submitted for a degree in any other University

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Acknowledgement

First and foremost my gratitude goes to God the Almighty for granting me this opportunity to pursue a Masters degree Programme. I would like to thank the University of Nairobi for giving me a chance to undertake this study. Sincere thanks also go to DAAD for their generous financial support without which this work would not have been possible.

In the same vein, I wish to extend sincere appreciation to my two supervisors. Prof. Gaciri and Dr Olago all at the Department of Geology for their invaluable contributions, comments and advice, which assisted me a great deal in completing this thesis in time.

I also feel greatly indebted to Brother Kassim Ochiba for the commendable field assistance. In addition, my sincere appreciation go to Mr. Maritim K. and Tanguo of the Department of Water Ministry of Environment and Natural Resources, for the laboratory tests, analyses and equipment. I thank Mr. Katoo of the Department of Geology for wonderful cartographic work.

Finally, I would like to thank my family for their courage, patience and unfailing support during the entire study period.

Last but not the least; I would like to thank all my colleagues for their suggestions, assistance and encouragement.

Abstract

The results of hydrogeochemical analysis of Nairobi borehole waters are presented. Seventy-eight boreholes, and two shallow-wells were sampled in this study, and seventeen physico-chemical parameters were determined. Using computer techniques the overall distributions of the physico-chemical parameters were plotted. The distribution patterns have been interpreted in terms of geology, of water types, and of human influences. The chemical data obtained from the study area were subjected to statistical analysis. The results of the physico-chemical parameters of the groundwater analysis of the study area indicate that the dominant cation is Na^+ and the dominant anion is HCO_3^- alkalinity. The results from the descriptive statistics for all the hydrochemical parameters of the study area reveal that the Na^+ has the highest mean for the cations whereas; HCO_3^- has the highest mean for the anions. The results obtained from the statistical correlation coefficients of all physico-chemical parameters of the groundwater of the study area (Nairobi) indicate a positive correlation between Na^+ , and HCO_3^- ions. The results of the principal component analysis / factor analysis (PCA/FA) of the physico-chemical parameters of the groundwater of the study area indicate a significant and positive correlation among Na^+ , and HCO_3^- ions. The results from a plot of the concentration of the major constituents on the Piper (Trilinear) diagrams have revealed that the Na^+ , and HCO_3^- as dominant ions, and thus the water of Nairobi area may be termed as Sodium-bicarbonate waters. Therefore, Na^+ and HCO_3^- alkalinity are the prevailing major components, which are determining the groundwater chemistry in Nairobi. Groundwater flow within the study area has been determined by the use of piezometric water surfaces within the boreholes. The flow direction of groundwater is roughly NW-SE direction and is the same direction as the surface water and is controlled basically by the geology and topography. A lot of groundwater recharge and discharge areas were established within the study area, which could be attributed to faulting activities, which affected the western part, the area. Quality aspects of the water resources have been discussed in relation to use or intended purpose to which the water is to put for. The groundwaters of the study area were generally found to be suitable for most purposes, domestic and industrial, but not good for agricultural activities, when compared to the international standards.

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CHAPTER 1

INTRODUCTION

The rapid growth of the City of Nairobi has a characteristic settlement problems and, in some cases, environmental degradation. The spatial growth of the city of Nairobi can be viewed in the light of the prevailing geological conditions, which influence or result from human activities. For example a leachate forms when wastes are disposed off through open dumping and sanitary landfills. Running water percolates into the landfills or through the open dumps and dissolves the soluble fractions of the wastes. Then the leachate, which commonly contains high concentrations of organic and inorganic substances, has the potential to cause serious groundwater pollution. Due to the water pollution problems, water consumers in many parts of the country have complained water borne diseases such as gastro-enteritis, typhoid, cholera and even physiological problems (Ogege, 2001).

These problems have become more apparent as people have progressively switched from the traditional surface water sources to groundwater sources that hitherto had been relatively free of microbiological contaminants (Ogege, 2001).

Nairobi City is faced by the same problems mentioned earlier, and has also experienced more than its share of flooding. These problems are compounded by site development without corresponding provision of drainage (Nyambok, 1992). There have been reports of disease outbreaks in the area, which indeed, are attributed to contamination, or pollution of the available water resources. More interesting is the fact that even areas that predominantly use groundwater resources for their water supply have not been spared from these problems either.

It is therefore important to understand the groundwater characteristics with respect to groundwater flow patterns and chemical quality. Since groundwater has got its own health and acceptability problems basing on concentration levels for certain chemical parameters, proper knowledge of toxicity, mobility and bio-essentiality of these chemical constituents as may be contained in water is thus a fundamental necessity (Ogege, 2001). It is important also to compare the concentration levels of the various chemical parameters with those levels recommended by international organizations for the different and varied applications to which the water may be put into (Lloyd and Heathcote, 1985, Andrews, 1972). Control of problems related to groundwater geochemistry relies very much upon the understanding of the processes taking place within the groundwater regime, for example, the groundwater flow system, rates of reaction and residence times (Hem, 1970; Heath and Trainer, 1968, Lloyd

and Heathcote, 1985). It is important to note at this point that the health and acceptable toxic levels in groundwater are only acute for a small number of chemical elements, some of which are highlighted later in this study.

1.1 SCOPE OF THE STUDY

In this study, a comprehensive geochemical evaluation of the groundwater resources in Nairobi area has been conducted. The physico-chemical properties of the groundwater were determined with the aim of examining extent of contamination and to identify the sources of pollution. Certain indicator major and minor constituents in water were therefore analysed from selected boreholes in the area. The chemical quality of water in this area has been discussed in relation to use i.e. suitability of the groundwater resources for domestic, agricultural or industrial use. The groundwater flow pattern in the study area has also been discussed based on potentiometric water surface data (water rest levels) and groundwater flow contour map drawn so as to delineate recharge and discharge areas. Based on the cation - anion relationships (element concentration) of the waters in the area, and stable isotopes of hydrogen and oxygen, a classification of the water types in this area has been also carried out.

1.2 Literature Review

1.2.1 General Back ground

The chemical analyses carried out in this study area were basically for groundwater. A single groundwater sample may be representative of its source for many years (Hem, 1970, Powell, 1964, and Horowitz et al., 1994). Water is an excellent solvent (Heath and trainer, 1968) and all groundwater contain salts carried in solution. However, the kinds and concentrations of salts depend on water movement, time of residence, rock types, temperature, and the concentration of the recharging processes operative in a given environment (Robert, 1996). Groundwater salt concentrations are usually much higher than those of surface water. In most instances due to the limits of mineral solubility, the dissolved solids are within a range where the water can be used for many households, agricultural and industrial uses. Occasionally natural processes may lead to high concentrations of salts, where the water is no longer fit for human consumption; it may be too salty for livestock watering. Saline water may affect plant growth and can break down the soil structure of

certain fine textured soils. In geologically active environment where exhalative gasses may still be present (e.g. Rift valley), groundwater frequently has higher salt content (Robert, 1996). Higher temperatures are usually associated with these geologically active environments; increases the solubility of many elements and salinity. These type waters are frequently referred to as mineral waters and may be associated with sulphur gases in the Rift valley (Robert, 1996). The number of major dissolved constituents in groundwater is limited. The most abundant cationic constituents in groundwater are in two groups, the alkaline earth elements which, include Ca^{2+} and Mg^{2+} and the alkalis, which include Na^+ and K^+ . However, the latter (i.e. potassium) occurs in less abundant amount than sodium (Piper, 1944). Piper (1944) further remarked that the most common anion constituents in any water are the weak bicarbonate (HCO_3^-) acid and the two strong acids, which are the sulphate (SO_4^-), and chloride (Cl^-) ions. Less common cation and anion constituents such as fluoride (F^-) were noted to occur in small quantities.

Todd (1980) and Walton (1970) observed that the groundwater quantity is of nearly equal importance as quality. The chemical composition of water is thus a result of the spectacular characteristics of its ability to dissolve a wide range of substance (Johnson, 1972). Chemical quality of groundwater is therefore a function of the geological media through which it passes, the biological activities taking place near the surface, the subsurface temperature, and dilution factor with respect to recharge potential and other physico-chemical phenomena that may be responsible for the composition of groundwater. It is therefore important to note that there exist slight seasonal fluctuations in the overall groundwater composition. Ongweny (1973, 1975) further noted that, the quality of water resources might be greatly influenced by anthropogenic activities such as the disposal of domestic, municipal, industrial and agricultural wastes. Piper (1944) and Hem (1970) remarked that all-natural water contain anions and cations in chemical equilibrium with one another. Nevertheless, some waters contain high concentrations of such ions as Fe^{3+} and F^- in such waters the total equivalents of anions and cations may not necessarily be in equilibrium. Actually, such exceptional cases are almost unavailable as certain anion - cation concept is based on assumptions (Horowitz et. al, 1996).

The primary water quality problem in developing countries is the presence of water - borne organisms and other pollutants, which makes the water unsuitable for use. The chemical elements that are considered by international organizations to be toxic in natural waters are reviewed in relation to their bio-essentiality and mobility under the changing hydrogeochemical conditions. For example, the concentration of fluoride and iron may give

rise to health problems due to their deficiency/excess in groundwater and natural environment in general. Todd (1980), Maina (1982), Mailu (1983) and Ogege (2001) all reiterated the fact that the chemical quality of groundwater is quite as important just as the quantity. If the objectives of taking water to every household in Kenya by the year 2020, is to be achieved by the time in which the country is expected to be fully industrialised, then rational judgment and informed decisions have to be made on the planning, development and future management of water resources available in Nairobi and the entire country in general (Ogege, 2001). Nearly all groundwater originates as rainwater infiltrates through soil and rock into the flow patterns in the underlying geological materials (Freeze and Cherry, 1979). Groundwater composition is therefore largely controlled by how fast the water moves through the aquifer. The slower the rate of percolation in the aquifer, the more it interacts with the aquifer material hence more concentrated. Water is an excellent solvent (Heath and Trainer, 1968) and all groundwater contain salts carried in solution. However, the different kinds and concentrations of the salts depend upon the environment, movement and source of groundwater (Todd, 1980). When composition of the groundwater shows that some solutes have been introduced then they are referred to as contaminants (Nyambok and Davies, 1993). As the surface resources of this country are inadequate (Ongweny, 1975) and unevenly distributed, the growing population not only in rural areas but also in the rapidly growing urban areas requires alternative sources of water to meet this challenge. Information as to the hydrogeochemical components affecting not only the quantity but also of the quality of the groundwater can be of vital necessity.

1.2.2 Geology

Sikes (1939) has written some notes on the geology of the country surrounding Nairobi and suggested that the volcanic activity in the area was intermittent, recurring at intervals of long periods. Inactivity, denudation and faulting and was probably spread over several geological periods (Fig 1.1). Muff (1908) described the phonolites in the region of the Athi River, which form the Kapiti and Athi plains, while Gregory (1921) attributed the origin of the Yatta phonolite to a flow of lava poured down in a river valley parallel to the present Athi River. Following the work of Shackleton (1945) around Nyeri, a correlation of the volcanics in Nairobi and Nyeri areas was drawn up. The correlation was based on the belief that Kerichwa valley tuffs are of the same age as thin basalts at Thika and the tuffs at Nyeri.

The following associations were envisaged: that in the region of Thika the rocks were related to the volcanicity of Aberdare Mountain; while in the region of Lukenya the rocks form part of Nairobi sequence.

1.2.3 Groundwater quality and pollution

The Nairobi City Council (1974) in their report on sewerage and surface water survey pointed out that the two main drainage problems in the city were the pollution of Nairobi river and its tributaries by the discharge of domestic and industrial waste into stream water ditches and the flooding of certain areas during and after rains. It was noted that to improve the situation the worst discharges into these rivers should identified and the necessary remedial measurements be undertaken. The city council observed that the first step to be taken in reducing polluting discharges in the rivers was to list all the existing discharges, especially those, which flow even during the dry season. It was recommended that the quantity of water discharges ought to be estimated and an analysis made to determine their composition.

Njuguna (1978) studied the effects of pollution on the Nairobi - Athi - Sabaki river system during the period from October 1976 to March 1978. He covered sections of the present area of the study, particularly Nairobi River. He noted that pollution in the area was chiefly due to domestic and industrial wastes and run - off. He observed that the results of his study would provide the baseline data upon which future changes in the river ecosystem could be followed and which would form a basis for future comparative study on African rivers.

1.2.4 Influence of geology on groundwater quality

Ongweny (1975) in his preliminary account of the geologic background of the variation of groundwater chemistry in Kenya had classified groundwater association with different rock formations in which he based the TDS concentrations within each geological period. His report is summarised in the Table 1.1.

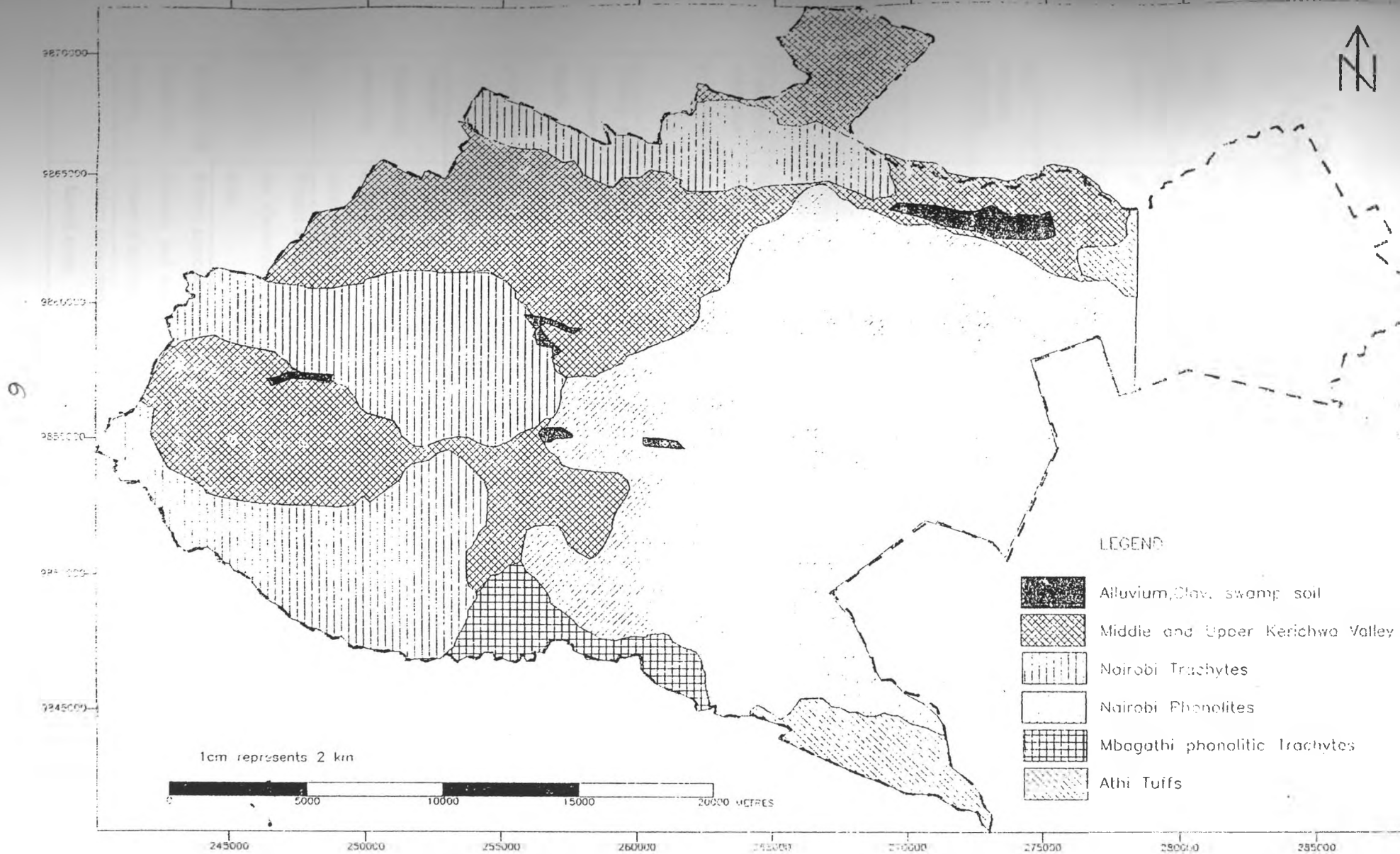


FIG 1.1 GEOLOGICAL MAP OF NAIROBI AREA

Table 1.1: Summarised groundwater association with different rock formations based on TDS concentration in Kenya including the study area (Modified after Ongweny, (1975).

Age	GROUNDWATER ASSOCIATIONS WITH DIFFERENT ROCK FORMATIONS	TDS in ppm
Pleistocene and Recent	Waters associated with sedimentary formations (e.g. coral reef)	Up to 2000
Quaternary sediments	Waters associated with sedimentary formations in arid and semi-arid areas of northern – eastern part of the country	Up to 8000
"	Waters associated with sedimentary formations in well watered parts of the rift and lake Victoria	<5000
Post – Miocene sediments	Water associated with sedimentary formations of post – Miocene time	Up to 800
"	Waters associated with sedimentary formations of the eastern part of the country	up to 3000
"	Water associated with sedimentary formations of post-Miocene age in the Rift	>1000
Jurassic sediments	Waters associated with sedimentary formations of marine origin (salines, limestones, impermeable shales etc.)	Up to 5000
Cretaceous sediments	Water associated with sedimentary formations for example Duruma sandstone series	>5000
"	Water associated with sedimentary formations of Cretaceous age sands	> 3000
Tertiary and Quaternary basalts	Waters associated with volcanic formations of Tertiary and Quaternary age with an appreciable permeability.	> 600
"	Waters associated with volcanic formations occurring in the arid northern parts of the rift valley	Up to 1000
Tertiary Quaternary phonolites	Waters associated with volcanic formations of the under-saturated Tertiary and Quaternary phonolites mainly composed of such silicate minerals as: orthoclase of the sanidine variety, nepheline and other felds pathoids occurring in high rainfall and low temperature humid area	<300
"	Waters associated with volcanic formations of the under-saturated Tertiary and Quaternary phonolites occurring in less rainfall and high temperature areas	Up to 500
Tertiary and Quaternary trachytes	Waters associated with volcanic formations (e.g. trachytes) which are rich in potassic and sodic feldspars, biotite hornblende and olivine for certain classes of trachytes	<500
"	Waters associated with volcanic formations of trachytes occurring in the less – humid areas	Up to 700

Age	GROUNDWATER ASSOCIATIONS WITH DIFFERENT ROCK FORMATIONS	TDS in ppm
Tertiary and Quaternary rhyolites	Waters associated with volcanic formation of rhyolites which are quite rich in the insoluble silica (SiO ₂)	100
"	Those occurring in less humid areas	Up to 150
Tertiary and Quaternary pyroclastics, tuffs and nephelinites	Water associated with volcanic formation of pyroclastic, tuffs and nephelinites, which have less appreciable amounts of silica (SiO ₂)	<300
"	Those occurring in the less rainfall and high temperature zones	Up to 4000
Precambrian	Water associated with metamorphic formations of pelitic and semi-pelitic rocks where the movement of groundwater is restricted by the overburden of silicate minerals and other materials of low solubility and permeability	Up to 5000
"	Waters associated with metamorphic formations of calcareous metasediments which range from pure marbles and ophicalcite to the more complicated lime silicate rocks	<4000
"	Water associated with metamorphic formations of Quartzo-feldspathic rocks and migmatites which are mainly composed of the relatively insoluble silica (SiO ₂) and silicate minerals	2000
"	Those waters occurring in the humid areas have ground waters of less	< 1000
"	Water associated with metamorphic granites, which are rich in silica.	500
Precambrian	Water associated with metamorphic formations of the undifferentiated Basement complex rocks, which comprise migmatites, gneisses, schists and other metamorphic	Up to 5000
"	Those occurring in humid areas	< 4000
"	Water associated with acid - base volcanics (Nyanzian) and the relatively unmetamorphosed sediments of the Kavirondian and Bukoban systems are located in areas where the rates of leaching are high and there is adequate water for groundwater recharge.	500

Njenga (1982) sampled waters from rivers and boreholes in Kiambu, Nairobi and surrounding rift areas. Nairobi Rivers were not used for drinking purposes because of industrial pollution. Her pH measurements of the water from these rivers ranged between

(7.5 to 8) while the hardness varied from 32 ppm to 146 ppm. The fluoride concentrations varied from 0.3 ppm in (Westwood Park) to 2.1 ppm in the Athi River.

Njenga (1982) observed that groundwater in Nairobi had high fluoride content. She suggested that the fluoride concentration was not related to the geological formations since boreholes that were close and penetrating identical formations had different fluoride concentrations. She also found that the Embakasi boreholes in the east had higher fluoride content than those in Kikuyu and Kabete areas in the west. She stated that the fluoride concentrations increase with borehole depths. Here in the study area, the same problem exists, as far as some neighbouring boreholes exhibit different fluoride concentrations (table 4). Therefore, it is not easy to point out the real cause of the problem, but it can be assumed to be related to a certain fluoride-bearing strata, which penetrate into different formations of different depths, whereby the water extraction depth changes along these formations, which resulted the different fluoride contents within neighbouring boreholes.

Maina (1984) analysed sewage sludge in Nairobi City for some heavy metals using the X-ray fluorescence technique and investigated its environment implications. The Ministry of Water Development monitored the chemical composition of the water of Nairobi and its tributaries at various sampling stations over the period from 1983 - 1986. The analyses were done for the ions: Fe^{3+} , Mn^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , F^- , NO_3^- , SO_4^{2-} and orthophosphate (H_3PO_4), which is an essential element in farmed land.

The pH and electrical conductivity of the water were also determined together with Total Dissolved Solids (TDS), Total Suspended Solids (TSS), the Chemical Oxygen Demand (COD), the Biochemical Oxygen Demand (BOD), the total hardness (T.H). Total Alkalinity (T.Alk) and the temperature at the time of sampling. The water struck level (WSL), the water rest level (WRL), the total depth of the borehole and yield of the borehole and the date when it was completed. Data information is presented in (table 1.2).

Table 1.2: Borehole data of Nairobi City (Source Ministry of water Development)

Borehole Register No.	Source/owner	Water Level in meters	Rest in meters	Water Struck level in meters	Total Depth in meters	Yield M ³ /h	Elevation Above sea level in meters
C2291	Nairobi Club	117.76		140,231	296	8.6	1725
C11701	Public Service club	166.4		225	250	1.9	1725
C12874	Silver Spring Hotel	176		192	290	6	1740
C12331	Lake Star	140.52		49-55 193-217	283	9	1695
C9765	Hilton Hotel	122.60		132-140 168-170	200	9	1660
C12965	World Bank (wish-born)	159		199,241	300	12.64	1690
C6352	University of Nairobi Kabete Campus	14.9		18,56			1800
C9754	Serena Hotel	123		-	201	7.83	1680
C4001	British America Tobacco	25.3		109.197	200	15	
C9762	Nairobi Hospital	231		195,235	246	7.0	1730
C10122	Mater Hospital	87		4,165	170	5-6.5.7	1650
C10774	Memon/Bilal Mosque South C	-		120.74	127	4.5	1665
C10306	Kenya Bus service	14		6-8,108-116	186	4	1640
C11327	Muslim Girls' School	80,116		-	182	9.6	1660
C4955	Starehe Boys Centre	111.6		-	192.6		1640
C11243	New Starehe Boys Centre	150-167		15,36	160	1.3	1640
C5518	Kenyatta National Hospital	150.3,149.7		182,192	278	7.68	1720
C11590	Sarit Centre	126.45		197.8-202.7	220	14.399	1720
C11230	Gurunank Temple	-		28,166	184		1650
C10497	University of Nairobi Main Campus	74.6		192-200	250	17.6	1680
C12575	Kenya Bus Service	115.2		1149, 13103	233	4.32	

Borehole Register No.	Source/owner	Water Level in meters	Rest in meters	Water Struck level in meters	Total Depth in meters	Yield M ³ /h	Elevation Above sea level in meters
C10298	Maji House	152		56,124, 162, 220	260	12.78	1720
C13088	National research laboratory	93.94		169-198 144-156	252	7.92	1770
C10797	Jamie Mosque	118.1		121,184	234	6.0	1665
C8697	Tru-foods	105.4		28,14.2	164.5	7.84	1640
C9737	Kenya cold storage	29		136	166	4.5	
C11018	Sterling craft	94		32,104	280	7.2	
C2987	Impala club	115.8,164.5		15,292.5	305.3	4.54	
C2918	Race course Club	77.1		107,244	305.8	13.6	1820
C12824	Meteorological Department	90,151		102,150,230	304	9.0	
C4666	Kenya police dog unit	108		62, 200, 210	306	6.82	
C11696	Catholic University East Africa Sisters' Hostel	97,99		100-118 270-272	275	4.6	1800
C9748	Carnivore Restaurant	16		6,136	200	4.8	1700
C3736	Consolata Missionary seminary	114.3		122.5	152	3.2	1782
C10201	Catholic University Main Campus	80		50,126	210	7.92	1800
C3700	Bomas of Kenya	98.4		105.2	305	1.8	1785
C11761	Brook House	-		-	280	6	1783
C11086	Thomas Barnardos	114.3		142-146 204-220	233	5.04	1675
C6310	Kewi	77		132-160	169	6	1653
C11348	Samaj school	105		85,148	204	6	1660
C11171	Central glass industry	143.8		218-228 140-156	260	10.7	1600
C9746	Safari Park Hotel	108,35		108,147	246	35	1620
C11965	Queen of Apostle Seminary	114.5		84.140	176	7.2	1620
C10072	Kenya Utali college	96.4		23,116, 153-	218	12	1640

Borehole Register No.	Source/owner	Water Level in meters	Rest in meters	Water Struck level in meters	Total Depth in meters	Yield M ³ /h	Elevation Above sea level in meters
				212			
C404	Norfolk Hotel	-	-	-	152	9.4	1670
C12664	Brae bun School	121.9		145,218.4	230	15	1800
C11316	Methodist Guest House	125.4		84-88 129-138	248	14	1760
C12902	Yaya Centre	166		216,276	300	12	1750
C6324	Afya House	112		165-176 182-190	195.5		1665
C10282	South C. Mosque	94.5		64,162	178	4.2	1654
C12143	Nyumbani children home	42		190,120	202	9.31	1860
C7396	W.N Karigacha	28.26		63,96	104	0.2	1860
C6215	Bul-bul mosque	5		5,30	160	8	
C11083	Bul-bul water supply	54		88-100 112-130	142		
C11105	Elida Ponds	20.6,89.8		30-38 174-212	215	6	1625
C13148	Forest View Academy	25		25, 106	150	32.4	1960

Informations on the chemical analysis of the water in the boreholes are also available in the Water Department, Ministry of Environmental and Natural Resources. This Ministry also keeps records of the water discharge data for a number of gauging stations along the river Athi and its tributaries. The gauge reading is usually carried out on a daily basis. Masibo (1990) noted that the upper reaches of the rivers (i.e. Nong at Kibera, Nairobi at Westland, Gitathuru at Spring Valley and RuiRuaka at Ruaka) have less anthropogenic influence with higher amounts of the major cations: Ca, Mg, K, and, Si than the lower reaches (Fig 1.2). He suggested that the factor possibly explaining this observation had a geological origin (i.e. the high concentration of these cations reflects to the parent rocks of the area). He also found high amounts of heavy metal ions of Cd, Pb and Cr in the lower reaches of the rivers, especially at the industrial area, and these could be attributed to water pollution. He noted that waste effluents were discharged into the streams at various points

along their courses and could have contributed to the observed enrichment in the heavy metals.

He found that there was general depletion in the cations: Ca, Fe, Na, K, and Cr immediately after the outfall of the sewage effluent at Kariobangi. He attributed the depletion to be due to adsorption in the increased load of suspended particles, as well as to the decrease in the water pH. He also noted a remarkable increase in the amounts of all cations and also in the total dissolved solids and electrical conductivity as the Nairobi River flowed close to an old solid waste disposal site at Dandora. He said this phenomenon could be attributed to water seepages from the waste site, which contaminated the water. His electrical conductivity values and Total Dissolved Solids (TDS) were highest in the Mathare River after it had flowed through the Mathare and Huruma Slum areas. He found fairly high values on the Ngong River at the industrial area, at Kibera near the abandoned solid waste disposal site in Nairobi after the sewage effluent and in Rui Ruaka after the effluent inflow of the Kenya Breweries factory. His lowest pH values were obtained in Rui Ruaka River after it had received the Kenya breweries effluent. His highest amounts of Total Suspended Solids (TSS) were obtained at Kariobangi in the river after it received the sewage effluents and also in the Ngong River after it had flowed through the industrial area (Fig 1.2). His lowest amounts of Total suspended solids occurred in the partially wet month of November as result of dilution due to higher water flow rates. The river water discharge data values of Nairobi area according to Masibo (1990) are shown in Table AI (Appendix I)

1.2.5 POPULATION

Obudho and Aduwo (1992) estimated that the population of Nairobi would be at 2.5 million people in the year 1993 and will be growing at an annual rate of 7.5% mainly due to rural-urban migration. It was estimated that by 1999 population of Nairobi would be between 3.0 to 4.5 million (Fig 1.3). This increase has and will continue to exert a lot of demands on the environment unless proper and adequate measures are taken to contain the situation. This increase in population would subject the available water and water resources to intense pressure in coping with and sustaining the increasing demand.

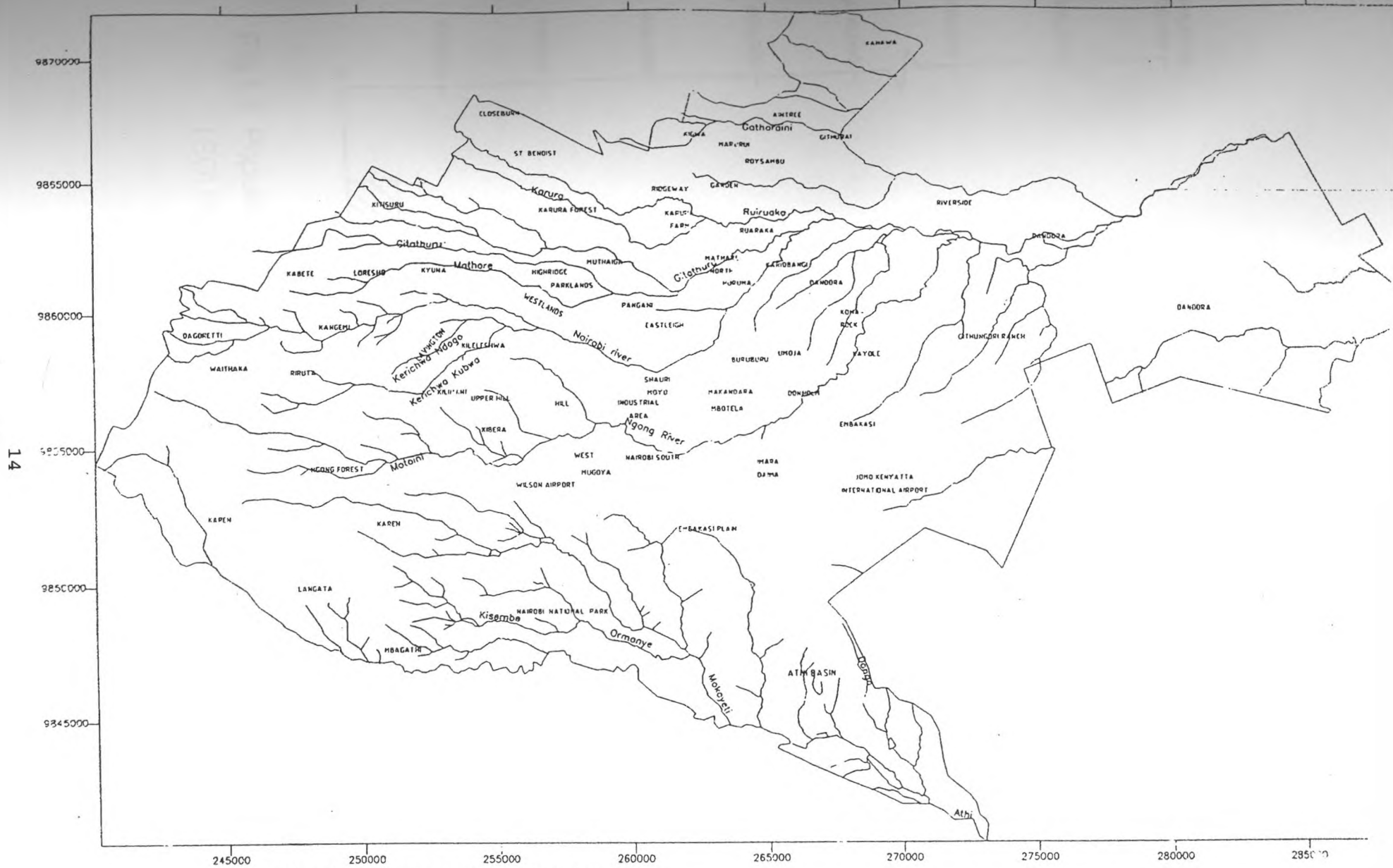


Fig. 1.2 Drainage Map of Nairobi Area

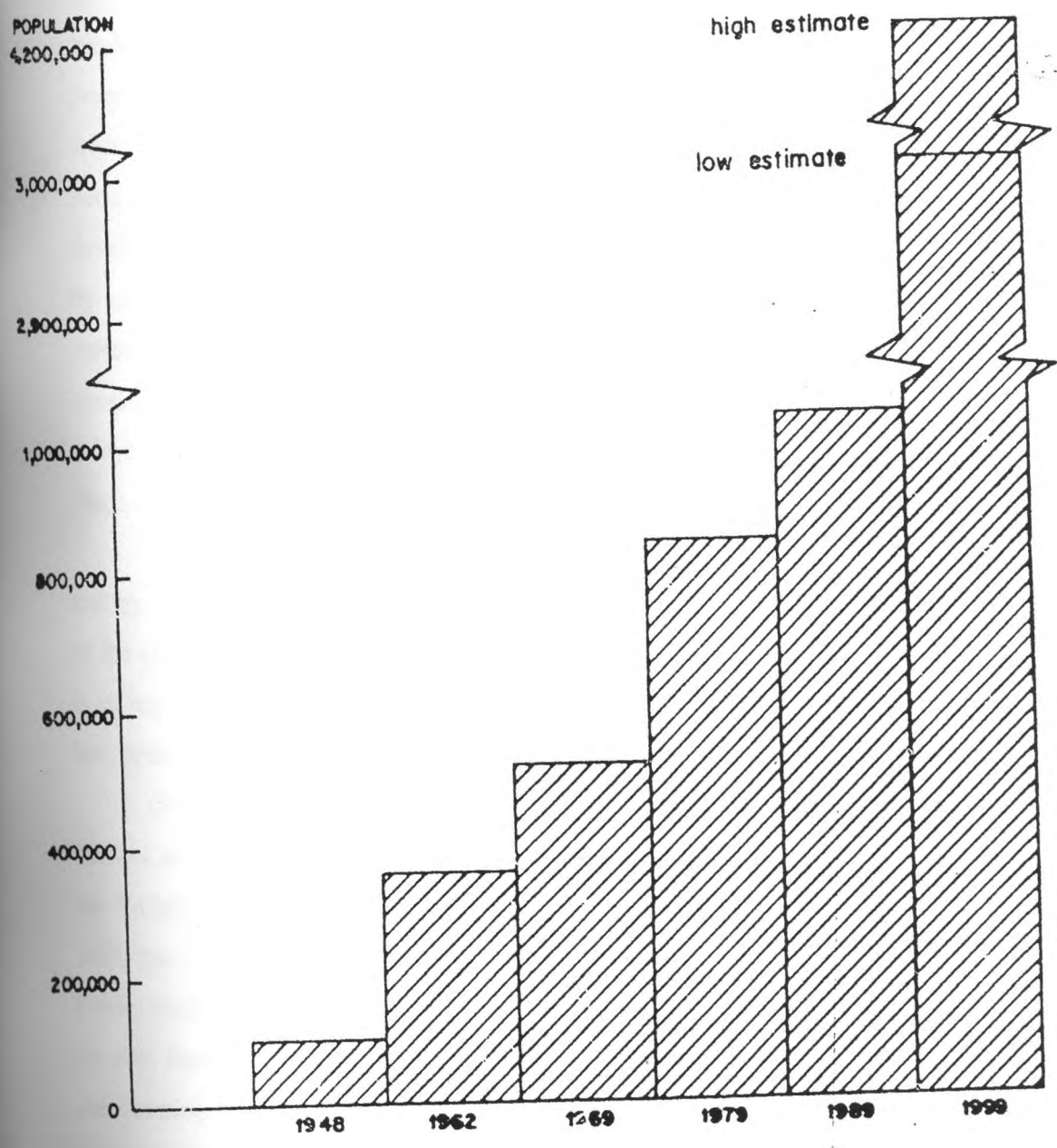


Fig.1.3 Population growth of Nairobi city (1948 – 1999)
 (SOURCE : Obudho and Aduwo,1992)

1.2.6 Land Use

According to (Francis, 1992) land use entails the utilisation of land in a given area as per the physical development or land use plan with each category user properly assigned so as to produce satisfactory environment. In planning terms the preparation of a land use plan is a prerequisite to all other development proposals. Such land use plans would normally deal with distribution patterns which would best accommodate the various types of development such as residential, industrial, commercial, institutional, recreational, transportation and other development activities envisaged at different stages in growth and are subsequently linked up by various modes of communication. The style and approach of planning encompasses various principles, and above all planning must be comprehensive so as to take into consideration the social, economic, cultural and political values within a given environment. It lays down a framework through which goals and objectives are achieved for both short-range and long-range strategies.

The objective of a maximum utilisation of resources could be sought to be effectively met by the grouping together of industries in an industrial estate outside the municipal limits of the city. The relation between sewage, water transport and similar amenities to public use is an important criterion in any land use regulation. Such zoning requirements, if imposed by law, could give an orderly cohesion and sense of direction to any development.

(Francis, 1992) noted that the general principles regarding land use in the city of Nairobi are enacted in the various Nairobi City Council (NCC) policies, the Building Code, the Building By-laws 1948 (planning) revised 1978, the Local Government Regulations 1963, the Local Government Act¹, the Land Planning Act², the Land Control Act³ and the Public Health Act⁴. The essence of these acts is to control and regulate the development in the city. However, studies carried out on the efficiency of these instruments reveal that land use planning has not been strictly implemented in the city (Francis, 1992). This has resulted in an uncoordinated and haphazard development that does not comply with planning regulations and guidelines. These uncoordinated and haphazard developments manifest themselves in the form of unregulated slum settlements and illegal waste disposal sites; commercial structures within residential areas (Francis, 1992).

Therefore lack of a comprehensive urban planning policy to regulate human development accounts for the illegal commercial structures and building that are found in all the middle and low-income residential areas. Therefore, poor planning of land produces

unsatisfactory environmental conditions (Francis, 1992). For instances anthropogenic pollution from agricultural chemicals, like nitrates and pesticides, once considered a problem of developed countries is now also a rapidly growing problem in developing countries with most widespread effect resulting from use of fertilisers that are categorised with their content of nitrate (nitrogen), phosphorous and potassium.

Agricultural practices including the use of fertilisers containing nitrogen, cattle feeding operations and the cultivation of virgin soils (leading to the oxidation of large quantities of nitrogen existing in organic matter in the soil) are important sources of contamination (Robert, 1996).

CHAPTER 2

The Study Area.

The area covered by this study is in Nairobi Province and lies within the latitudes $1^{\circ} 10' S$ and $1^{\circ} 25' S$ and longitudes $36^{\circ} 40' E$ and $37^{\circ} 05' E$. The area is bounded by Kiambu Town and Kenyatta University in the North, by Ngong Town and Ongata Rongai to the West, by the Nairobi National Park and the Athi River Tributaries to the South, and by Koma Rock and Kateni area to the east (Figure 2.1).

2.1 RAINFALL

Ng'ang'a (1992) noted that the Inter Tropical Convergence Zone (ITCZ) is the main rain producing synoptic system over the city area. Following the movement of the overhead sun the ITCZ passes over the city area twice in a year resulting in a bimodal distribution of rainfall. Once during the long rains centred around April and again during the short rains occurring on November. (Fig 2.2) shows the mean monthly values of rainfall over the city based on data from two stations, namely Jomo Kenyatta International Airport (JKIA) and Dagoretti corner. The higher values for Dagoretti are due to orographic influence (i.e. weather phenomena caused by the flow of air over prominent features of the terrain). However, the figure shows clearly the bimodal distribution of rainfall over the city. Although climatologically the long rains are expected to start in the middle of March, observations show that the onset varies significantly from year to year. Rainfall occurs mainly in the afternoon and nighttime. This is because of the strong surface heating during the days, which enhance convection; which during the night atmospheric radioactive cooling enhances instability and thus inducing further vertical development of clouds (Ng'ang'a, 1992).

2.2 CLIMATE

Ng'ang'a (1992) noted that the climate of the study area could be divided into four seasons in accordance with prevailing meteorological conditions. The dry season is characterised by the following observed conditions, which prevail during the month of January. During this period the winds are northerly to north easterly as they flow in to the heat low of the Southern Hemisphere. They are dry, resulting in low relative humidity. The skies are generally clear and strong solar radiation reaching the surface results in high mean

temperatures during the day. The clear nights result in strong radioactive cooling and low nighttime temperatures. Low rainfall is realised during the period.

The long rains season starts in the middle of March and continues on to May. The winds are mainly south-easterly and bring in considerable amount of moisture and the relative humidity is high. Some of the heaviest rains occur during this period. The cessation of the long rains coincides with the northward movement of the ITCZ towards the end of May but the advection of moisture from the Indian Ocean continues on to the cool season. The conditions during the month of July characterise the cool season. A high pressure ridge originating from southern Indian Ocean extends over East Africa as part of the Indian monsoon and the prevailing south easterlies advect moisture into the city of Nairobi area resulting in considerable amounts of low clouds during this season. Typical conditions over the city area are overcast skies, light rains or drizzle mainly in the morning hours, low temperatures and occasional fog, especially in the morning. The short rains season around the month of November is often of short duration but cold air outbreaks from middle latitudes and influx of moist Congo Air mass may bring rains during the month of December. The prevailing winds quickly become northerly to north easterly, as the dry season is re-established (Ng'ang'a, 1992).

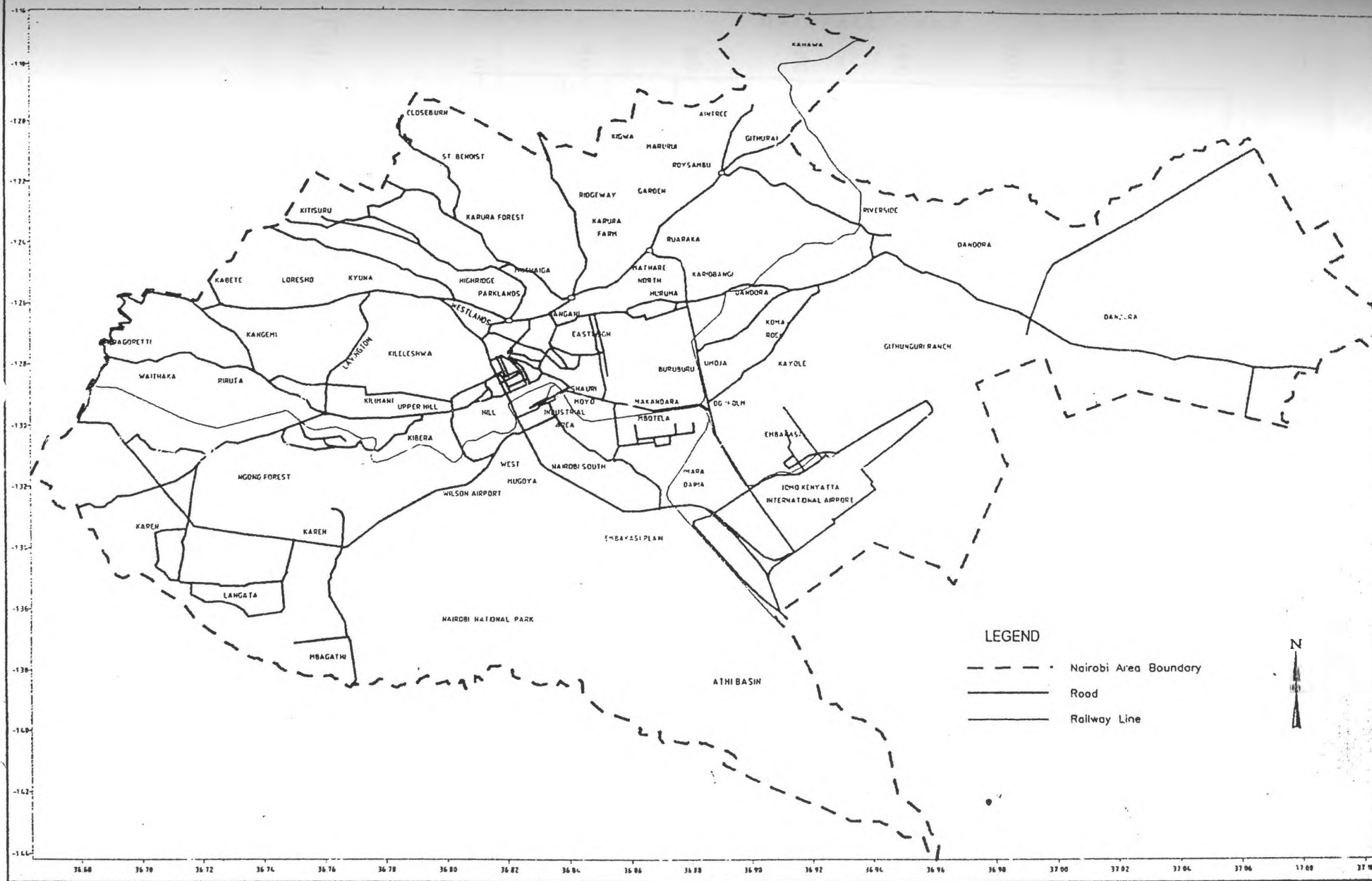


FIG 2:1 MAP OF NAIROBI (STUDY AREA)

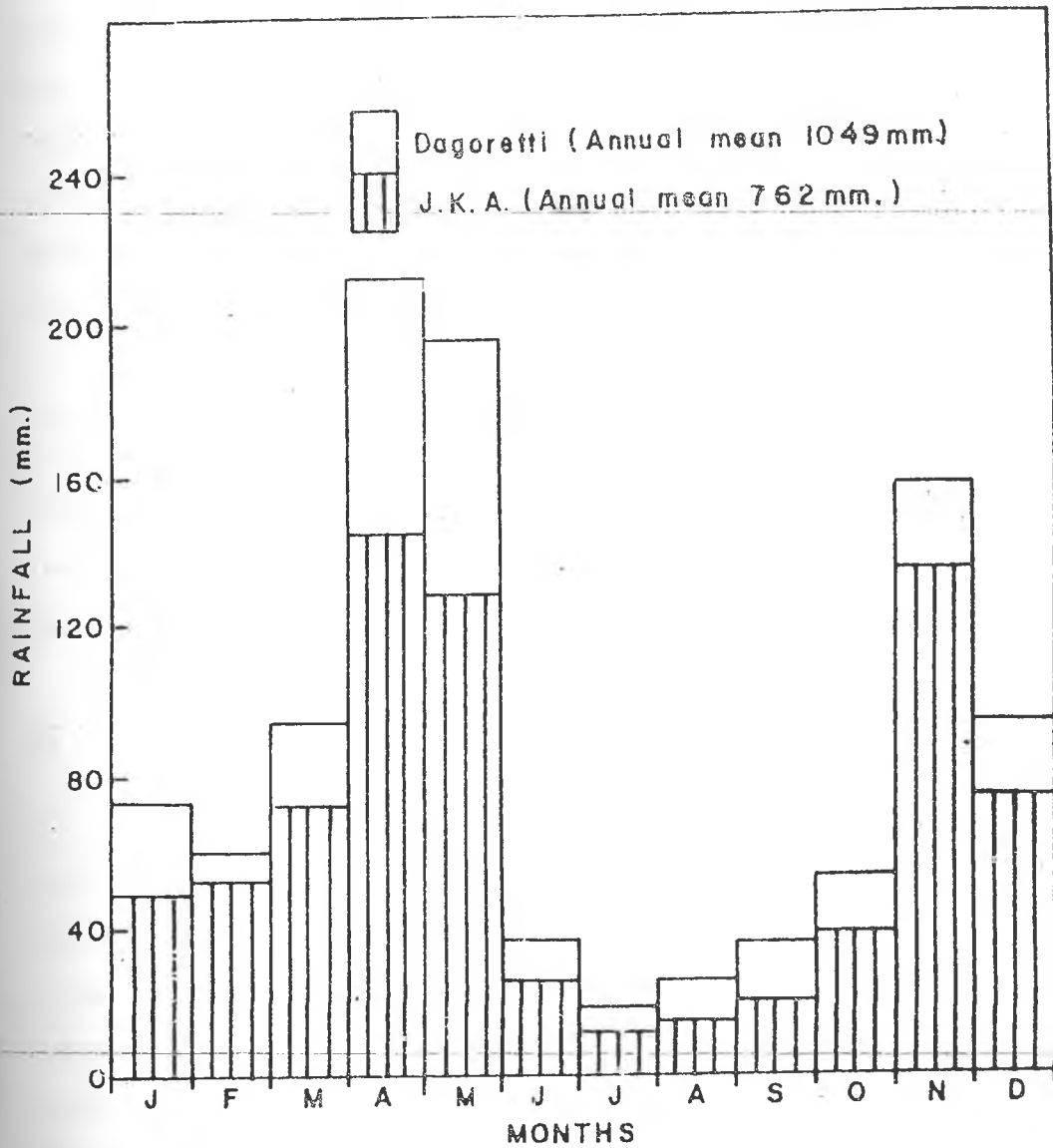


Fig. 2.2 Mean monthly rainfall of Nairobi city.(J.K. Ng'anga, '92)

2.3 Vegetation and Evapotranspiration

Masibo (1990) stated that the natural vegetation in the area is mainly savanna grassland with a fringe of mountain forest and grassland in the western part of the area. This fringe forms the Kiambu, Ngong, Ololua and Dagoretti forests. In addition to the natural vegetation many varieties of exotic trees have been found, particularly in the central and western parts of the area. The eastern region has scanty vegetation except for the sisal estates towards the Northeast. Coffee plantations are found in the elevated northwestern parts of the area (Masibo, 1990). The evapotranspiration of Nairobi area in mm is presented in Table 2.1

Table 2.1: Evapotranspiration of Nairobi area.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Evap. (mm)	220	215	240	165	140	130	130	130	170	190	170	180

Source; Krhoda (1986, 1987)

2.4 Physiography and drainage

Williams (1967) gave an outline of the geology of Nairobi in its regional setting and noted that the volcanic activity has dominated the geological history of Nairobi area since Miocene times and has controlled the geomorphological evolution. Apart from a few isolated occurrences of Precambrian and Quaternary rocks, the area is composed of volcanic rocks that originated in the Rift region and flowed eastwards on to a warped and partly dissected, pre-Miocene erosion surface, cut across the older crystalline rocks (Williams, 1967). The western part of the area near the Rift valley flanks has a succession of ridges and troughs trending north - south in sub-parallel orientation. The eastward flowing streams bisecting the area have given it a hilly manifestation. There is a prevailing eastward slope of land with maximum altitude of 2300 m in the Northwest, 2000m in the Southwest and minimum of 1700m in the east (Masibo, 1990).

Morgan (1967) has given a comprehensive review of the physiography of the area and has recognised four prominent physiographic units in the area reflecting the type of volcanic rocks and the tectonic movements, which have affected them. These are the lava plains, the Kikuyu highlands, the Rift flanks and, the Ngong hills (Fig 1.2). The drainage of the area is marked by a number of streams, which form a dendritic pattern (Masibo, 1990). Most of the streams originate from the rift-valley flank in the western part of the area and

flow eastwards (Fig 1.2). In addition to the natural vegetation many varieties of exotic trees have been planted particularly in the central and western parts of the area. The largest of these streams is Nairobi River, which meanders through the city towards northeast. The main tributaries are Gitathuru and the Mathare, which drain into the northwest joining it at Ruaraka. Other tributaries are Kerichwa, which joins it at city centre in the Northwest. River Ruaraka also drains into the Northwest and is joined by the Karura stream before it enters the Nairobi River at a point about 2.5 Km from Dandora Railway station. The streams, Kitembe, Ormanya, Makoyeti and Sosian drain the southern part of the area, and flow south-eastwards into the Athi River which is out of the present area of study (Masibo, 1990). Mbagathi River drains the south-western part of the area and is joined by the Kiserian at Kingfish (Fig. 1.2).

2.5 Geological Setting

The Nairobi area covers part of the eastern flank of the Great Rift Valley and its geological history has been dominated by widespread volcanic activity of Cainozoic age (Table 2.2 and Fig 1.1). Lava, welded tuffs and other pyroclastics cover nearly the entire area and overlie a foundation of poorly exposed, folded and metamorphosed Precambrian rock of the Mozambique Belt. Superficial deposits are of Pleistocene and Recent age. All the volcanic rocks have undergone extensive faulting on more than one occasion during the formation of the Rift Valley (Saggerson, 1991)

The main rock types exposed in the area of study and its surroundings (from the oldest to the youngest) are shown in (Table 2.2) (Saggerson, 1967)

- a) Basement System: Precambrian metamorphic rocks of the Mozambique Belt.
- b) Tertiary volcanics and sediments.
- c) Pleistocene sediments
- d) Recent Deposits

Table 2.2
Generalised Cainozoic Succession in Nairobi Area
(Modified After saggerson, 1976). Report. NO. 98.

Geological Age		Stratigraphy
Quaternary	Recent	Soils, Alluvium
	Pleistocene	Limuru Trachytes Tigoni Trachytes Karuar Trachytes Ruiru Dam Trachytes Kabete Trachytes Kerichwa Valley Tuffs Nairobi And Kiambu Trachytes Nairobi And Kiandizi Phonolite Athi Tuffs And Lakes Sediments
Tertiary	Pliocene	
	Miocene	Simbara Series Kapiti Phonolites
Precambrian	Basement	Metamorphic Rocks Of The Mozambique Belt

2.5.1 Basement System

The Basement outcrops further east of the area studied. The Basement is Precambrian in age (Table 2.2) and is believed to represent an original sedimentary series of limestone, shale and sandstone into which basic magma has intruded. The foliation of the members of the basement is parallel to the original bedding planes of the sedimentary rocks from which the system was derived (Fairburn, 1963; Baker, 1954 and Joubert, 1957). Intense compression with rising temperature has resulted in these rocks being transformed into highly folded metamorphic rocks. The metamorphic rocks vary in grain size from fine-grained schists to coarse gneiss, and in composition from pure quartzites and marbles to varieties rich in biotite, muscovite and hornblende, the intrusives being converted to

plagioclase amphibolites over much of the basement. Considerable alkali metasomatism took place-giving rise to microcline-rich rocks. The lengthy period of time between the end of the Precambrian and the Tertiary was probably one of repeated rejuvenation and erosion but the oldest clearly recognisable erosion bevel is only end-Cretaceous in age (Table 2.2). A younger peneplain matured in sub-Miocene times after renewed uplift (Saggerson, 1991).

2.5.2 Tertiary volcanics and sediments.

2.5.2.1 Kapiti Phonolites.

The Kapiti Phonolites appears to be resting on the sub-Miocene peneplain (Table 2.2). The thickness of the phonolite varies. Borehole evidence shows that the sub-volcanic floor over which the Kapiti Phonolites were extruded was irregular and cut in Precambrian rocks. The Kapiti phonolite is exposed in the southeastern corner of the area near Athi River Township. The Kapiti phonolite outcrops are not extensive and are mainly confined to the Valley of Athi River a point that is about 2 miles west of the Nairobi National Park to eastern border of the area. More extensive outcrops occur farther south in the valley of the stony Athi River, which forms the northwestern border of the Kapiti plains. The upper surface of the phonolite outcrops in pits about 12m above river level in the north bank of the Athi River station. The Kapiti phonolite also occurs under pyroclastics in Thika and Athi valleys. The phonolite is a hard, black and fine-grained rock with prominent phenocrysts of orthoclase and nepheline. Microscopically, the groundmass consists of prisms of orthoclase with abundance of soda pyroxene, aegerine and aegerine-augite, soda amphibole, cossyrite and kataphorite. Euhedral nepheline is also present with iron ore and analcite (Saggerson, 1991 and Yusuf, 1994)

2.5.2.2 Simbara Series

Overlying the Kapiti phonolite in Nairobi and its surroundings is a variable sequence of basaltic agglomerate of the Simbara series described by Shackleton (1945) in the Chania valley at Nyeri. He correlated Simbara series of basaltic lava and agglomerates with those

feldspars and small inlets of iddingsite and iron oxide, probably representing altered olivine phenocrysts. Tabular prisms of labradorite can also be seen in the fine-grained groundmass consisting of small feldspar prisms, granular magnetite, and pyroxene, and small specks of iddingsite (Fairburn, 1963).

2.5.2.3 Athi Tuffs and Lake Beds in the Nairobi area.

Shackleton (1945) in a provisional correlation of Tertiary to Pleistocene rocks east of the rift valley had grouped all sediments lying between the Nairobi and Kapiti phonolites east of Nairobi in his Athi Tuffs and Lake Beds. The Athi Tuffs and Lake Beds were formed by consolidation of fragmental volcanic material, which was deposited sub-aerially, into water at distances from the centres of eruption, or washed into a lake from areas to the west (Fig 1.1) Their wide extent throughout the Nairobi and adjacent area indicates the former presence of an extensive lake or swampy country into which rivers drained from the shoulders of the Rift valley and from the Mua hills and Kanzalu range.

Gevaerts (1964) has subdivided the beds on the appearance of basaltic lava, and their weathered derivatives in boreholes in the northern part of the area. The greater part of the outcrop of these Athi Tuffs and Lake Beds in the Nairobi area (Fig 1.1) are likely to fall within his upper group, and welded tuffs within the sequence probably occur at the same stratigraphic level as that in the Nairobi National Park (Fig 2.1). Although some of the pyroclastic rocks are of sub-aerial original, many are lacustrine and can be conveniently grouped together. Certainly they are distinct from the demonstrably younger Kerichwa Valley Tuffs. The basalts are probably of the same age as the thin basalts mapped in Githyu by Thompson (1964). The rock is a fine-grained, apparently non-porphyrific and platy with numerous amygdales of calcite. Iddingsite is fairly abundant giving the rock a speckled appearance. The basalt contains olivine, pyroxene, augite, magnetite, calcite, feldspar and analcite.

2.5.2.4 Nairobi and Kandizi phonolites.

These formations of Nairobi phonolites cover a large portion of the Athi plains (Fig 1.1) and extend from the Nairobi National Park northwards to Kiambu. To the Northwest of Nairobi, the Nairobi phonolites show several thin flows separated by phonolitic sands whereas Kandizi phonolites outcrop in the Magadi-Nairobi road and in the Valley of the

Kandizi River. Both phonolites (Nairobi and Kandizi) are stratigraphically the same and are overlain by the Nairobi and Kiambu Trachytes (Table 2.2) (Saggerson, 1991).

2.2.5.6 Nairobi and Kiambu Trachytes.

Nairobi trachytes (Fig 1.1) have a wide distribution, extending from the Dagoretti-Karen area to the Far East as Nairobi City and northwards to Kiambu and south Githunguri. The Nairobi Trachytes have a thickness of about 61 metres at Ruaraka. Nairobi trachyte probably has greater affinities with the phonolitic rocks, though lacking nepheline, than to the younger trachytes of the Limuru area. The Kiambu Trachytes are exposed in the vicinity of Kiambu Township where it crops out in the valleys of the Riara and Gatharaini rivers. The trachytes underlie the coffee estates of Fairview and Kiu, Southeast of Kiambu. Nairobi and Kiambu Trachytes are similar (Saggerson, 1991).

2.5.2.5 Kerichwa Valley Tuffs

The Kerichwa Valley Tuffs (Fig 1.1 and Table 2.2) are well exposed on the Kerichwa stream that flows through Nairobi (Gregory, 1921). These tuffs overlie the Nairobi and Kiambu Trachytes. These tuffs consist mainly of thickly impermeable strata but some strata of tuffs can act as aquifers.

2.5.2.6 Kabete Trachytes

Saggerson (1991) explained that the Kabete Trachytes outcrop in the Kabete area where it overlies both Kerichwa Valley Tuffs and the Nairobi Trachyte and are, in turn, overlain by Ruiru Dam Trachytes, Karura Trachytes, Tigoni and Limuru Trachytes (Fig 1.1).

2.5.3 Pleistocene Sediments.

Saggerson (1991) explained that the Pleistocene Sediments are found in the Kedong River. Sediments of lacustrine and fluvial origin deposited mainly during Pleistocene time (Table 2.2) underlie a large part of the floor of the Rift in the Kedong valley. Loose soil and superficial deposits cover much of the floor but in some of the deep gullies bedded deposits are exposed. The most interesting lacustrine deposits are those occurring on the eastern flanks of the rift at Gicheru. At Gicheru, the diatomite is associated with the most siliceous

rocks. Within the faulted area west of the Nairobi-Nakuru road, numerous bedded sedimentary deposits, consisting of ashes, tuffaceous gravel conglomerates and partly consolidated pyroclastics were noted. These sediments are mainly composed of coarse, poorly cemented sandstone. They cannot be definitely dated, but as they lie on the highest pyroclastics in the area, they are considered to be late Tertiary or Pleistocene in age (Fairburn, 1963).

2.5.4 Recent Deposits.

(Saggerson, 1991) marked that the recent deposits include soils and alluvial sand deposits (Fig 2.3). The soils are normally residual weathering deposits whose composition is controlled more by the physical considerations of formation than by the type of the rock from which they were derived.

The alluvial sands include river deposits and outwash fans and badly drained, black cotton soils, which are mostly confined to the area under investigation (Saggerson, 1991). They are probably derived from the volcanic displayed under the plains of the area (Fig 1.1). On the eastern edge of the area probably on the Kapiti phonolite near Oldoinyo Sabuk, chocolate brown soil has developed which contains materials derived from the basement system. Saggerson (1991) stated that the black soils show more alkaline tendency than the red soils. Black swamp soils and clays are developed at the foot of the fault scarp near Limuru where drainage is locally impeded. Many of the depressions are near-permanent swamps and include the Nyakumu swamp, where black clays fill the fault depressions. Brown to black soils and clays (Fig 2.3) are developed in the fault troughs of the Rift valley where the floors of the numerous grabens are covered in sheets of superficial gravel and soils derived from volcanic ash.

2.6 Hydrogeology

Tigoni and other main faults to the west of the area study are oriented roughly NW-SE direction. The faults provide storage for large quantities of groundwater (Gevaerts, 1957). The recharge of the groundwater reservoirs is derived mainly from rain falling to the west and Northwest of the main faults. Transverse fissures and notches in the major faults allow the groundwater to seep to the east, providing permanent springs that form the source of certain rivers. The most important of these springs are the Tusoga springs discharging from the Tigoni fault and Kikuyu springs from the Ondiri fault (Masibo, 1990).

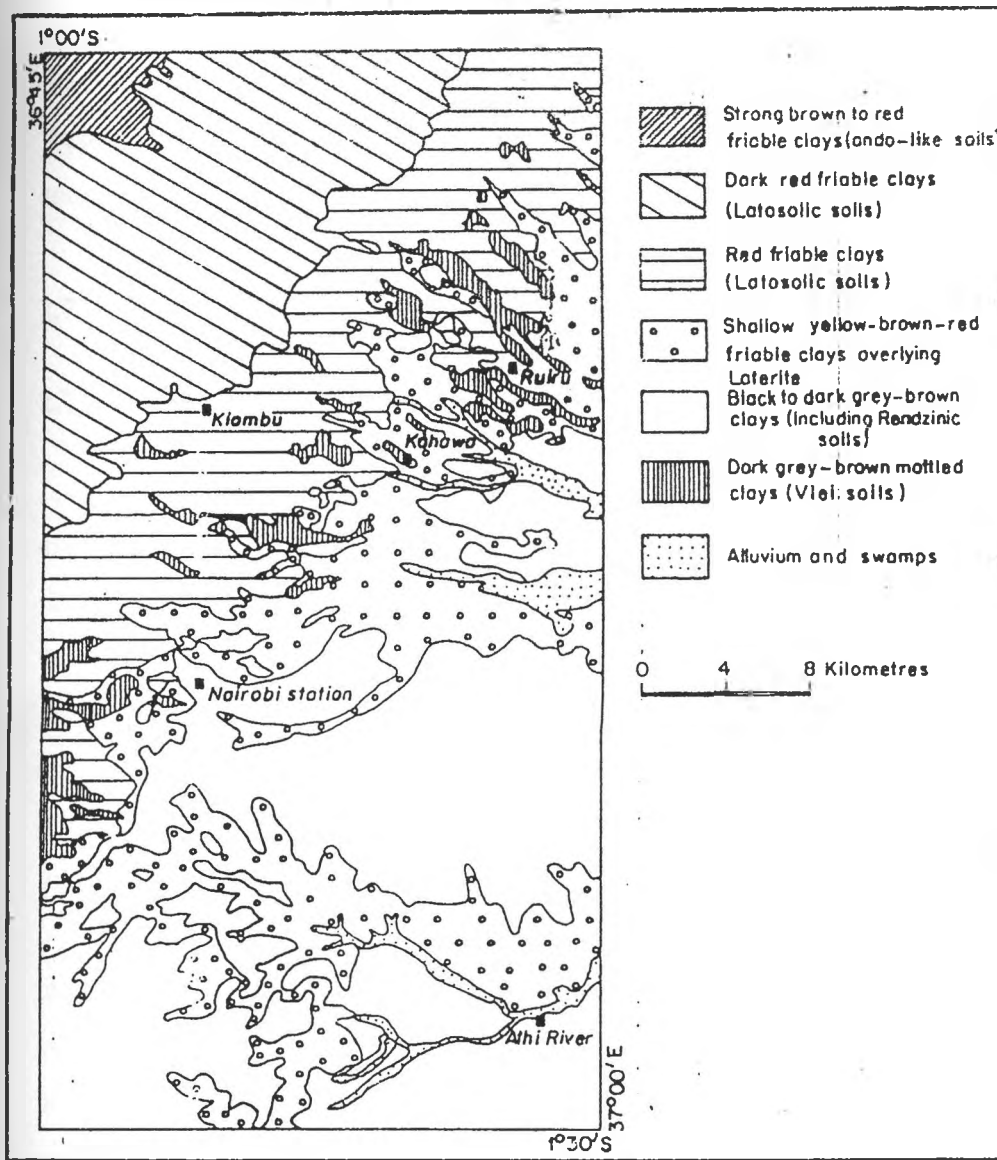


Fig. 2.3 Map of soils which includes the study area (Modified after Scott 1963)

The Tussoga springs give rise to Rui Ruraka and Karura Rivers, while the Kikuyu springs drain into the Nairobi, Gitathuru, Ngong and Mbagathi Rivers (Fig 1.2). The importance of these springs lies in the fact that during periods of extreme droughts, these are the only sources of surface water in the river system in the area (Gevaerts, 1957).

2.7 Groundwater Recharge, occurrence and path flow.

2.7.1 Groundwater Recharge.

Groundwater is usually encountered between 5 and 90m below surface with an average depth of about 60m. The shallower levels are found in high rainfall areas and in discharge zones, while deep water levels are usually associated with the arid parts of the country or hill – tops (Robert, 1996)

Recharge to an aquifer occurs from rainfall, which could recharge directly in outcrop areas or percolate through soil layers, ponding on surface may allow recharge to continue long after a rainfall event. Effluent rivers loose water to the subsurface over, which they are following and thus may aid in recharging the groundwater.

Recharge is envisaged as passing through interconnected pores as a pulse following a rainfall event, with successive pulses following each other after closely spaced rainfall events. This is referred to as piston recharge. This recharge model possibly holds for primary aquifers in high rainfall areas but it does not always apply, especially if there is an impervious clay rich soil horizon. In such a case preferred pathway recharge appears to occur. In this model water enters the subsurface via animal and insect excavations and desiccation cracks. The water follows these preferred paths until a porous stratum or fractures enable to penetration downward to the water table. Some parts of the soil profile do not get wet in this model sampled with the blanket of moisture movement through the soil profile envisaged by piston recharge (Robert, 1996). Recharge requires a threshold rainfall rate, estimated at more or less 300 mm/month, below which it will not occur because of surface storage and water being held in the unsaturated zone as soil moisture. Many places do not even get 300mm/year rainfall; this does not mean that they have no recharge. Some recharge may take place by direct precipitation onto outcrops where water immediately enters the secondary porosity. Generally, groundwater at the discharge zones tend to have higher mineral concentration levels compared to that at the recharge areas because of the longer residence time and prolonged exposure to geological factors (Todd, 1980 and Walton, 1970).

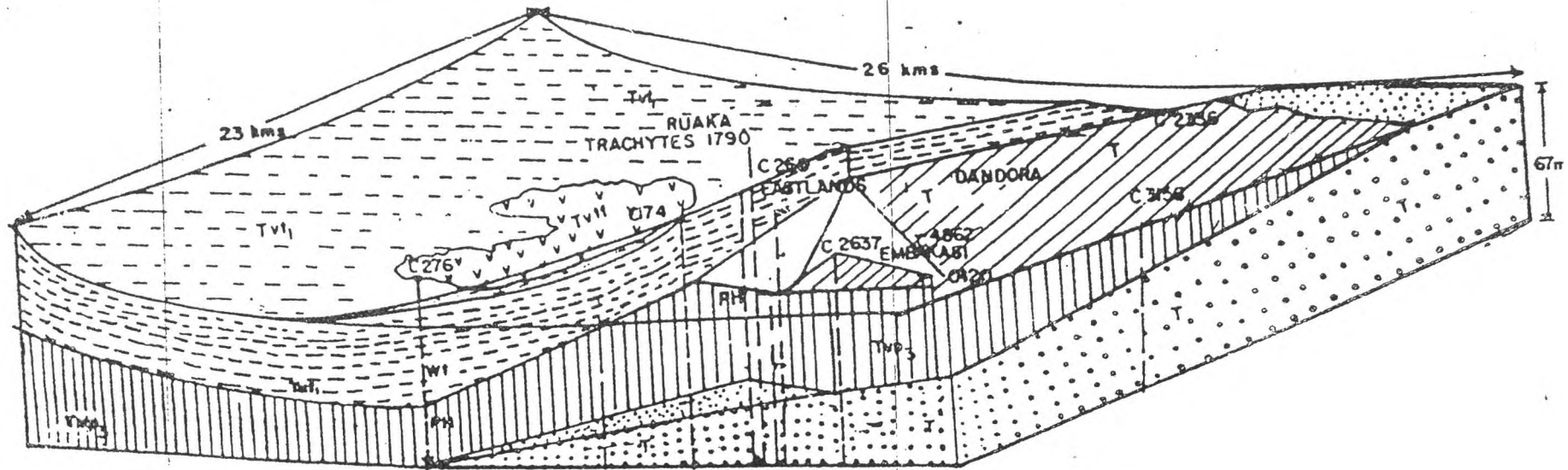
2.7.2 Groundwater Occurrence in relation to the study area.

Masibo (1990) noted that the geology of the area consists mainly of the Athi Tuffs and Lake Beds overlain by the Nairobi phonolites and trachytes respectively (Fig 2.4 and Fig 1.1). This sequence is again overlain by volcanic tuffs. The central and eastern parts of the area are also covered by black cotton soils varying from 0.5 to 2m in thickness (Fig 2.2). The major water aquifers in the area are in the Athi Tuffs and Lake Beds at the bottom of the series (Fig 2.4). Other sources of water are in the weathered zones representing old land surface and also in superficial deposits overlying the lakes at the top of the series. The trachytes, phonolites and tuffs (Fig 2.4) give no water supply because they are unfractured and impervious unless they are weathered. The tuffs may to some extent be porous but they do not transmit water (Gevaerts, 1964). Faults, fissures and cooling joints, which are mainly developed within the tuffs, are potential aquifers.

2.7.4 Groundwater Path flows.

The regional groundwater flow in any groundwater basin(s) can be defined as the movement of groundwater caused by potential difference at a rate perceptible on the human time scale and over distances commensurate with common landform and structural features. This definition was adopted in the proceedings of an advisory group on the interpretation of environmental isotope and hydrogeochemical data in groundwater hydrology held in Vienna (Austria) in 1976. This definition underscores the influence of topography on groundwater flow, which is from high altitudes to lowland discharge areas. Groundwater flow is also dependent on the amount of local recharge into the aquifer. In the study area, recharge occurs where rocks of favourable permeability are exposed and where precipitation is sufficient to provide enough water to infiltrate through the soils and rocks. Proper understanding of groundwater flow characteristics of a basin and distinctions of the water recharge and discharge zones is necessary and this is particularly important in the development and planning of groundwater resources. It is, therefore important to understand the nature of groundwater movement in drainage basins, the distribution of water potential, transmissivity and geochemical qualities (Ogege, 2001).

Fig.2.4 FENCE DIAGRAM SHOWING THE STRATIGRAPHIC SEQUENCE IN NAIROBI AREA.



KEY



VOLCANIC TUFF.



NAIROBI TRACHYTES.



NAIROBI PHONOLITES



THE ATHI TUFFS AND LAKE BEDS.

C 276 BOREHOLE NUMBER

SOURCE: Masibo, 1990

concentration doesn't exceed 1 ppm. Groundwater is supplied by a number of aquifers, either in fluvial or lacustrine deposits, intercalated in most formations or between the principal lava flows. Gevaerts (1964) noted that the faults, fissures and joints all might carry water.

CHAPTER 3 METHODOLOGY

3.1 Introduction to Analytical Procedure.

In order to achieve the objectives of this study, the following methodology was adopted: The first phase involved desk study in which all the information was gathered, before the actual field work was conducted. Fieldwork was then conducted so that the obtained data could be compared with that from earlier works relating to the study area and also provides raw data that was to be used on the basis of the study. The samples from the field were then taken for analytical tests in the laboratory. This marked the second stage of the study. The third and final phase of the methodology involved statistical analyses of the results (data). This was meant for synthesising and interpreting the information obtained from the above stages.

3.1.1 Desk Studies.

This stage included a study of journals, reports, theses, maps (both topographical and geological), aerial photos and satellite imageries etc. This was done prior to the field survey. It also included a review of field data on boreholes from the Water Department, Ministry of Environment and Natural Resources (MENR) with respect to the previous work done in the area. This embraced the literature review to enable the researcher to select relevant materials available for the hydrogeological investigation. The geological data has put emphasis on lithological, stratigraphic and structural factors that control groundwater in a basin. Hydrological data embraced rainfall, temperature and evaporation in the area while hydrogeological data embraced bore hole logs, aquifer depths, water rest levels, water struck levels etc, while hydrogeochemical data included Total Dissolved Solids (TDS), conductivity (E.C), pH, temperature, major and minor cations and anions.

3.1.2 Field Observations and sampling methods.

Field observations comprised confirmation of existing hydrological data and analyses of fresh borehole logs. Most data from already existing boreholes e.g. depth and water rest levels (WRLs) couldn't be recorded in the field as most of the boreholes were completely sealed. Seventy-eight boreholes and two shallow wells were randomly sampled in this study

area. Each sample was analysed for the contents of the following chemical and physical parameters respectively: Na, K, Ca, Mg, Fe, Si, SO₄, Cl⁻, F⁻, HCO₃⁻, Total alkalinity (as CaCO₃) and NO₃ together with TDS, total hardness, electrical conductance, pH and turbidity

3.1.2.1 Field observation

3.1.2.1.1 Electrical Conductivity (EC).

Electrical conductivity (EC) also called specific conductance is a measure of water samples' ability to conduct an electric current and is generally related to water temperature and concentration of dissolved mineral salts or ion (Great Britain Department of Environment, 1972; Mathess, 1982).

Pure water has very low conductance and can be regarded as a non-conductor. Conductance takes place when ions in solution are free to move and hence conduct an electrical current. This ability depends on ionic strength; ionic charges i.e. the type of ion and the ability of the ions to move.

In the study area, the electrical conductivity levels range from 114 μ S/cm to 4800 μ S/cm. Conductivity measurements were carried out at room temperature. Variations in this property (EC) are thus taken as a function of both concentration and the type of dissolved ions only. Conductivity values in this study area were therefore used to help especially in the evaluation of the chemical quality of the water. Their measurements were also used to establish not only the degree of mineralization of the water, but also to assess the effect of the concentration of ions or chemical equilibria and corrosive rate of the water (AWWA, 1971).

Total dissolved solids (TDS), electrical conductivity (EC) and temperature were measured at the collection site by use of HACH CND/TDS, T meter P/N 4400-00 and JENWAY model 4076 TDS T meter. The instrument used to measure EC values was standardised at 25° C. Before and after each measurement the conductivity cell was rinsed with distilled water. An Orion model 801 specific ion meter with an expandable scale was used to take pH measurements.

3.1.2.1.2 TDS (Total Dissolved Solid).

The total concentration of dissolved minerals in water is a general indication of its suitability for any particular use. Measuring the total dissolved solids (TDS) of the water is a first step in getting an indication of the water quality. Here in this study the total dissolved

solids were determined by using portable, reliable and inexpensive TDS meter, model 4076 and type Jenway.

3.1.2.1.3 pH and Temperature.

Acid or base properties and the ambient temperatures of the water generally influence the geochemical and biological factors, which control the quality of water. Temperature is very vital especially in its role towards dissolution of minerals. It is a primary factor in controlling most geochemical and biological activities.

The hydrogen potential (pH) is a measure of acidity or alkalinity of water and therefore determines the ability of water to dissolve mineral salts from rocks.

Hem (1959) observed that pH values are used as a measure of the solvent power of water or as an indicator of the chemical behaviour that certain solutions may have toward rock minerals. The pH values are therefore a means of measuring the balance of certain chemical equilibria in water solutions. Hem (1959) noted that the environment of water is important since the pH changes with changing conditions. Therefore the pH of most groundwater results from the balance between dissolved CO₂ gas derived from the atmosphere and biological activity, and the dissolved carbonate and bicarbonates derived from carbonate rock (Driscoll, 1986). This balance occurs naturally in the existing geologic and biologic environment or near earth's surface.

Most of the water in this area of study has a pH, which ranges from 5.6-8.5. The lowest pH value (i.e. 5.6) was recorded at station C 13088, whereas the highest pH value (i.e. 8.5) was recorded at station C 3700 (Bomas of Kenya).

3.1.2.2 Sampling

The period of data collection was limited to the months of April and June 2001. This was meant to insure that any seasonal variations in the quality of water could be avoided. Errors that could arise because of the variations of some of the parameters due to the time of sampling and laboratory analysis were thus minimised (Maina, 1982). It is important to understand at this stage that sampling which is a vital part of the studies of natural-water constitution, is one of the major sources of errors for water quality information (Hem, 1970; Horowitz et al, 1994). To ensure proper handling in the field, the number of samples collected in any one field trip was limited to a maximum of five wells that is 10 samples. This was to ensure ease in plotting down in the base map and proper sampling procedure.

Conductivity, pH and TDS and temperature were determined in the field by using portable meters and with stringent measurements. Random sampling was adopted whereby 78 boreholes and two (2) shallow wells were sampled. The sampling points for groundwater (boreholes) can be seen in Fig 3.1. The sample quantity was based on the geochemical principle that the more the samples collected the more representative they are of an area (Hem, 1970, Ongweny, 1973).

The containers used for collection of water samples were half litre polyethylene bottles with screw caps to prevent leakage during transportation. The polyethylene containers were chosen because they have no problem of metals being adsorbed to their walls, a phenomenon that is common with glass containers, and breakages are also minimised during transportation as opposed to glass bottles. Stringent measurement was taken when cleaning the bottles to ensure no contamination. The bottles were cleaned with metal-free nitric acid, and then rinsed three times with distilled and deionised water in the field. Each container was again washed with the water to be sampled. Samples from wells were taken or sampled after the water was allowed to run (flow) for some time to limit the contact of the water sample with the pipe as much as possible. This was to ensure that at each sampling point, the sample collected was homogenous enough and representative of the source material. This is because when the water had been standing in contact with iron pipes, then there could be addition of iron content in the water to be sampled (APHA, AWWA and WPCF, 1985; Hem, 1970; Todd, 1980). Two water samples were collected at each sampling station. One sample was passed through a 0.45 μm filter membrane (APHA, AWWA and WPCF, 1989 and U.S.E.P.A, 1983) and into the polythene bottle and tightly closed ready for transportation. To the other sample collected in the second bottle 3ml of concentrated nitric acid was added to prevent precipitation of hydrous iron oxides and absorption and at the same time inhibit the growth of micro-organisms. The untreated and treated bottles were clearly marked for the former was to be used for determination of anionic parameters while the latter was for cationic parameters. The samples were then kept in a cool place, and with a room temperature awaiting laboratory analysis. The pH of aqueous solutions is dependent on temperature. Hence it is necessary to aim to measure natural waters in situ. Because for solutions that are in contact with the atmosphere, pH measurement can be upset by the entrance or escape of gases (particularly the pH-controlling CO_2 or H_2S ; the same applies to the escape of gases as a result of pressure or temperature changes during processes in wells or on emergence at springs. The pH measurements obtained in laboratory experiments that are conducted for prolonged periods can be misleading both because of heating and because

of microbial activity inside the sampling containers. Therefore, field measurements are essential for exact measurement of natural conditions. The other parameters were analysed from the stored samples after a week.

3.2 Laboratory Analyses and techniques.

The laboratory work was divided into two with the first aspect of laboratory investigations involving determination of cation element concentration in the collected samples of the study area. This was carried out in the geochemical laboratories at the Government Chemist and at the Department of Geology, University of Nairobi. The second aspect of the laboratory work was that concerning analysis of anionic concentration in the water samples and this was done at the Central Water Testing Laboratory of Water Department Ministry of Environment and Natural Resources in Industrial area. In the determination of the all chemical parameters i.e. (Cations, Anions, Total-Alkalinity, Total-Hardness), and Turbidity (see Table 4.1) were utilised standard laboratory techniques. Details of the various procedures and methods used in this will be more elaborately discussed in the following sections.

3.2.1 Direct Aspiration Method Atomic Absorption Spectrophotometry (A.A.S).

In the determination of each metal, stock solutions were used in the preparation of standards of known concentrations to calibrate the instrument. The absorbencies were determined and from these, straight - line graph against concentration was drawn for each of the elements. The absorbencies for the samples for individual elements were determined and the concentrations obtained from the calibrated curves. The procedures followed in the analysis for each element were similar and in agreement with the set operating conditions indicated in the A.A.S manual. Deionised water was used in all preparations.

A Chem. Tech Analytical (CTA - 2000) Atomic Absorption spectrophotometer was used for the analysis of metals (cations) in this study. The metals examined in this case included Fe, Mg, Ca, Na, K, and Si. The optimum conditions of the flame photometer were set and specific wavelengths were used during the determination for best accuracy for each metal.

3.2.2 Cation Determination.

The choice of analytical techniques used was determined by availability of equipment, and concentration of the element sought both in absolute terms and in relation to the constituents of the sample (Gaciri and Mailu, 1989). The laboratory procedures that were used in the analysis of the water sample are generally quite acceptable and widely used for water analysis and are compiled in several publications (Hem, 1970; Ediger, 1976; Horowitz et al; 1994). One such publication has been prepared jointly by the American Public Health Association and the Water Pollution Control Federation (1985). The common feature is the use of atomic absorption, and as (Ediger, 1976) stated atomic absorption is now considered the method of choice for the determination of almost all metallic elements that are dissolved in water. Therefore Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K) Iron (Fe) and silica (Si) were analysed by atomic absorption spectrometry. Standard techniques were used for the determination of other parameters as soon as they were brought to the laboratory.

3.2.3 F⁻ and Cl⁻ Determination.

In specific or selective determination, electrodes are employed in the determination of single ion activities from a number of ions in solution. These electrodes are basically membranes mounted at the end of either glass or plastic tubes, and are designed to determine the ion to which they respond. The body of the electrode contains a reference solution of constant composition and when such an electrode is immersed in a solution, an electric potential develops across the membrane. The magnitude of this potential depends on the concentration of the ion activity to which the electrode responds. The relationship between this ion activity and the electric potential so developed is logarithmic and measurement of the potential against the fixed potential of the electrode thus provides a measure of concentration of that particular ion in that solution. An Orion Model 801 specific ion meter (Ionalyser Orion Research Model) with an expanded scale was used for the determination of both fluoride (F⁻) and chloride (Cl⁻) ions. The fluoride ion activity electrode is a specific ion meter with the principal element being the laser type doped single lanthanum fluoride crystal across which a potential is established by the presence of fluoride ions.

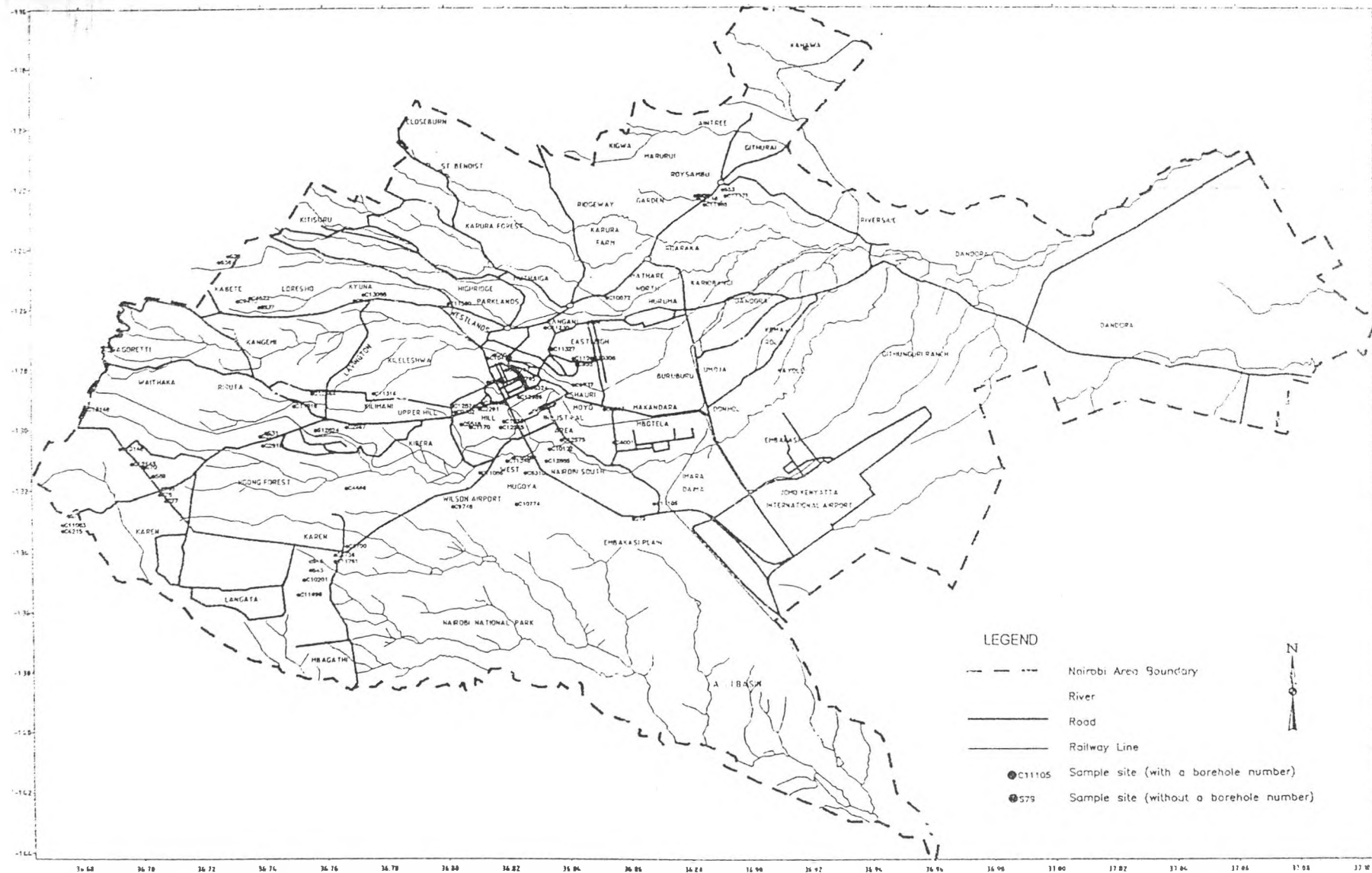


FIG 3.1 MAP SHOWING GROUNDWATER SAMPLING STATIONS IN THE NAIROBI AREA

The crystals get into contact with the sample solution at one face and an internal reference solution at the other. The fluoride activity electrode can be used to measure the activity or the concentration of fluoride in aqueous samples by use of an appropriate calibration curve of U.S. Environmental Protection Agency (1983).

3.2.4 Turbidimetric Technique.

The principal behind the technique is that the sulphate ion is precipitated in a hydrochloric acid medium using barium chloride such that barium sulphate crystals are formed. The absorbance of the barium sulphate suspension is then measured by a spectrophotometer at 420 micrometers and the sulphate ion concentration determined by comparison with a standard curve. Any suspended matter, which might interfere, is filtered out before commencing on analysis (Horowitz et al; 1996). It is important to note that no ions other than sulphate will form insoluble compounds with barium under strongly acid conditions in normal waters.

Reagents:

a) Conditioning Reagent.

Mix 50 ml glycerol with a solution containing 30ml concentrated HCl, 300ml distilled water, 100 ml 95% ethyl (or isopropyl) alcohol and 75 gm sodium chloride.

b) Barium chloride crystal 20-30 mesh

c) Standard sulphate solution.

Prepare a standard sulphate solution as described below 1.0 ml = 100 $\mu\text{g SO}_4^{2-}$. Dissolve 147.9 mg anhydrous sodium sulphate, Na_2SO_4 , in distilled water and dilute to the 1000 ml mark.

Reliability of already established calibration curve was checked by running a standard solution after every three or four unknown samples. No interference was noted during the analysis; this could be attributed to the fact that the water was acidified.

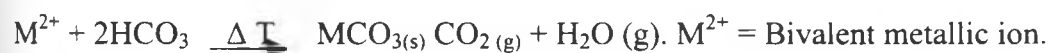
3.2.5 Titrimetric methods for determination of Total Hardness, Total Alkalinity and Bicarbonate ions.

3.2.5.1 Total Hardness and Total Alkalinity

The presence of certain metal ions in water, which is used for industry or domestic use, can cause certain practical problems, for example when water forms a grey scum with soap and a hard scale in kettles, geysers and industrial boilers, it is called hard water. This water may also have a brackish taste.

All polyvalent metals contribute to hardness for example, Ca^{2+} , Mg^{2+} , Ba^{2+} , Sr^{2+} , Zn^{2+} , Fe^{2+} and Mn^{2+} . The properties of hard water are largely determined by the nature of anions accompanying the metal cations (Robert, 1996).

1) If the water contains bicarbonate (HCO_3^-) it displays carbonate hardness (formerly temporary hardness). Boiling hard water that contains carbonate hardness drives off CO_2 , leaving carbonate ions that form insoluble salts.

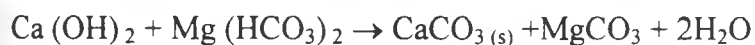
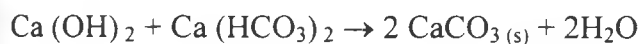


Carbonate hardness is undesirable since the insoluble metal carbonates form a scale, called boiler scale, in pipes and coat the inside of heater and the equipment loses efficiency. Pipes may become blocked.

2) Water that contains metal cations (Ca^{2+} , Mg^{2+} and Fe^{2+}) but no HCO_3^- has non-carbonate hardness or permanent hardness. Most water contains sulphate (SO_4^-) or chloride (Cl^-), which can combine with these metal ions for example CaSO_4 , or CaCl_2 . Calcium sulphate is less soluble in hot water than cold water so it too can contribute to boiler scale in vessels that continually hold hot than cold water (Robert, 1996). Water softening can be achieved by:

i) Removing the ions that cause hardness (chemical precipitation).

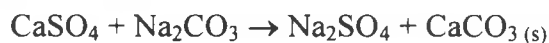
Temporary hardness may be removed by precipitation with lime ($\text{Ca}(\text{OH})_2$) called lime softening.



Magnesium carbonate is relatively soluble so excess lime causes the following reaction to occur: $\text{Ca}(\text{OH})_2 + \text{MgCO}_3 \rightarrow \text{CaCO}_3(\text{s}) + \text{Mg}(\text{OH})_2(\text{s})$

Permanent hardness can be removed by precipitation with washing soda

($\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$). Ca^{2+} , Mg^{2+} , and Fe^{2+} precipitate as metal carbonates, for example



Caustic soda precipitation treats both temporary and permanent hardness.



Thus the temporary hardness is treated accompanied by the formation of sodium carbonate, which will react with the permanent hardness.

Synthetic detergents contain builders, which tie the metals up in soluble complexes thus preventing the formation of precipitates.

Replacing the ions with Na^+ ions, which neither form a precipitate with soap nor form scales, this is a process called ion exchange. Zeolites have this capacity but ion exchange resins are more efficient.

The part of total hardness that is chemically equivalent to the bicarbonate plus carbonate alkalinity is considered to be carbonate hardness. Since alkalinity and hardness are both expressed in terms of CaCO_3 the carbonate hardness can be found as follows:

When alkalinity < total hardness.

Carbonate hardness (mg/l) = alkalinity (mg/l).

When alkalinity > total hardness.

Carbonate hardness (mg/l) = Total hardness (mg/l).

Hardness may be reported as calcium hardness, magnesium hardness or Ca + Mg hardness as total hardness. This is usually reported as mg/l equivalent CaCO_3 . It can be calculated from the divalent ion species as follows:

$$\text{Hardness (in mg/l) as CaCO}_3 = M^{2+} \text{ (in mg/l)} \times \frac{\text{Eq. Weight of Ca CO}_3}{\text{Eq. Weight of M}^{2+}}$$

Total hardness is the sum of the individual divalent ion hardness

Alkalinity is defined as the capacity of water to neutralise acids; it is determined by titration with strong acid. An alkaline solution has an excess of (OH^-) ions. Any weak acid, which dissociates to give strong bases, contribute to alkalinity including silicic, phosphoric and boric acid. These contributors are relatively insignificant in most groundwaters compared to bicarbonate and carbonic acids, which are the most common and abundant. Therefore, the most evaluation of alkalinity ignores the other acids. In polluted water with nitrates or phosphates they may not be insignificant. Organic acids and metal hydroxides also affect alkalinity. The first are usually insignificant except in polluted water and the second are usually filtered out during the sampling procedure. In groundwater systems alkalinity can be related to the carbonate system.

1). Samples containing only hydroxide alkalinity have a high pH, usually above 10, and titration is complete at the phenolphthalein end point (8.3). In this case, hydroxide alkalinity is equal to the phenolphthalein alkalinity.

2). Samples containing only carbonate alkalinity have a pH of 8.5 or higher, and titration to the phenolphthalein end point is equal to half of the total titration. In this case, carbonate alkalinity is equal to the total alkalinity.

3). Samples containing hydroxide and carbonate alkalinity have pH usually above 10, and titration from phenolphthalein to the methyl orange endpoint represents half of the carbonate alkalinity. Therefore carbonate alkalinity may be calculated as follows:

Carbonate alkalinity = 2(titration from phenolphthalein-alkalinity to methyl-orange alkalinity) = Total alkalinity - carbonate alkalinity.

4). Samples containing carbonate and bicarbonate alkalinity have PH > 8.3 and < 11 and the titration to the phenolphthalein end point is half of the carbonate. Carbonate alkalinity may be calculated as follows: Carbonate alkalinity = 2(titration to p-alk end point) x 1000/ml sample. Bicarbonate alkalinity = Total alk - carbonate alkalinity.

5. Samples containing bicarbonate alkalinity only have a pH of 8.3 or less in this case:

Bicarbonate alk = Total alkalinity.

Titrimetric method was used in the determination of alkalinity and total hardness. The water samples were titrated with standard indicator. Total alkalinity was then calculated using the expression (APHA, AWWA, WPCF, 1985) below:

$$\text{Alkalinity Mg CaCO}_3/\text{L} = \frac{A \times N \times 5000}{D}$$

Where A- is the volume of standard acid used.

N- is the normality of standard acid.

D- is the volume in ml of water sample.

3.2.5.2 Bicarbonate

HCO₃⁻ was determined by titrating the water samples with a standard sulphuric acid solution of 0.01N using cresol red and bromocresol green indicator. The carbonate alkalinity value expressed as MgCaCO₃/L is taken as the carbonate ion content while the bicarbonate alkalinity values are considered to be equal to the bicarbonate ion concentration. In the determination of total hardness, water samples were titrated with Ethylene Diamine Tetra-Acetic Acid titrants. The amount of total hardness was then calculated from the volumes of titre and the sample using the following expression (APHA, AWWA, WPCF, 1985):

Where: A - is the volume of titre EDTA

B - is MgCaCO₃ equivalent to 100ml EDTA

And D - is volume of sample used.

3.3 Statistical Methods.

A Microsoft window Excel package together with SPSS for windows version 10.00 was used for correlation analysis, descriptive statistics (i.e. the use of numbers to summarise information, which is known about some situation e.g. mean, variance standard deviation etc). Statistical Correlations, Principal Components and Factor analysis and Cluster analysis were also used. Trilinear (Piper) diagrams were also used in the determination of the type of water in subject area.

3.3.1 Statistical correlation Coefficients, Cluster analysis and Factor and Principal Component Analysis.

Pearson's product moment coefficient of linear correlation, which is normally referred to as r , the correlation coefficient, is used to assess the linear relationship between samples of two variables (e.g. x and y). Value for r , which is dimensionless measure, varies between $+1$ and -1 . A correlation of $+1$ indicates a perfect direct relationship between the two variables. A correlation of -1 indicates that one variable changes inversely with relation to the other. When $r = 0$ means that there is no relationship between variables (Davis, 1973 and Till, 1974).

Therefore to demonstrate statistically relationships between each pair of the parameters analysed here in this study, are simple correlation, cluster analysis, factor and principal component analysis.

The correlation equation is expressed as follows:

$$r = \frac{\sum xy - (\sum x)(\sum y) / n}{\sqrt{\sum x^2 - (\sum x)^2 / n} \sqrt{\sum y^2 - (\sum y)^2 / n}}$$

Where r = Pearson's correlation

x, y = variables

n = number of observations

The Cluster analysis technique was used, by joining the most similar pairs of objects together (i.e. correlation coefficients) as follows:

1. The correlation coefficients are used as a similarity measure.
2. Highest similarities are clustered or linked first.
3. Two objects can be connected only if they have mutually highest correlations with other.
4. After two objects are clustered, their correlations with all other objects are averaged.

Principal component/Factor analysis technique starts with the covariance matrix describing the dispersion of the original variables (measured parameters and extracting the eigenvalue and eigenvectors). An eigenvector is a list of coefficients (loadings or weights) by which it is multiplied with original correlated variables to obtain new uncorrelated (orthogonal) variables, called principal components (PC), which are weighted (linear combinations of the original variables). A principal component is the product of the original data and an eigenvector; the result of projecting the data on to a new axis is a new variable.

The main purpose of FA is to reduce the contribution of less significant variables in order to simplify the data structure coming from PCA. This last purpose can be achieved by rotating the axis defined by PCA, according to well-established rules and constructing new groups of variables, also called varifactors (VFS). During the computation of FA/PCA, a varimax rotation (raw) of the PCs from the original standardised variables is done in order to reduce the contribution of variables with minor significance. The number of PCS/VFS considered for each situation was mainly decided on the basis of the percentage of explained variance. Then all factors with eigenvalues higher than one are selected or extracted.

The various parameters examined in this study and further endeavour to relate the statistical values with the possible environmental factors that might contribute to them.

CHAPTER 4: FIELD AND LABORATORY RESULTS

4.1 Brief Description of Results

The results obtained from the analytical measurements of the various hydrochemical components and parameters for the groundwater in the study area have been summarised in Tables 4.1 and 4.2 respectively. This chapter represents and explains quantitative analysis of the various parameters examined in this study and further endeavours to relate the statistical values with the possible environmental factors that might contribute to them.

a) pH

The groundwater pH values ranged from 5.6 to 8.5 (Table 4.1). The lowest pH value of (5.6) was recorded at station C13088 and highest (8.5) at C 3700 (Bomas of Kenya) (see Fig 3.1)

b) Conductivity and TDS.

In the study area, the electrical conductivity levels in groundwater range from 114 to 4800 μ S/cm. Electrical conductivity was generally seen to increase with increasing values of both TDS and with temperature (Table 4.1). TDS values measured in the groundwater of the study area lies in the range from 0 to 5210 mg/l.

c) Na

Sodium is the dominant cation (with a range of 13.0 mg/l to 288.0 mg/l) (Table 4.1). Highest concentration levels of sodium are found at C 6310 (Kewi), and at C 5510 Kenyatta National Hospital (K.N.H.) and at Safari Park Hotel.

d) K

Potassium is present in all the waters examined though in lesser amounts than sodium. K has a range of 2.30 mg/L to 23.0mg/l.

e) Ca

Calcium levels were generally high compared to potassium (Table 4.1) and were varying between 1.74 mg/l and 65.30 mg/l.

f) Mg

Magnesium concentration levels in the study area vary from 0.012 mg/l to 16.0mg/l and with a mean concentration of 1.96 mg/l. The highest Mg concentration level was recorded at C 7396 (Karigaca borehole) in Karen, and the lowest values were recorded at C 10122 (Mater Hospital) and at C 10496 (UON Main Campus) (see Table 4.1 and Fig 3.1).

g) Fe

Concentration levels were relatively lower than other cations (Table 4.1). Fe has a range of 0-0.890 mg/l and a mean of 0.102 mg/l (Table 4 .2). The highest value of Fe was found at C12902 (Yaya Centre) (Fig. 3.1).

h) SiO₂

Silica values in the study area range from 10mg/l to 100 mg/l with a mean 58.8 mg/l (Table 4.0 and 4.2). High values of silica were noted at S37 (Coopers K Ltd) and at C11701 (Public Service) (see Fig 3.1).

i) NO₃

Nitrate levels in the groundwaters of the study area range between 0.089 mg/l to 133.0 mg/l, and with a mean of 9.1 mg/l (Table 4.1). These levels primarily emanate from the decomposition of plant and animal materials in the soil and which later reacts with other substances forming different nitrate compounds in water. The highest and the lowest values of nitrate were found at CS75 (Shade Hotel) and at C10774 (Memon/Bilal Mosque), respectively. The boreholes, which are listed here below, have the highest NO₃ concentration levels of the study area. Generally natural nitrate concentrations in ground water range from 0.1 to 10 mg/l (Davis and De Wiest, 1966). Therefore, these high nitrate levels of the study area may enter the groundwater from sewage discharges on land, where many chemical industrial wastes contain concentrations of nitrogen. Other sources of soil nitrogen are decomposing plant debris; animal wastes and nitrate fertilisers, which latter on can enter into the groundwater.

j) HCO₃

Bicarbonate is the most dominant anion in the waters of this area of study (Table 4.2). The concentration levels of bicarbonate in the waters examined in this area ranges from 34 mg/l to 498 mg/l, and with a mean 188.1 mg/ (Table 4.2). The highest and the lowest concentrations of HCO₃ are found at C6310 (Kewi) and at C13088 (National Research Lab) respectively

K) SO₄

Sulphate levels in the waters range from 0 mg/l to 42.5 mg/l (Table 4.1), and with a mean of 4.89 mg/l (Table 4.2).

Table 4.1: Physico-Chemical Parameters of Groundwater in Nairobi area.

B/N0 Sample source	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Si (mg/l)	HCO3 (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3 (mg/l)	F (mg/l)	E.C (µS/m)	T.H (mg/l)	T.Al (mg/l)	Tur	PH	TDS (mg/l)	Temp. oC
C2291 Nairobi Club	72	6.8	4	0.066	0.15	80	199	10	2.4	0.22	6.6	410	130	12	0	8	410	22
C1170 Public Service	79	7.7	12.6	0.176	0.02	100	183	10	1.6	0.22	11.5	348	150	36	0	8.1	800	22
C12874 Silver spring Hotel	73	8.52	4.88	0.117	0.14	60	183	10	0	0.27	6	327	150	22	50	8.1	400	22.2
C12331 Lake Star	106.5	18.3	9.88	1.55	0.01	30	195	39	21.3	5.1	3.2	508	160	44	34	7.4	580	22.1
C9765 Hilton Hotel	29.1	2.72	5	0.695	0.04	30	73	4	3.7	0.44	3.2	148	60	14	0	7.5	-	22.5
C12965 Wish-Born(W.I.Bank)	87	6.78	4.3	0.013	0.06	80	181	9	1.6	0.22	11.5	445	148	10	0	8.2	420	22.1
C6352 Upper kabete U.O.N	50	11.4	10.3	0.016	0	50	107	44	1.9	4.7	1	332	88	46	0	6.1	600	22.5
C9754 Sarana Hotel	66.5	5.1	3.38	0.08	0.08	50	129	8	1.9	0.18	11	374	106	6	0	8	360	22.6
C4001 B.A.T Linkoni RD	106	7.1	4.13	0.102	0.1	80	212	17	2.9	0.35	12.5	462	180	8	0	8.4	1,260	22.6
C9762 Nairobi Hospital	73	6.22	4.13	0.014	0	40	139	13	1.1	0.18	13	417	114	8	0	8.1	400	22.2
C10122 Mater Hospital	83	6.3	4.63	0.012	0	80	188	10	1.6	0.22	10	465	160	8	0	8.4	460	22.2
C10774 South C Mosque	134	7.6	2.97	0.12	0	70	273	31	11.7	0.22	5.2	682	224	20	18.5	8.1	650	22.4
C10306 Kenya Bus service	55	4.5	2.27	0.26	0.13	40	120	7	2.1	0.31	5.3	460	98	12	0	8	470	22.3
C11327 Muslim girls, School	68	5.3	2.97	0.029	0.02	60	168	8	0.3	0.27	4.5	294	138	8	2.5	7.6	860	22.7
C955 Starehe boys, centre	76.3	6	5.16	0.028	0.02	70	183	9	1.4	0.35	7.8	453	150	10	0	8.1	410	22.6
C11243 N.Starehe boys, centre	70	6	2.76	0.293	0	50	166	7	1.6	0.27	6	1378	136	20	1	7.9	1,330	22.7
C5518 Kenyatta National Hosp	170	9	11.8	0.045	0.02	30	232	108	22.4	0.22	8.4	845	190	12	0	8	800	22.4
C11590 Sarit centre	50	14	16.4	6.48	0	40	120	26	21.9	40.7	0.9	388	98	72	0	6.5	1,320	22.4
C11230 Gurunanak Temple	60	23	20	4.04	0.07	80	155	42	13	28	0.74	448	127	76	0	6.8	830	22.6
C10497 U.O.N Main Campus	72	5.2	2.11	0.012	0.04	80	144	6	1.3	0.22	11.5	455	118	8	0	8.1	430	22.2
C12575 K.C.B Ent RD	98	6	1.98	0.042	0	80	195	11	2.4	0.31	13	4800	170	4	0	8.4	4,610	22.3
C10298 Maji House	73	6.1	4.63	0.12	0	80	146	9	2.1	0.22	11.5	392	120	8	0	8.1	400	22.4
C13088 National Research Lab	20.4	4	8.16	0.689	0	40	34	3	0	42.4	0.19	139	28	24	2.5	5.6	880	22.5
C10797 Jamia Mosque	83	6	4.71	0.87	0	50	230	7	0	0.18	11.6	449	190	34	10.5	7	440	22
C8697 Tru Foods	140	8.2	17	0.111	0	60	317	34	12	6.9	1	777	260	14	3	8.2	760	22.1
C9737 Kenya Cold storage	110	17	7.89	6.1	0.01	50	232	12	2.5	72	8.4	664	190	90	0	7.3	1,110	22
S27 Coopers (K) LTD	43	9.3	6.6	2.44	0.03	60	120	28	0.4	1.7	0.5	295	98	42	0.3	6.2	340	22.1
S28 Vet farm U.O.N.	32	6.3	9.84	0.868	0.01	80	88	14	0.3	3.41	0.54	227	72	28	0.3	6.7	260	22.3
C9410 Vet Lab sports Club	45	14	5.9	5.4	0.04	50	66	34	3.2	44.7	10.2	320	54	50	0.7	5.9	360	22.2
C11018 Starling Craft	52	9	4.8	1	0.04	80	144	11	1.4	0.39	3	290	118	22	0.7	7.6	320	22.5
S31 Gandu Area (47m)	60	19.1	37.2	9.95	0.03	60	146	69	18.1	72.2	0.58	685	120	157	1.5	7	490	22.5
S32 Gandu Area (80m)	60	16	30	10	0.08	60	146	66	18	70	0.58	476	190	144	3.6	7.6	690	22.3
C2987 Impala Club	65.3	8.3	65.3	0.041	0.05	80	144	7	1.7	0.35	9.4	312	118	14	0.2	7.9	360	22.3
C2918 J.C.K Club	55.5	10	2.67	0.743	0.14	80	171	8	0.8	0.39	0.88	294	140	24	1.2	7.3	310	22.6
C12824 Mat Dept	68	8.1	9.9	0.062	0	80	154	13	1.2	0.44	13	323	126	12	0.7	7.9	370	22.6
C4522 Upper kabete Field St	35.1	11	12	6.8	0.02	60	188	8	0.4	22.3	8	290	72	58	0.2	6.3	320	22.6
S37 Coopers (K) LTD	47.2	13	5.91	2.58	0.02	100	166	0.35	0.4	0.39	0.35	298	136	34	0.2	7	320	22.5
S38 Vet farm U.O.N.	43.1	5.6	1.74	1.91	0.52	60	100	5.6	1.4	0.49	5.6	244	82	28	0.52	6.5	1,320	22.3
C12986 Kenya Phtecnic Main camp	83.1	5.3	4.43	0.025	0.05	80	183	11	1.6	0.53	11	369	150	16	2.5	7.9	370	22.4
C4666 Dog unit section	87.4	6.8	4.8	0.319	0.05	80	203	4.8	1.8	0.75	4.8	411	166	20	0.5	7.9	470	22
C11696 Catholic Uni Sisters, Hostel	74	8.5	6.64	2.23	0.07	60	198	2.3	7.4	1.15	2.3	409	162	44	1	7.4	460	22.2
C9748 Carnival TML	63.3	8.1	6.14	0.489	0.05	80	159	8.4	3.4	0.75	8.4	348	130	28	0.2	7.6	1,150	22.6
S43 Apostle of Jesus Seminary	65.8	10	3.48	0.86	0.07	60	176	3.6	1.4	0.35	3.6	333	144	30	0.1	7.5	400	22.6

Continued Table 4.1.

B/ND	Sample source	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Si (mg/l)	HCO ₃ (mg/l)	Cl (mg/l)	SO ₄ (mg/l)	NO ₃ (mg/l)	F (mg/l)	EC (μ S/m)	T.H (mg/l)	T.Al (mg/l)	Tur	PH	TDS (mg/l)	Temp. oC
C3736	Consolata Seminary	70.2	7.2	3.35	0.107	0.08	50	159	6	2.5	0.27	6	346	130	14	0.3	7.8	390	22.1
	S45 Apostle of Jesus Youth	67	8.6	3.2	1.5	0.03	60	173	1.4	1	0.27	1.4	324	142	14	1	7.8	630	22.1
C10201	Catholic Uni Main Campus	58.3	10.8	9.6	0.11	0	50	176	1.45	1.6	0.35	1.45	339	144	40	0	7.8	370	21.9
C3700	Bomas of Kenya	99.2	5.3	4.13	0.201	0.09	100	220	6.6	2.6	0.35	6.6	460	180	8	1	8.5	490	22.2
C11761	Brooke House	74.3	8	2.6	0.07	0.12	80	178	4	2.1	0.44	4	351	146	36	0.9	7.9	860	22
C11086	Thomas Barnardos	83	7	3.86	0.12	0.14	60	188	8.4	1.6	0.31	8.4	378	154	20	0.3	8.3	810	22.4
C6310	Kewi	288	10.4	2.57	0.08	0.05	40	498	3	42.5	49.84	3	1254	408	4	0.4	7.7	1,310	22.4
C11348	Sarnaj School	87.4	6.4	5.02	1.39	0.08	80	195	9	2	0.31	9	394	160	10	1.8	8.2	5,210	22.4
	S52 Baitul-Mal Mosque	13	2.3	3.03	0.08	0.08	10	39	0.35	5.7	0.93	0.35	114	32	26	1	6.6	1,320	22.3
	S53 Kasarani Sports Complex	114.4	9.4	1.98	0.043	0.04	100	273	7.2	2.1	0.31	7.2	507	224	12	0.4	7.8	550	22.3
C11171	Central glass industry	88	7	5.06	0.27	0.79	80	212	4	1.6	0.09	4	456	174	6	5.5	8	490	22.4
C9746	Safari Park Hotel	140	15	2.79	0.41	0.03	100	359	1.7	2	0.133	1.7	622	294	18	0.2	7.5	620	22.5
	S56 Safari Park Hotel	152	12	5.93	0.32	0.14	60	359	6.1	2.7	0.18	6.1	617	294	12	0.4	7.8	630	22.5
	S57 Safari Park Hotel	159	16.1	7.15	0.709	0.1	50	432	5	1.9	0.44	5	723	354	22	0.2	7.9	720	22.5
C11965	Queen of apostle	108	10.8	2.46	0.09	0	40	171	6.6	0	80.6	6.6	853	140	32	4.5	6.6	510	22.5
C12885	Kenya Polytechnic Mens' Hos	85	6.3	5.07	0.302	0.02	50	205	7.8	2.4	0.31	7.8	407	168	8	0.2	8.3	450	22.3
C10072	Utali/Hotel/College	63.4	7.2	6.83	0.956	0.19	20	161	3.8	1.4	0.35	3.8	302	132	24	1.1	7.6	360	22.3
C9440	Nairobi School	53	10.2	1.92	4.8	0.01	20	168	1.35	0.3	0.27	1.35	275	138	30	0.5	6.8	490	22.6
	C404 Norfolk	71.5	10.2	10.6	2.59	0.02	20	176	5.3	12.9	0.35	5.3	406	144	48	1.5	6.9	460	22.2
C12664	Braebun School	58.1	9.3	13.6	8.8	0.68	30	162	2.5	7	0.22	2.5	386	133	66	3	6.8	900	22.4
C11316	Methodist Guest House	61.1	5.3	2.55	0.07	0.14	20	150	5.5	3.1	0.18	5.5	276	123	8	0	7.5	340	22.8
C12902	Yaya Centre	68	5.9	6.74	0.92	0.89	30	170	7	2.7	26.6	7	403	139	10	1.5	8	1,230	22.5
C6324	Aiya House	104	8.5	6.74	0.06	0.03	60	156	8.2	8.7	0.22	8.2	542	128	26	0.5	7.5	1,270	22.7
C10774	Mamoni/Bilal Mosque	114	7.7	2.95	0.5	0.03	80	278	6.7	9.1	0.089	6.7	508	228	8	0	7.6	580	22.4
	S68 Kah Ndani	51.4	11	35.2	9.3	0.03	50	278	1.2	0.9	0.27	1.2	478	228	140	1	7.2	510	22
	S69 Robin Hunt Saafaris	67.3	9.7	12.2	4.83	0.05	50	205	5.1	1.4	0.27	5.1	402	168	76	1	7.5	430	22.1
	S70 Mt' Recka	66.3	11.2	7.4	3.9	0.03	80	188	2.7	1.1	0.18	2.7	362	154	48	0.5	7.2	410	22.1
C12143	Nyumbani Children Home	53	8.8	6.4	2.9	0.22	40	176	1.5	0	0.31	1.5	301	144	38	9.9	6.7	340	22.2
C7396	Karigaca Karen	61	11.1	15	16	0.03	40	188	0.62	4	0.66	0.62	460	150	84	0.5	6.7	510	22
C6215	Bul-Bul Mosque	81.2	13	17.3	3.98	0.05	50	273	1.45	5.4	0.49	1.45	505	224	78	0	7	530	22
C11083	Bul-Bul Waater Supply Stat	97	8	2.5	2	0.05	10	188	8.2	7.4	0.22	8.2	408	154	36	0	8.1	410	22.6
	S75 Shade Hotel	106.4	13.8	30.1	8	0.87	30	176	2.2	26.7	133	2.2	772	144	156	3.5	6.4	860	22.5
	S76 Little Missionary Sisters' Cl	74.5	11.5	10.7	6.78	0.06	60	188	4	1.7	2.4	4	388	154	58	1.5	7.2	410	22.5
	S77 L.T.Kuria	64	10.5	10.3	6.78	0.05	50	178	4	2.1	0.97	4	365	146	58	0	7.3	400	22.1
C11105	Elida Ponds	140	10.7	3.75	0.099	0.05	50	315	6.5	12.4	0.44	6.5	589	258	16	5	7.9	640	22.5
	S79 Bob Mill industry	120.5	8.6	2.57	0.1	0.08	80	261	10	10.9	0.89	10	519	214	10	0	8.3	540	22.6
C13148	Forest View Academy	64	7.3	8.9	0.591	0.59	50	161	3.8	0.3	0.71	3.8	338	132	38	24	8.1	400	22.1

L) Cl

Generally, low concentration values of chloride were obtained in the groundwater analysis of this study area (Table 4.1). Chloride concentration values of the area of interest range from 0.35 mg/l to 108 mg/l, and with a mean of 11.98 mg/l (Table 4.2). The highest concentration level chloride of sample C5518 may contain an analytical error

M) F

For the fluoride content of the water samples from both boreholes and shallow wells have fluoride concentration levels ranging from 0.19 mg/l to 13.0 mg/l and with a mean value of 5.5 mg/l (Tables 4.1 and 4.2). The highest fluoride concentration levels were recorded at C12824 (Meteorological Department), and at C 12575 and at C 4001(B.A.T)

Table 4.2: Descriptive statistics for all the hydrochemical parameters for groundwater in Nairobi area.

Element/parameter Symbol	Mean (mg/l)	Variance (mg/l)	Standard Deviation (mg/l)
Na	80.10	38.70	25.10
K	9.10	3.70	20.96
Ca	8.50	9.60	9.40
Mg	1.96	3.10	8.10
Fe	0.10	0.18	7.10
Si	58.80	22.10	6.00
HCO ₃	188.10	74.80	5.35
Cl	11.98	17.00	3.96
SO ₄	4.89	7.27	3.58
NO ₃	9.11	23.29	2.68
F	5.48	3.78	2.18
E. C	498.92	527.60	1.89
T.Alk	154.25	62.00	1.47
T.H	33.94	33.82	1.24
Turb	2.62	7.46	0.60
pH	7.50	0.66	0.17
TDS	708.50	742.86	0.08

4.2 Interpretation of Field and Laboratory Analysis

4.2.1 Electrical Conductivity

The (EC) of the groundwater of the study area ranged from 114 $\mu\text{S}/\text{cm}$ to 4800 $\mu\text{S}/\text{cm}$ and with a mean concentration of 499 $\mu\text{S}/\text{cm}$. Chemically pure water has a very low electrical conductance, indicating that it is a good insulator. In solutions as dilute as most groundwaters the specific conductance varies almost directly with the amount of dissolved minerals. However, the conductance for solutions of different minerals is not the same. EC is dependent on temperature and on the type and concentration of the dissolved ions. Therefore the specific electrical conductance permits a rapid evaluation of the chemical quality of the water sample (i.e. its total dissolved electrolyte content). In this study area, high EC concentrations are shown (Tables 4 .1, Table 4.2 and Fig 4.1). These high concentrations of

EC are found around Industrial Area and especially at C 6310 (Kewi), where Nairobi phonolites outcrop (Fig 1.1). Therefore, these high concentrations of EC are related to weathering of these phonolite rocks of the area, which are washed down into the water system by the action of percolation water.

4.2.2 pH and Temperature.

The pH value of the groundwater samples ranged from 5.6 to 8.5 (Table 4.1). The pH range of the natural water is 6 to 9 (Stumm and Morgan, 1981). The pH value of most groundwater samples of the study area falls within the above-said mentioned range. Only two samples have pH values that fall below the range of the natural water. According to (WHO, 1984), the pH recommended limits of permissible drinking water range between (6.5-8.5). The pH results of the study area (Table 4.1) shows that 17 samples fall below the lower limit of WHO range, whereas the remaining 63 samples fall within the limited range.

In this study area the pH high concentrations are shown (Tables 4.1, 4 .2 and Fig 4.2). The difference in pH values of the boreholes water samples may depends on several factors such as the chemistry of the groundwater, which could be reflected by the composition of the aquifers, or by human activities, chemical and biological processes occurring during infiltration.

4.2.3 Total Dissolved Solids (TDS)

TDS is determined as the total amounts of solids dissolved in water whether it is fresh or saline. Drinking water is recommended to have no more than 500 mg/l TDS. However, water up to 1000 mg/l TDS is often used if no other source is available. Therefore groundwater can be classified on the basis of TDS content (Table 4.3)

Therefore, according to the above classification of TDS, 68 samples of the groundwater of the study area belong to the first class (fresh water) (Table 4.3), while the remaining 12 samples pass into the second class (brackish water) (Table 4.1). The highest TDS concentrations of the study are shown in (Fig 4.3).

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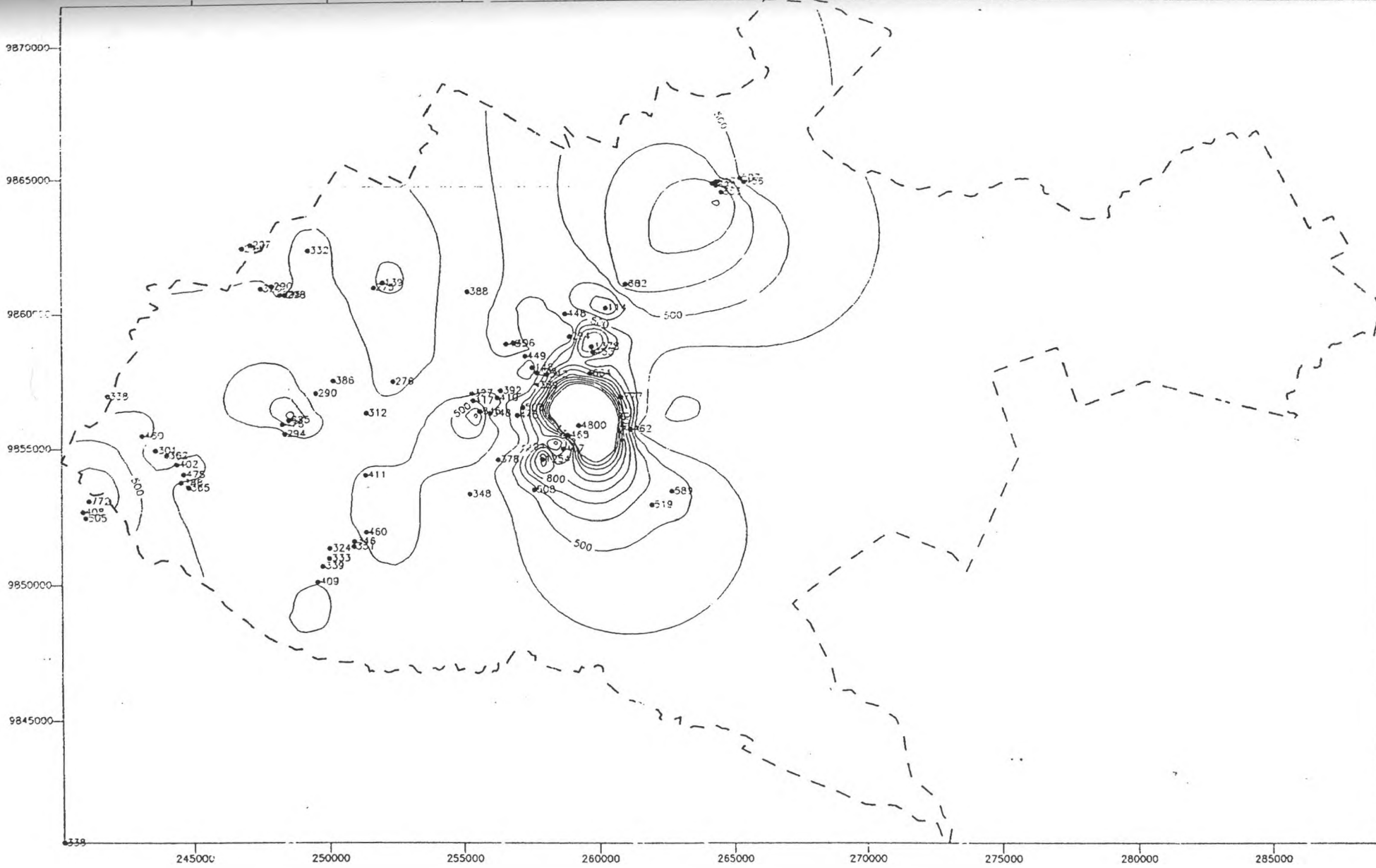


Fig. 4:1 Distribution of Electrical Conductivity in the Groundwater of Nairobi Area

Table 4.3: Comparison of simple groundwater classification Based on Total Dissolved Solids (after Freeze and Cherry 1979) with TDS resulted from the study area.

Classification	Total Dissolved Solids in mg/l	Corresponding water samples to each class
Fresh water	0- 1,000	68
Brackish water	1,000 - 10,000	12
Saline water	10,000 - 100,000	0
Brine water	More than 100,000	0

4.2.4 Total Hardness (T.H) and Total alkalinity

The amount of Calcium, Magnesium, and Iron contribute to the hardness of water. These cations react with soap to form a precipitate, thus reducing the cleansing action of the soap. Hardness is removed by exchanging the Calcium, Magnesium, and Iron for Sodium cation (Section 3.2.5.1). Water is classified according to T.H content as CaCO_3 mg/l by Hem (1970). Hardness of water is classified according to the (table 4.4) below:

Table 4.4: comparison of water hardness classification of Hem (1970) with the resulted hardness from the study area.

Hardness range mg/l of CaCO_3	Description
0 - 60	Soft water
61 - 120	Moderately hard water
121 - 180	Hard water
Greater than 180	Very hard water

Therefore according to the above water hardness classification of the of the study area, 69 water samples fall within the first class of soft water, while 7 samples fall within the second class of moderately hard water, and the remaining 4 samples fall within the 4th class of hard water (Table 4.2 and Table. 4.4).

The highest concentration level of T.H is found at C6310 (Kewi) (Fig 4.4a and Table 4.1), where Nairobi phonolites outcrops (Fig 1.1)

57

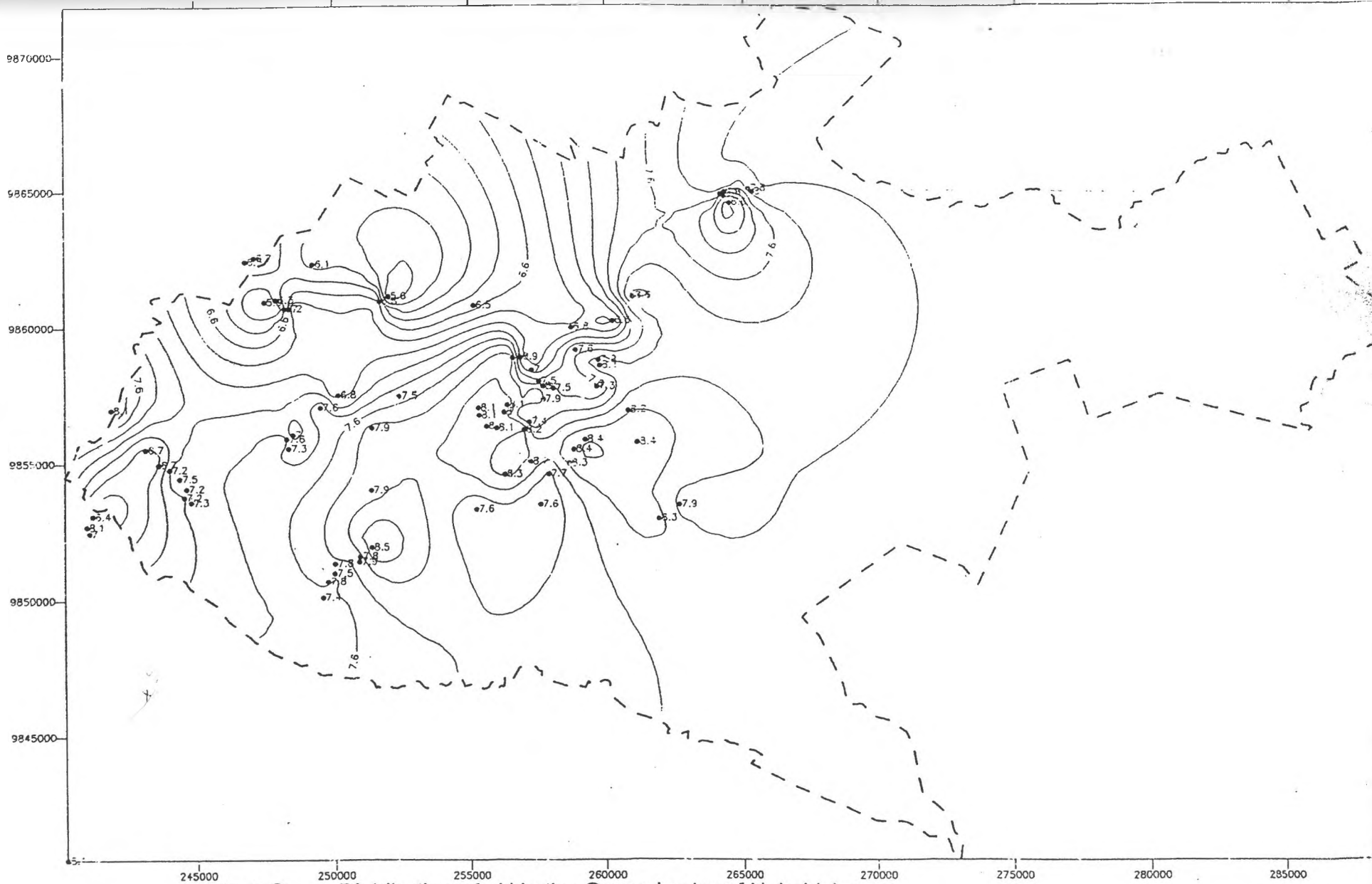


Fig.4.2 Distribution of pH in the Groundwater of Nairobi Area

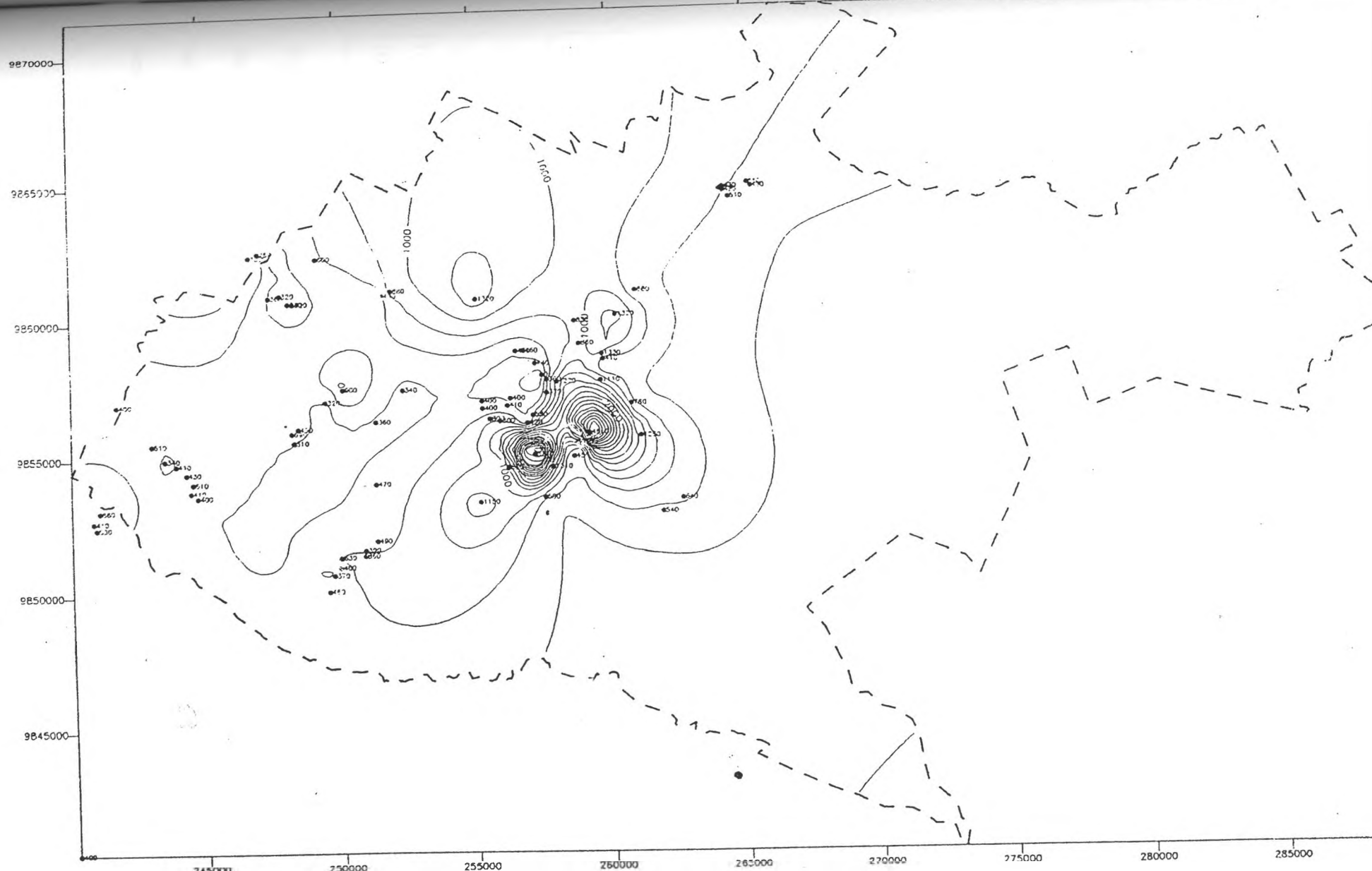


Fig. 4.3 Distribution of TDS(mg/l) in the Groundwater of Nairobi Area

Total alkalinity is a measure of the equivalent concentration of all cations associated with the alkalinity producing anions, except hydrogen ion. In acid conditions where $\text{pH} < 6$ the predominant species is undissociated carbonic acid (H_2CO_3). In the normal groundwater where pH ranges 6-8 the predominant carbonate species is bicarbonate (HCO_3^-). In the alkaline conditions where $\text{pH} > 8$ the predominant carbonate ions are carbonates. In this study area, the pH ranges from 5.6-8.5 and therefore the predominant carbonate species is bicarbonate alkalinity (Table 4.1). In this case bicarbonate alkalinity $\times 1.2 = \text{Total alkalinity}$. High Talk concentration levels are found at S31 (Gantt area) and at S75 (Shade Hotel) respectively, whereas the lowest Talk are found at C12575 (K.C.B ENT Rd) and at C 6310 (Koei) (Table 4.1 and Fig. 4.4b).

4.2.5: Isotopic composition of Nairobi Groundwaters

Mass Spectrometer (MS) method was employed in the determination of isotopic composition of water. Natural water can be a combination of six of the nuclides listed in the following table.

Table 4.5: Environmental Isotopes used in Geohydrological Studies.

Isotope	Relative Abundance %	Type
^1H protium	99.984	Stable
^2H Deuterium	0.0016	"
^3H Tritium	0 to 10-15	Radioactive (half life 12.3 yrs by β - emission)
^{16}O	99.76	Stable
^{17}O	0.04	"
^{18}O	0.2	"

Eighteen combinations of the water molecule are possible using these nuclides. Water is therefore a mixture of these isotopic combinations, and its molecular weight can range between 18 ($^1\text{H}_2\ ^{16}\text{O}$) and 24 ($^3\text{H}_2\ ^{18}\text{O}$). Environmental isotopic studies have focused on isotopes of hydrogen, carbon, oxygen, nitrogen and sulphur.

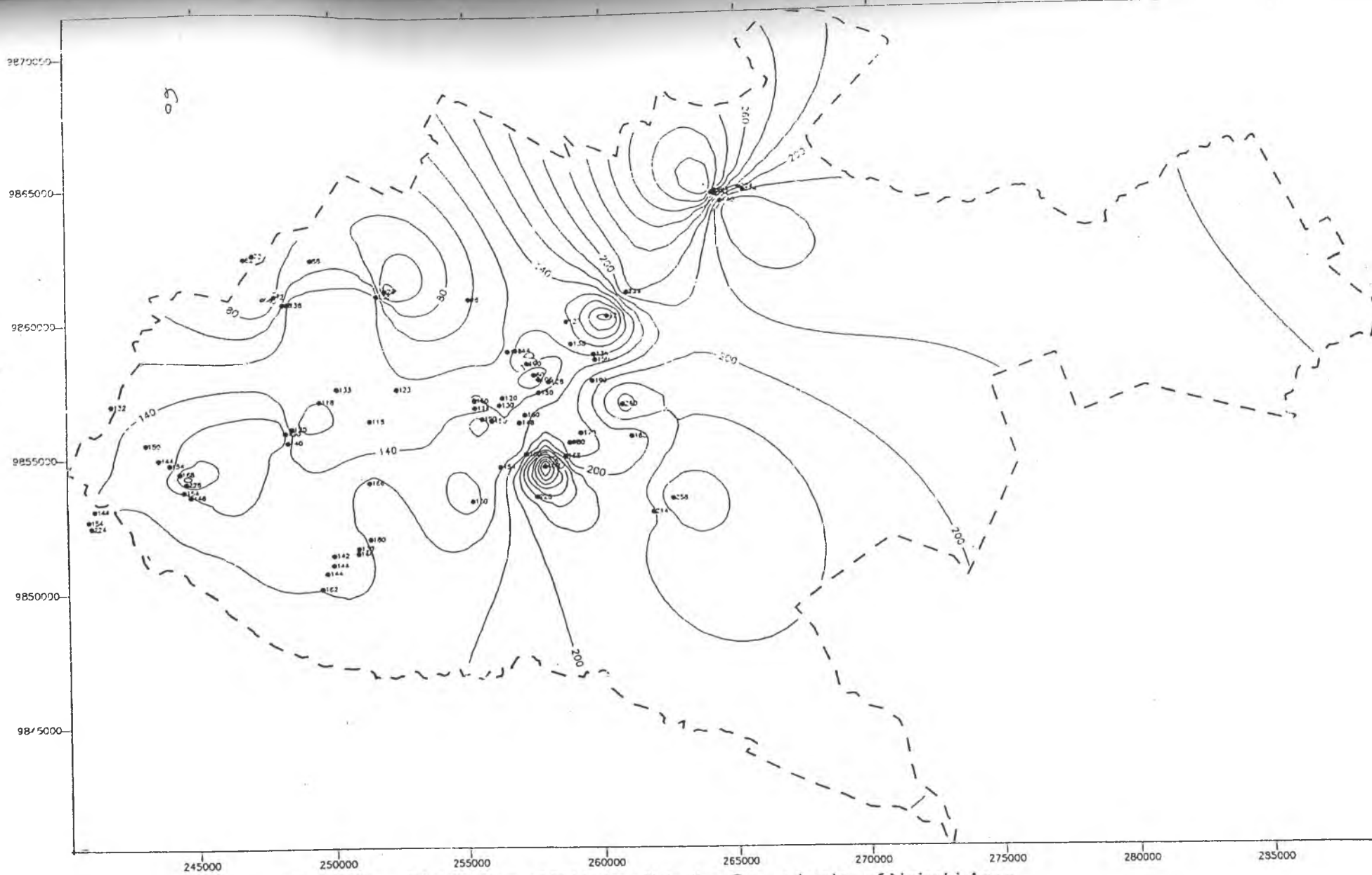


Fig. 4.4a: Distribution of T.H. (mg/l) in the Groundwater of Nairobi Area

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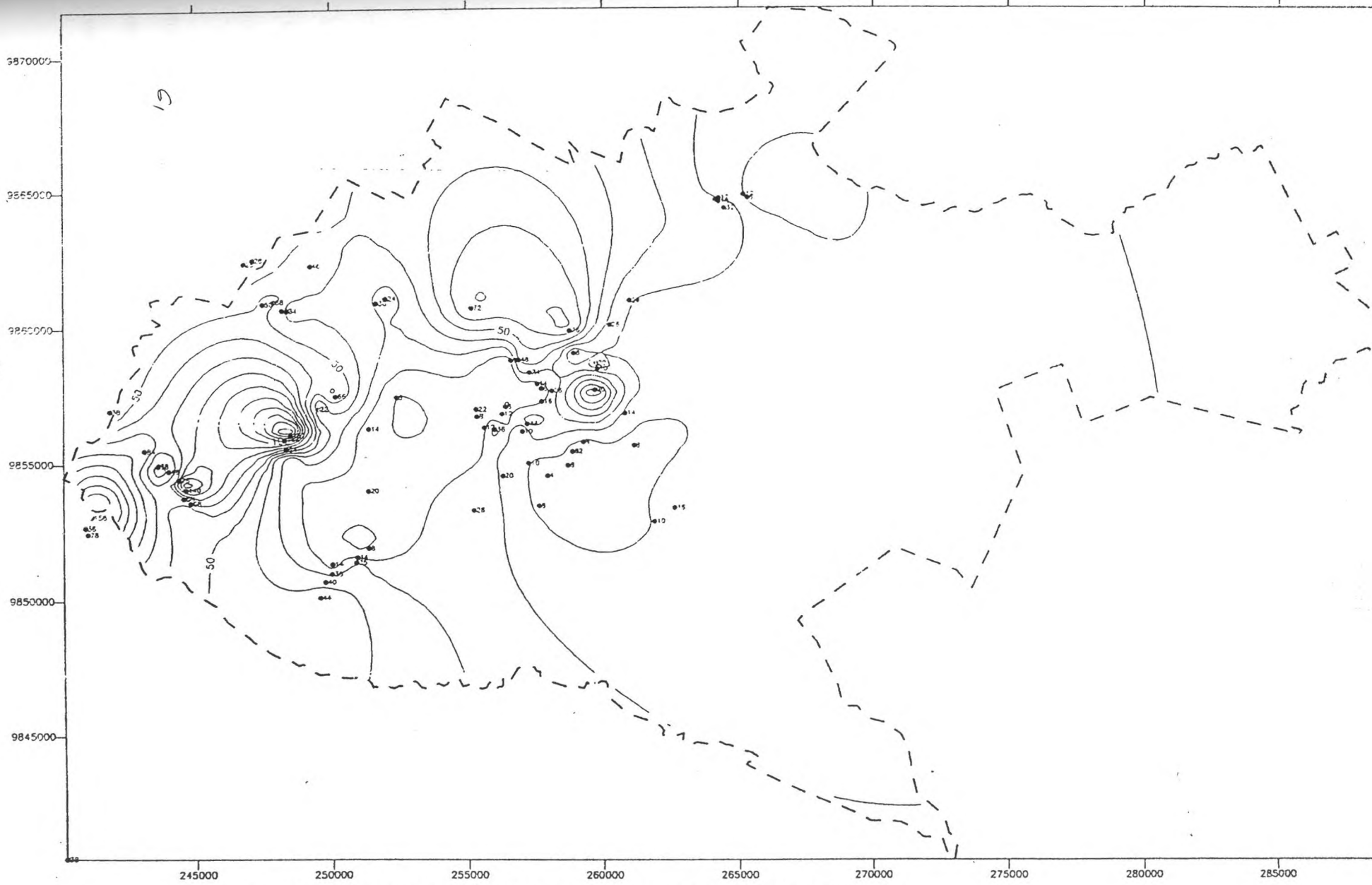


Fig.4.4b: Distribution of T. Al (mg/l) in the Groundwater of Nairobi Area

For hydrological and geohydrological studies, isotopes of hydrogen and oxygen are important because they are part of the water molecule and they therefore move at the same rate and undergo the same changes as the water molecules

The stable isotope concentrations in the water are controlled by the number of condensation stages before precipitation and by evaporation after precipitation. Seawater being the largest uniform body of water is used as a standard with which measured concentrations are compared, SMOW (standard mean composition of ocean water). The abundance deviation (δ) is usually expressed as the difference of heavy to light isotope with that of SMOW.

$$\delta = \frac{R - R_{SMOW}}{R_{SMOW}} \times 1000 \text{ (Parts per thousand)}$$

Where: R- is the isotopic concentration of the sample

R_{SMOW} - is the isotopic concentration of the standard

Isotopic concentrations for oxygen and hydrogen are determined by measurement with a mass spectrometer and the concentrations are calculated from the following relationships.

$$[{}^2H] \equiv [D] \equiv \frac{{}^2H}{{}^1H} \text{ and } [{}^{18}O] \equiv \frac{{}^{18}O}{{}^{16}O}$$

As water is evaporated the heavier isotopes are left behind, atmospheric water will contain less of the heavy isotopes. This is a natural distillation fractionation process which continues with rainfall, as atmospheric moisture moves inland, the heavier isotopes precipitate first so that, it becomes more and more depleted in heavy isotopes each time it rains. Precipitation in a certain area will have a distinctive stable isotope concentration. A plot of $\delta^{18}O$ against δD gives a straight line for meteoric water called global meteoric water line.

Most rainwater will plot close to and parallel to this line. Water that collects in surface water bodies will again undergo evaporation and the heavy isotope concentrations will increase. They will plot on an evaporation line of lesser slope than the meteoric line. It is possible for δ to be negative or positive depending on whether the water sampled contains less than, or more than, the isotopic concentration of the standard.

Hydrogen has three naturally occurring isotopes: 1H (protium) and 2H (deuterium) which are stable with relative abundances of 99.84% and 0.016% respectively, the third isotope is 3H (tritium), which is unstable and has a half-life of 12.4 years. Tritium permits the history of the water to be dated. Oxygen has three naturally occurring isotopes, ${}^{16}O$, ${}^{17}O$, and

^{18}O ; all are stable with relative abundances of 99.76%, 0.04%, and 0.20% respectively. Stable isotopes enable the history of water to be studied for evaporation preferentially lifts the lighter ^{16}O into the vapour phase thus concentrating ^{18}O in the remaining water. Ratios of $^{18}\text{O}:^{16}\text{O}$ (normally 0.002) and $^{18}\text{O}:^2\text{H}$ (normally 6.25:1.0) provide the water molecule with an isotopic signature than can be used to identify in the groundwater, water of different histories (Blyth and. 1974). Therefore implementing the above-mentioned techniques to certain borehole water samples in Nairobi, the following data was obtained (Table 4.6).

The best-fit line defines the close and consistent proportionality between ^2H and ^{18}O in meteoric waters, ($\delta^2\text{H}=8* \delta^{18}\text{O} +10$) and commonly known as Global Meteoric Line (GMWL) (Schotter, oldfield and Frohlich, 1996). The meteoric water line provides an important key to the interpretation of ^2H and ^{18}O data. Water with an isotopic composition falling on the meteoric water line is assumed to have originated from the atmosphere and is unaffected by the other processes. Therefore, as shown in the above (Fig 4.5) the isotopic composition (i.e. ^{18}O and ^2H) of Nairobi groundwater are drawn almost along or on the Global Meteoric Line which is assumed to have originated from the atmospheric precipitation and is unaffected by the processes.

The graph shows that Nairobi groundwaters are depleted in their isotopic compositions.

Table 4.6: Isotopic Composition of Nairobi Groundwaters

Sample	Location	BH/NO	$\delta^{18}\text{O}$ ‰	$\delta^2\text{H}$ ‰
Nairobi 02	Public Service Club	C11701	-3.94	-19.9
Nib 05	Hilton Hotel	C9765	-3.97	-18.5
Nairobi 10	Nairobi Hospital	C9762	-3.78	-18.7
Nairobi 11	Matter Hospital	C10122	-3.67	-18.8
Nairobi 17	K.N.Hospital	C5518	-3.34	-17.6
Nairobi 22	Maji House	C10298	-3.69	-17.7
Nairobi 30	Sterling Craft (Dag)	C11018	-3.83	-19.8
Nairobi 48	Brook House Mom.Rd	C11761	-3.64	-19.5
Nairobi 62	Norfolk Hotel	C404	-3.53	-17.8
Nairobi 78	Elida Ponds	C11105	-3.35	-19.2
Nairobi 80	Forest View Academy	C13148	-4.31	-24.9

Source: Personal communication Prof. S.J.Gaciri (2001)

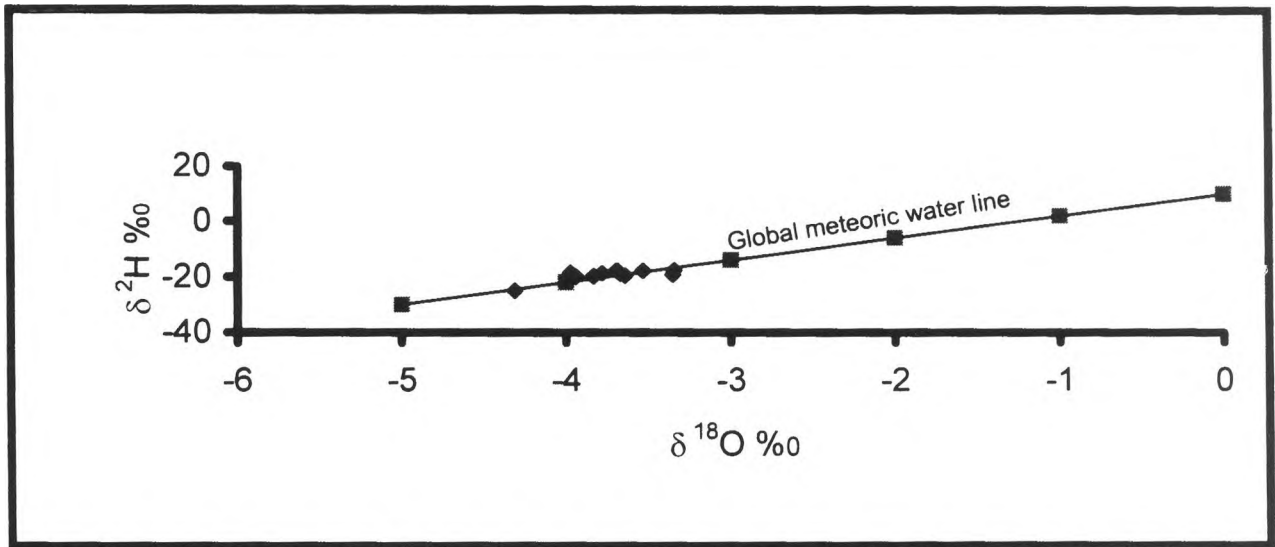


Fig 4.5: Isotopic Composition of Nairobi Groundwater.

4.2.6 Groundwater Path Flow.

Depths of water as evidenced from the borehole data (Table 1.1 and Fig. 4.6) indicate that the groundwater profile is closely related to the topography of the area. The general flow of water direction looks a bit complex, as there is no particular regional direction of water flow. However, as shown on Fig 4.6 there are several recharge and discharge areas as indicated by the notation 'R' and 'D' respectively. Diverging and converging arrows in Fig 4.6 represent recharge and discharge areas respectively. Groundwater seemingly discharges in some streams and rivers (e.g. Tusoga, Kikuyu Springs, Ruaraka and Karura Rivers, Nairobi, Gitathuru, Ngong and Mbagathi Rivers) thus replenishing surface water sources.

4.2.7. Common major /minor chemical constituents.

Sodium

Sodium concentration in the boreholes within the study area, ranges between 13.0mg/l to 288.0 mg/l (Table .4.1) with a mean concentration of 80mg/l. High concentration levels of sodium are found in the boreholes at C 6310 (Kewi), at C 5518 (K.N.H) and at C 10122 (Lake Star) (Fig. 3.1 and Iia in Appendix II). All these boreholes with high sodium concentrations are found around the contacts of alluvium deposits with middle and upper Kerichwa Valley Tuffs with Nairobi trachytes and with Nairobi phonolites (fig. 1.1 and Iia in Appendix II).

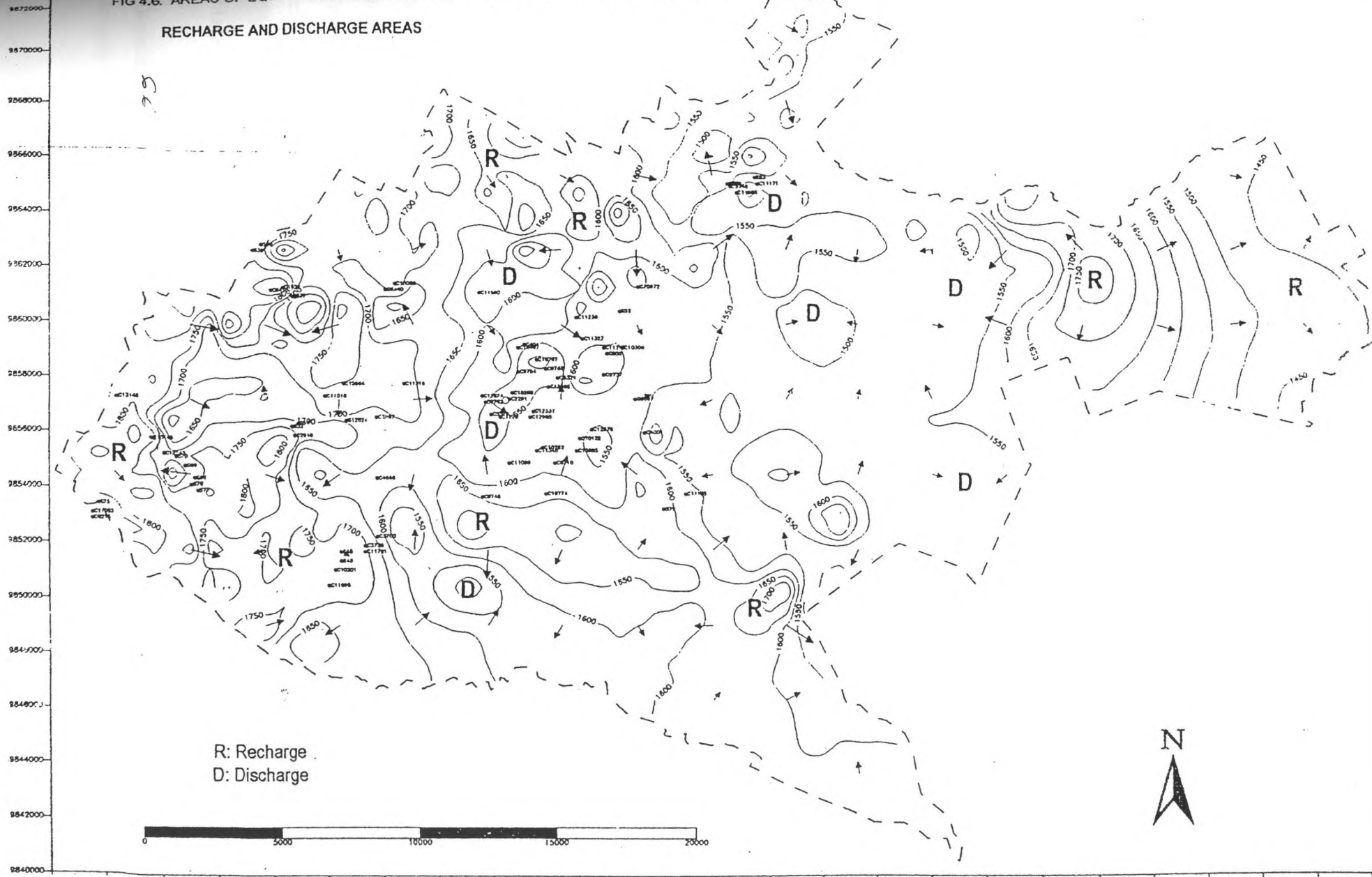
The concentration of Na^+ increases from the younger geological formations to the oldest (Fig.1.1 and IIa in Appendix II). Interestingly, it was also apparent that the least concentration was found in Eastleigh station at S 52 (Baitul-mal Mosque). No immediate explanation could be arrived at regarding this low concentration, but possibilities for this pointed towards a complex of geological changes around this area. High concentration levels of sodium are generally found throughout the study area with has a mean of 80 mg/l. A few relatively high concentrations are found towards South "C" and Langata estates area, industrial area and along Mombassa road. Other high readings of sodium are found around Kasarani area. Such high sodium concentrations may be related to the geology. Given that the area of Nairobi is mainly covered by volcanic rocks (fig.1.1), it is likely that the source of the high sodium content in this area may be purely geological, that is, it may be emanating from decomposition of acid lava. The rocks in this area (Nairobi) are rich in alkali feldspars, which compositionally consist of aluminosilicates that weather chemically to form the topsoil in the area (Saggerson, 1991). Basically, most of the ground water in the study area has sodium levels that are within both the recommended and also permissible drinking water levels (Table 4.1 and Table 4.7), and thus suitable for domestic purpose. Exceptions exist at stations C 6310 (Fig. 3.1, IIa in Appendix II and Table 4.1), which exceed or fall out of the recommended limits of permissible drinking water levels (i.e. Na^+ of 200 ppm according to WHO). Sodium in ground waters of Nairobi area is primarily from the geological rock formations even though to some limited extent, agricultural sources and domestic discharge (i.e. wastewater containing soaps and detergents, other sewage waters etc) may also have contributed towards its high concentration levels in groundwater.

Potassium

Potassium is available in all the waters examined although in low amounts relative to Na^+ . It has a range of 2.3 mg/l to 23 mg/l and with a mean of 9 mg/l and a standard deviation 3.7 mg/l (Tables 4.1 and 4.2). The highest K^+ concentration levels were recorded around at boreholes C11230 (Gurunnak Temple) and at borehole S31 (Gandu area) respectively (Fig IIb in Appendix II). The lowest K^+ concentration levels in the area are recorded at boreholes S52 (Baitul-Mal Mosque) and at C9765 (Hilton Hotel). Low potassium levels in the water could be attributed to the relatively higher resistance of potassium-containing minerals to weathering.

FIG 4.6. AREAS OF EQUAL PIEZOMETRIC LEVELS OF GROUNDWATER IN NAIROBI AREA

RECHARGE AND DISCHARGE AREAS



Potassium levels are higher around Pangani, Industrial, and Upper Hill areas (Fig 3.1, and IIb in Appendix II). The high potassium concentration areas are found at C 6310 (Kewi), where the Nairobi phonolites which are made of sanidine and biotite as phenocryst, and alkali feldspar and nepheline as matrix outcrop (Table 4.1, Fig 1.1 and IIb in the Appendix II).

Since reactions involved to weathering are subject to the laws of chemical equilibria, the breakdown of a mineral can proceed beyond the state of equilibrium only if components are added and/or removed from the system. Thus in the alteration of potash feldspar to kaolinite according to the following reaction all the potash must be lost in solution (Loughman, 1969). The same weathering process could be resulted here in this study area.



Potash feldspar water Kaolinite Silica potash

If some is retained, illite and not kaolinite will be the residual product:



potash feldspar water illite silica potash

Calcium

Calcium is one of the major cations in groundwater. In the study area calcium varies from 1.7 mg/l to 65mg/l. The predominant sources of calcium in water are igneous minerals such as silicates, ferromagnesian minerals and feldspars (Bouwer, 1978).

The calcium content in groundwater in the area investigated is generally low. For drinking water a limit of 75 mg/l is desirable. For some industrial applications such as feed water for high - pressure boilers, calcium free water is desirable. Therefore in the case of the study area, all the samples fit for the desirable limit of drinking water. High calcium concentration levels of the study area are found towards Langata and Karen and particularly at C 2987(Impala Club), where the main outcrop is Nairobi Trachytes (Fig. IIc in the Appendix II and Table 4.1). The reason for which, the calcium concentration is high could be related to weathering of these trachyte rocks.

Magnesium.

Magnesium values were relatively high around Karen Shopping Centre towards Dagoretti Road (Fig IIId in the appendix II). The high concentration levels are increase towards the west of the study area. Magnesium is a common element and is found in all

natural waters. Magnesium ion in waters from igneous and metamorphic rocks is derived primarily from ferromagnesian minerals and their alteration products.

Table 4.7 - WHO Standards for Drinking Water quality

Chemical constituent	Permissible Limit (ppm)
Sodium	200
Calcium	75
Magnesium	50
Potassium	
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	0.005
Selenium	0.01
Cadmium	0.005
Chromium	0.05
Hardness	500
Total dissolved solids (TDS)	1000
pH	6.5-8.5
Colour	Not objectionable to 90% of users
Turbidity	5 NTU
Coliforms	Absent in 100 ml

Source of Tebut 1983

Magnesium together with calcium are responsible for water hardness, which results in scales in boilers and can cause cathartic and diuretic effects to consumers. Desirable and permissible levels of less than 60 mg/l have been recommended for both calcium and magnesium in drinking water (Ogege, 2001). Due to its low geochemical mobility magnesium occurs in water in concentrations generally below that of calcium except in magnesium rich aquifers (Mathess, 1982). In the study area high magnesium concentration

levels are found at C 7396 (Karigaca), where the Middle and Upper Kerichwa Valley Tuffs outcrop (Fig 1.1, and Table 4.1). These high magnesium concentration levels are related to the weathering of ferromagnesian rocks of the area, which could be enriched towards Dagoretti area (Fig.1.1 and IId in the Appendix II)

Sulphate.

For the anions, sulphate levels in the groundwater examined were in the range of below detection limit to 42.5mg/l and with a mean of 4.9 mg/l (Table 4.1). Other sources are, decaying of organic matter, volcanic exhalations, and the weathering products of some magmatic rocks (Mandel and Shiftan, 1981). In this area, the sulphate levels were generally low but rather significant with respect to the water chemistry. High concentration of sulphates should be discouraged as it can exert cathartic action on human beings (Johnson, 1972). The high sulphate concentrations in the study area are found in the industrial area, Nairobi South and West and particularly at C 6310 (Kewi) and at S75 (Shade Hotel), where the Nairobi Trachytes and phonolites outcrop respectively (Fig.1.1 Iie in the Appendix II and Table 4.1).

Bicarbonate and Chloride.

Bicarbonates and chlorides were the most two dominant anions in the waters of this area of study. Chloride levels were found to be in the ranges of 0.35 mg/l to 108 mg/l. Chloride content in rocks is very low, few minerals contain chlorine: sodalite and apatite (Robert, 1996). Evaporite minerals and connate water and some brines are the main source. Chloride may also emanate from cyclic salts, leachates, etc, where it is commonly associated with sodium and potassium. In the groundwater of this area it could also be introduced as a disinfectant because chlorination is widely used for drinking water treatment to kill bacteriological pathogens in water (Ogege, 2001). The sludge, which originates from the chlorinated water of the water tanks, could be discharged into the surface of the ground that could seep into the groundwater. Chloride is responsible for brackish taste in water and is an indicator of sewage pollution because of the chloride content of urine (Tebbut, 1977). Abundant chlorides in groundwater may indicate seepage from certain types of sewage facilities. Human wastes are generally deposited in sewage lagoons chlorides often move into the groundwater system. Because they are not absorbed by soil, chlorides can travel great distances (Driscoll, 1986). In the study area, high chlorine readings were found at C 5518 (KNH) at Upper Hill and at stations S31 and S32 (Fig.1.1, IIf in Appendix II and Table 4.1),

where the Nairobi Trachytes and the Middle and Upper Kerichwa Valley outcrop respectively (Fig 1.1).

Bicarbonate was however, the most dominant of all the anions with concentrations varying from 34 mg/l to 498 mg/l and with a mean concentration of 188.1 mg/l (Table 4.1 and 4.2). The major source of carbon (CO₂) is the biota and other bacterial activities within the soil and in other deeper formations. This CO₂ is one of the major sources of bicarbonate levels in the groundwater of the study area although non-carbonate or calcareous rocks have also contributed significantly (Bouwer, 1978). The principal source of high bicarbonate might be related to the Silicate hydrolysis that can be illustrated by the reaction of the feldspars with water and aqueous CO₂ as follows:

$$\text{NaAlSi}_3\text{O}_8 + 2\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{Na}^+ + \text{HCO}_3^- + 3\text{SiO}_2(\text{aq}) + \text{Al}(\text{OH})_3(\text{ppt})$$
 In this study the high bicarbonate concentrations are found at C 6310 (Kewi), in Industrial area and around Safari Park Hotel at Kasarani in Ruaraka Estate (Fig IIg in Appendix II Table 4.1), where Nairobi phonolites outcrop and around Kewi, whereas the Middle and Upper Kerichwa Valley Tuffs and Nairobi Trachytes outcrop (Fig 1.1) at Safari Park Hotel.

Nitrate.

Nitrates levels of the study area were found to be in the range of 0.089 mg/l to 133 mg/l. Nitrates, unlike most other elements in groundwater are not derived primarily from the minerals in rocks that make up the groundwater reservoir (Driscoll, 1986). Instead, nitrates enter groundwater from another part of the nitrogen cycle in the Earth's hydrosphere and biosphere. Several nitrogen compounds are found in groundwater, nitrate (NO₃⁻), nitrite (NO₂⁻), and ammonia (NH₃). Nitrogen enters the ground from several sources. Certain plants, such as alfalfa and other legumes, fix atmospheric nitrogen and transfer it to the soil, where plants use it. Other sources of soil nitrogen are decomposing plant debris, animal waste, and nitrate fertilisers. Additional nitrogen may enter the ground from sewage discharges on land or from sewage lagoons (Driscoll, 1986). In addition, many industrial waste chemicals contain concentrations of nitrogen. Natural nitrate concentrations in groundwater range from 0.1 to 10 mg/l (Davis and De Wiest, 1966). Nitrate concentrations greater than 45 mg/l are undesirable in domestic water supplies because of the potential toxic effect on young infants. Methemoglobinemia is a disease caused by nitrates, which convert to nitrites in the intestines, resulting in an overabundance of Methemoglobin molecules. Cattle are also extremely susceptible to the disease. Loss of milk production and aborted calves are two signs of nitrate

poisoning. The safe nitrate limit for domestic water is set at 45 mg/l by the US. Environmental protection Agency (Driscoll, 1986). This is equivalent to 10 mg/l of elemental nitrogen (N). Water containing as much as 20 mg/l nitrogen or 90 mg/l nitrate is considered harmful to infants it should be noted that nitrates cannot be removed from water by boiling, but must be treated by demineralisation or distillation. Because nitrates in groundwater originate most often from sewage waste, its presence is taken as evidence of contamination (Driscoll, 1986). The use of soakaways for the disposal of domestic and industrial effluents may impair groundwater quality unless there is an impermeable stratum between the disposal area and the aquifer. Similar considerations apply to the siting of reuse tips for both domestic and industrial solid wastes. These potential hazards are much increased if the strata are fissured, since polluted water may rapidly reach the aquifer.

In this study, the nitrate concentration levels vary from 0.089 mg/l to 133 mg/l (could be an analytical error) and with a mean 9.1 mg/l (Tables 4.1 and 4.2). The high nitrate concentration levels of the study area are found at S75 (Shade Hotel) and around Gandu area (Fig Ili in Appendix II and Table 4.1), where the Nairobi Trachytes outcrop (Fig 1.1).

In this study, the minor constituents are defined as Fluoride (F), silica and Fe (Total) These minor constituents are put under this category and discussed.

Silica (SiO₂)

Silicon the most abundant element on the earth's crust may occur in rocks in the form of the oxide silica (SiO₂) (Hem, 1959). When combined with metals, it forms silicate minerals, which are important in the composition of rocks. Thus silica in water is mostly from weathering of silicate minerals (Hem, 1959).

Temperature, rate of water movement through the rock, and natural acids such as carbonic acid affect weathering and the degree to which silica dissolves in water. The principal dissolved silicon species in groundwater at typical pH values (6-9) is Si (OH)₄ (Freeze and Cherry, 1979). Most of the waters in this area of study have pH values ranging from 5.6 to 8.5 (Table 4.1) which are almost coinciding with the above pH values of Freeze and Cherry (1979). In this study area, the high (SiO₂) concentration (Table 4.1 and Fig 1.1, Ili in Appendix II) is found at C 3700 (Bomas of Kenya), at C 11710 (Public Service) and, at S37 (Coopers of Kenya Ltd), and at S53 (Kasarani Sports Club) in Ruiraka Estate. These high silica (SiO₂) concentrations were found at the different formations.

For example Bomas of Kenya and Public Service correspond to Nairobi Trachytes, whereas S53 and S37 are located at the contact of Nairobi and the Middle and Upper Kerichwa Valley Tuffs (Fig 1.1, Iii in the Appendix II and Table 4.1)

Iron (Total Fe)

Most water supplies contain iron because iron is common in many igneous rocks and is found in trace amounts in practically all sediments and sedimentary rocks. Some of the important mineral and mineral groups, which may obtain large amounts of iron, are pyroxene, amphiboles and magnetite (Hem, 1959, Walton, 1970). The amounts of iron present in the waters are so small that they are in the same range as trace constituents that are rarely determined (Hem, 1959).

Iron, which occurs in water at two levels of oxidization (either as bivalent ferrous iron or as trivalent ferric) is reported in the form of total dissolved iron for the purpose of this study. During this study, it has been established that most waters have an iron concentrations, which are below detection limit of 0.0 - 0.89 mg/l. (Table 4.1). In the study area, the high iron concentration levels are found at C12902 (Yaya Centre), at S75 (Shade Hotel) and at C13148 (Forest View Academy) (Fig. IIj in Appendix II and Table 4.1). The Shade Hotel and C 12902 are located within the Nairobi Trachytes, whereas C13148 is located at the contact of Nairobi and the Middle and the Upper Kerichwa Valley Tuffs (Fig 1.1).

Fluoride.

The principal independent fluoride mineral of igneous rocks is fluorite (calcium fluoride). This mineral is a source of fluoride in water but its solubility is low. There is a considerable number of complex fluoride - bearing minerals, the most important of which is apatite. Fluoride is found in igneous and metamorphic rocks as a component of amphiboles, such as hornblende, and of the mica and certain other minerals (Ogege, 2001). In these minerals it replaces part of the OH-groups in the minerals structure (Rankama and Sahama 1950). Alkalic rocks in general and also obsidian are high in fluoride as a class than most other igneous rocks (Hem, 1959). Fluoride is often associated with volcanic fumarolic gases, and in some areas it is probably added to water by such emanations (Ogege 2001). In water and particular groundwater fluoride concentrations of 10 mg/l or more are rare (Hem, 1959). Certain such rare concentrations were recorded in water from different boreholes at different locations in the study area, may be related to geological factors though different boreholes

penetrating an identical formations had different concentrations although being very close to each other (Table 4.1). The US Public Health Services (1962) have recommended 1.5 mg/l as the safe maximum concentration of fluoride in the water of human consumption. Higher concentrations may cause fluourosis. The recommendation has been adopted by WHO (1984). The high fluoride concentration levels are shown on Fig Iik in Appendix II and Table 4.1. The high fluoride concentrations with a mean (9.11 mg/l) are found at C 12824 (Meteorological Department) and at C4001 (British-American Tobacco) (Table 4.1 and Table 4.2)

4.3 Various types of water in the study area

Piper diagrams or vertical bar graphs or contour maps may present data on chemical analysis. For the purpose of this study, Piper diagrams were selected as the most comprehensive graphic methods of presenting the overall chemical and mineral composition of the groundwater in the study area. For analysis using the piper diagrams, data was expressed in milliequivalents (meq). The percentages of reacting values were therefore calculated for each cation and anion variable respectively for all the water samples analysed. The cation variables expressed as percentages of the total cations in (meq) per litre, plot as a single point on the left triangle (Fig 4.7a), while anions similarly expressed as percentages of total anions also appear as a points in the right triangle (Fig 4.7b). The two points on the triangular field indicate the relative concentrations of the several dissolved constituents of the natural water (Piper, 1994). In order to find out the overall chemical character of the water under study, the two points in each of the triangular fields were then extrapolated and projected into the central diamond-shaped area (Fig 4.7c) and third plot was obtained for each of the plots. The plot on the diamond-shaped field is thus uniquely related to the total ionic distribution. The Piper (Trilinear) diagrams conveniently reveal similarities and differences among groundwater supplies in that those waters with similar qualities will tend to plot together as groups. Simple mixtures of two source waters also tend to plot on a straight line on the diagrams. It is therefore easy to distinguish between the various water types of the study area, depending where they plot on the diamond-shaped field (Fig 4.7).

Details of the subdivision of the trilinear diagram are shown in (Fig 4.7). From the plots obtained in the trilinear diagrams, there are three different water types, called:

- Sodium -Potassium waters, which are drawn on sodium-potassium apex (Fig 4.7a).
- Bicarbonate waters, which are drawn on total alkalinity apex (Fig 4.7b).

1. Alkaline earths > alkalis
2. Alkalies > alkaline earths.
3. Weak acids > strong acids
4. Strong acids > weak acids
5. Secondary alkalinity
6. Secondary salinity
7. Primary salinity
8. Primary alkalinity
9. Area of no cation/anion domination

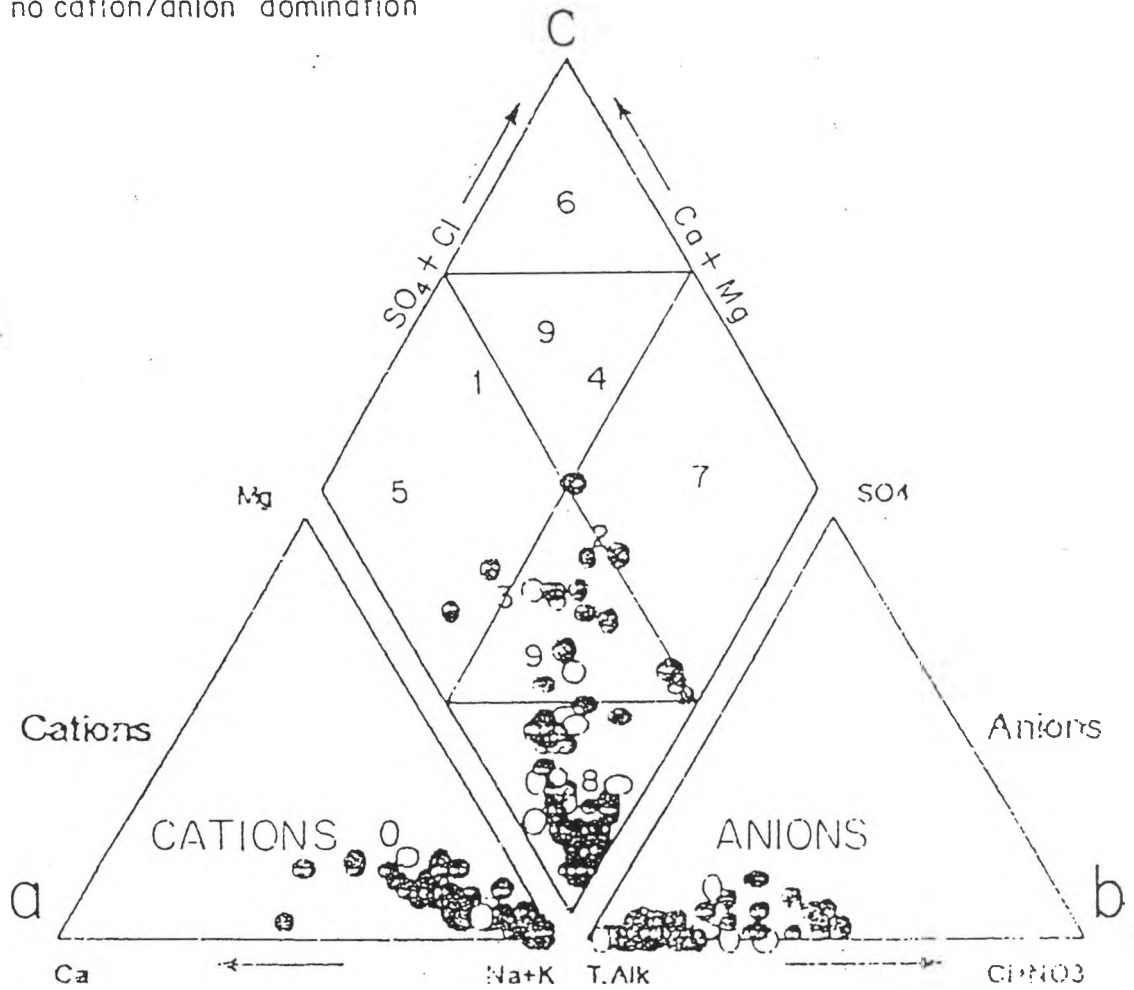


Fig. 4.7 Piper diagram

- And sodium-bicarbonate waters, which are drawn on the lower portion of the diamond-shaped field (Fig 4.7c).

Sodium is thus the most dominant cation. For the anions the diagram shows that carbonate and bicarbonates are the most abundant and dominant anions, projection of the plotted point in the diamond-shaped field (Piper, 1944) in this case plot where alkalies exceed the Alkaline earth's (2) and where the water have weak acids exceeding strong acids (3) and where the waters are basically of primary alkalinity (8) and where there is no dominant cations/anions (9) (Fig 4.7). From results obtained from the trilinear diagram, the groundwaters in the area may therefore be termed are sodium bicarbonate waters. In addition to trilinear diagrams, computations carried out to determine the values of both mean and standard deviation (Table 4.1) confirms the prevailing of Na^+ and HCO_3^- ions.

4.4 Statistical Analysis.

4.4.1 Statistical correlation coefficients Cluster analysis, Principal components and Factor analysis.

The correlation coefficients of all the physico-chemical parameters (Table 4.8) in the water resources of the study area were computed. Each pair of the physico-chemical parameters correlated and then the data shown in table 4.8 was subjected to cluster analysis, whereby the most similar pairs of objects were grouped together. The following clusters were resulted:

The first cluster contains Na^+ and HCO_3^- , which are positively correlated.

The 2nd cluster contains K^+ , Ca^{2+} , Mg^{2+} , NO_3^- , SO_4^{2-} , and Cl^- , which are all negatively correlated.

The 3rd cluster contains only Fe, which is negatively correlated to NO_3^- .

The 4th cluster contains pH, SiO_2 and F^- , which are positively correlated.

Saggerson (1991) analysed mineral composition of the rocks of Nairobi area as follows:

1. Alluvium, clay and swamps soils (Fig 1.1): these are derived from weathering of volcanic tuffs and ashes of mineral compositions of trachytes, which are made of Sanidine (K-feldspar or Orthoclase with chemical formula of $(\text{KAlSi}_3\text{O}_8)$, and phonolites, which are made of Sanidine (K-feldspar). The weathering reaction occurs as follows: $2\text{KAlSi}_3\text{O}_8 + 2\text{CO}_2 + 3\text{H}_2\text{O} \rightarrow 2\text{K}^+_{\text{aq}} + 2\text{HCO}^-_{\text{aq}} + 4\text{SiO}_{2\text{aq}} + \text{AlSi}_2\text{O}_5(\text{OH})_4$.
2. Middle and Upper Kerichwa Valley Tuffs: these are composed of Orthoclase (K-feldspar) and Anorthoclase (Na, K) AlSi_3O_8 or Na-K feldspar, and Plagioclase ($\text{NaAlSi}_2\text{O}_6 + \text{CaMgSi}_2\text{O}_6 + \text{SiO}_2$, and Sod-pyroxene (Na, Ca, Mg or Fe) silicates and Sod-amphibole $\{\text{NaAlCa}_2[\text{Mg, Fe}]_4(\text{Al}_2\text{Si}_6)\text{O}_{22}(\text{OH})_2\}$.

3. Nairobi trachytes are composed of Sanidine (KAlSi_3O_8) and Alkali feldspar (Na-K feldspar) or Orthoclase and Sodium feldspar or albite and Aegirin-Augite (with chemical formulas of $\text{NaFe}(\text{SiO}_3)$ and $(\text{Ca}, \text{Na})(\text{Mg}, \text{Fe}(\text{II})_2, \text{Al})\text{O}_6$ respectively).
4. Nairobi phonolites are composed of Sanidine (KAlSi_3O_8) and Biotite $\text{K}(\text{Mg}, \text{Fe})_3(\text{AlSi}_3)\text{O}_{10}(\text{OH}, \text{F})_{4-2}$, and Na-K feldspar and nepheline $(\text{Na}, \text{K})\text{AlSiO}_4$, and Aegirine $\text{NaFe}(\text{SiO}_3)$ and Augite $(\text{Ca}, \text{Na})(\text{Mg}, \text{Fe}(\text{II})_2, \text{Al})\text{O}_6$.
5. Mbagathi phonolitic trachytes are composed of Sanidine (KAlSi_3O_8) in accessory amounts, Anorthoclase $(\text{Na}, \text{K})\text{AlSi}_3\text{O}_8$, Alkali feldspar (Na, K feldspar) and nepheline $(\text{Na}, \text{K})\text{AlSiO}_4$, Aegirine $\text{NaFe}(\text{SiO}_3)$, Augite $(\text{Ca}, \text{Na})(\text{Mg}, \text{Fe}(\text{II})_2, \text{Al})\text{O}_6$, and Riebeckite $(\text{Na}_2[\text{Fe}, \text{Mg}]\text{SiO}_{22}(\text{OH})_2$.
6. Athi Tuffs and Lake Beds: These are composed of Obsidian (volcanic glass of rhyolitic composition and plagioclase feldspar (Na-Ca feldspar).

Rainwater contains dust and atmospheric gases, including CO_2 . While passing through the soil the water becomes enriched by biogenic CO_2 , which enables it to decompose and dissolve silicates, olivine, orthoclase, mica, and clay minerals. These decomposition processes take place in the soil horizon. Through the aerated zone and finally in the aquifer (Garrels, 1976).

Therefore, the source of sodium is either from the decomposition of Na-K feldspars or from plagioclase. The source of K is either from biotite or from hornblende, which are all found in the study area. The source of calcium is either from plagioclase feldspars or from pyroxenes, which are all, found in the study area. The source of Mg is either from biotite, amphibole, and pyroxenes or from olivine. The source of fluoride could be from the mineral decomposition of biotite. The source of HCO_3^- may come from weathering of Na-K feldspars, or it comes from hornblende, and the remaining bicarbonate comes from Ca-component of the plagioclase feldspars.

The results of the physico-chemical parameters of the groundwater of the study area (Table 4.1) indicate that the dominant cation is Na^+ and the dominant anion is HCO_3^- . The results of the descriptive statistics for all the hydro-chemical parameters of the study area (Table 4.2) reveals that the Na^+ has the highest mean for the cations whereas, HCO_3^- and show the highest mean for the anions.

The results of the statistical correlation coefficients of all physico-chemical parameters of the groundwater of the study area (Table 4.8) indicate positive correlation between Na^+ , HCO_3^- . The results of the Principal Component and Factor analyses of the

physico-chemical parameters of the groundwater of the study area (Table 4.9) indicate a significant and positive correlation between Na^+ , HCO_3^- . The results of the major cations/anions of the groundwater of the study area (Fig 4.7) indicate Sodium-Potassium Waters on Sodium-Potassium apex of the cation trilinear field (left or a). It indicates also bicarbonate alkalinity waters on T.alk apex of the anion trilinear field (right or b). It indicates also Sodium-bicarbonate waters on the lower portion of the diamond-shaped field (centre or c).

Therefore, as the above various results of the data concerned the major cations/anions that characterise the groundwater of the study area, are very unique throughout the results. Therefore, the geochemical evaluation of waters in volcanic terrains of this study is primarily controlled by silicate hydrolysis: Silicate hydrolysis can be illustrated by the reaction of the feldspars with water and aqueous CO_2 as follows:

$\text{NaAlSi}_3\text{O}_8 + 2\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{Na}^+ + \text{HCO}_3^- + 3\text{SiO}_2(\text{aq}) + \text{Al}(\text{OH})_3(\text{ppt})$. Similar equations can be written orthoclase and anorthoclase. The hydrolysis of fine-grained silicate minerals, pyroclastics or glasses in the rift volcanics takes place rapidly, producing bicarbonate-rich waters with silica content and leaving alumina behind in clays or residual gels (Eugster and Jones, 1968).

The table 4.9 indicates that the first principal component/factor score accounted for (79%) of the total variance showing positive loading for (Na^+ and HCO_3^-). The second principal component/factor score that is quite significant accounts for (8.7%) and indicates positive loading between HCO_3^- , Cl^- and NO_3^- , which are negatively correlated to Na^+ .

Factor 1, which accounts for (79%) of the total variance, is characterised by positive loading of Na^+ and HCO_3^- . These ions are significant in factor 1 and correlate well with each other. These ions are derived from the interaction of Na-K feldspars and the percolating water, which becomes enriched with CO_2 , while passing through the soil.

Factor 2, which accounts for (8.7%) of the total variance, is characterised by positive loading of HCO_3^- , Cl^- and NO_3^- . HCO_3^- could be derived from meteoric water. The most probable source of Cl^- is the water containing in rocks. NO_3^- could be driven from the soil or from the uppermost weathered rock through infiltration. Na^+ is inversely correlated to the above-said ions. This correlation contrast suggests that these ions have derived from different sources.

Table 4.8: Correlation Coefficient Values Calculated for 12 Parameters in Groundwater Samples in Nairobi Area.

	Na mg/l	K mg/l	Ca mg/l	Mg MG/L	Fe Mg/l	SiO ₂ MG/L	T.ALK MG/L	pH	F mg/l	SO ₄ mg/l	NO ₃ (mg/l)	Cl mg/l
Na mg/l	1.000	.180	-.126	-.241*	-.042	.075	.868*	.413*	.201	.567*	.116	.135
K mg/l	.180	1.000	.402*	.530*	-.070	.000	.290*	-.347*	-.376*	.399*	.464*	.377*
Ca mg/l	-.126	.402*	1.000	.477*	.069	-.029	-.033	-.193	-.213	.253*	.352*	.288*
Mg mg/l	-.241*	.530*	.477*	1.000	.111	-.248*	-.075	-.496*	-.403*	.206	.416*	.137
Fe mg/l	-.042	-.070	.069	.111	1.000	-.180	-.052	-.034	-.111	.072	.238*	-.169
SiO ₂ mg/l	.075	.000	-.029	-.248*	-.180	1.000	.159	.346*	.254*	-.271*	-.219	-.051
T.Alk mg/l	.868*	.290*	-.033	-.075	-.052	.159	1.000	.402*	.016	.376*	-.020	-.019
pH	.413*	-.347*	-.193	-.496*	-.034	.346*	.402*	1.000	.538*	-.066	-.404*	-.053
F MG/L	.201	-.376*	-.213	-.403*	-.111	.254*	.016	.538*	1.000	-.206	-.184	-.044
SO ₄ (mg/l)	.567*	.399*	.253*	.206	.072	-.271*	.376*	.206	-.206	1.000	.495*	.450*
NO ₃ mg/l	.116	.464*	.352*	.416*	.238*	-.219	-.020	-.404	-.184	.495*	1.000	.251*
Cl (mg/l)	.135	.377*	.288*	.137	-.169	-.051	-.019	-.053	-.044	.450*	.251*	1.000

*Correlation is significant at the 0.05 level (2-tailed)

Table 4.9 Loading for each variable on each of the five factors for the groundwater samples in Nairobi area

Variables	Factor1 79%	Factor2 8.7%	Factor3 4.92%	Factor4 3.7%	Factor5 2.4%
Na Mg/l	0.34	-2.021	.153	.571	-.415
K mg/l	-.001	.037	-.002	.010	-.007
Ca mg/l	.044	-.126	-.131	-.070	-.080
Mg mg/l	.000	.022	.001	.000	.015
Fe mg/l	.000	.000	.000	.000	.000
SiO ₂ mg/l	-.08	-.239	.049	.107	.992
HCO ₃ ⁻	.670	1.940	-.178	-.613	.340
Cl mg/l	-.015	.428	.991	-.313	.081
F mg/l	.001	-.033	-.006	.005	.001
SO ₄ mg/l	.017	-.051	.019	.013	-.042
NO ₃ mg/l	.010	.519	-.058	.951	.277
PH	.000	-.001	.000	.000	.000

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalisation.

CHAPTER 5 INTERPRETATION AND DISCUSSION

5.1 Overview of the Geochemistry

The results obtained in the previous chapter (4) have been compared with the results of the international averages (WHO, 1984) for unpolluted water. The results give maximum permissible levels for drinking, irrigation and industrial waters. The physico-chemical analyses and statistical analyses carried out in the study area were basically limited to borehole water samples (groundwater). As earlier indicated in section 4.3.1 the overall chemical environment, which determines the whole system, can be viewed from the principal components (see Table 4.9).

Jones (1966) suggested that the composition of alkaline waters in closed basins is chiefly the result of weathering reactions, or simply to the hydrolysis of silicates by CO₂ - charged waters as shown below: -



The primary silicates react with CO₂ -charged water, i.e. soil water, a clay mineral is formed that remains in the soil profile, and cations, HCO₃⁻, and SiO₂, are released into solution. Garrels and Mackenzie (1967) have shown that if this type of water is isolated and concentrated by isothermal evaporation in equilibrium with the earth's atmosphere, it produces a highly alkaline Na- HCO₃⁻ - CO₃ water.

5.1.1 Major Constituents

The data obtained in this study cannot agree more with the observations noted above. The most abundant cation is sodium (with a mean of 80.12 mg/l) while the second most abundant cation in the study area is potassium (with a mean of 9.1 mg/l). Calcium is the third abundant cation (with a mean of 8.5 mg/l), while magnesium is the least abundant. For the anions, bicarbonate is the most abundant while nitrates, sulphates, and chlorides occur relatively in small amounts. If the concentrations of several dissolved constituents are measured in terms of percentages of reacting value (according to their equivalents per million, expressed as sum of the equivalents of all the constituents) then the subtotals of the cations and anions should be necessarily be 50-50% in (Fig 4.7). Piper (1944) noted that since there are three variables among the abundant anions, it is possible to plot them on a

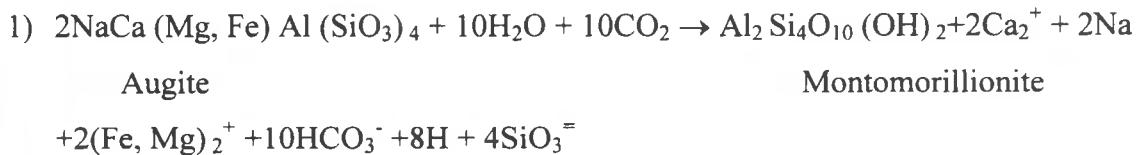
triangular field. The cations likewise can be grouped into three variables and plotted on another such triangular field.

- Given that the cation-anion relationship is (50-50) % of the total reacting values for Piper diagram, the total chemical character of the water can thus be represented graphically by a single point plotting on trilinear axis or co-ordinates.

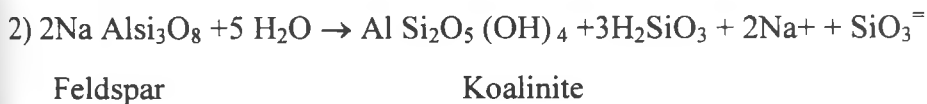
Therefore, bicarbonate and sodium ions were the most abundant and dominant of all the cations and anions with mean concentrations of 188.1 mg/l to 80.1 mg/l respectively (Table 4.1 and 4 .2).

The major source of CO₂ is the biota and other bacterial activities within the soil, and from other deeper formations like volcanic exhalations. This CO₂ is one of the major sources of bicarbonate and carbonate levels in the groundwater. Many authors have suggested that sodium carbonate may be produced from selective leaching of silica (Garrels and Mackenzie, 1967; Jones and Retting, 1976) from basic silicate rocks, and especially "mafic (dark igneous rock containing iron and magnesium) mineral alteration of pyroclasts augite (a dark pyroxene, an essential constant of many basic igneous rocks) or silica intrusive rocks". Jones reports examinations of the basin rocks "of lacustrine deposits of the western Great Basin showing that feldspars are not changed too but the mafic components of igneous (solidified from molten material) rocks have been extremely altered or completely broken down"

He assumes that the following reaction take place:



Van Denburgh and Philips (1971) also considered the following reaction to explain silicate solubilization in rivers and groundwater, and broadly stated "widespread silica extrusive rocks in the various Oregon basins are an ample source of sodium, potassium and silica"



Another mechanism commonly proposed for soda ash formation of companion ions is that of ion exchange. Some naturally occurring minerals such as clays, zeolite, feldspars, and

Silica (SiO₂)

Silicon the most abundant element on the earth's crust after oxygen may occur in rocks in the form of the oxide (SiO₂), (Hem, 1959). Silica species in groundwater are derived from the dissolution of igneous minerals and of their weathering products. They do not readily dissociate into ions but occur mainly in the undissociated form. The principal dissolved silicon species in groundwater at typical pH values (6 to 9) is Si (OH)₄ (Freeze and Cherry, 1979). Similarly in this work, most of the waters contain pH values ranging from 5.6 to 8.5 and almost coincide with the pH values of Freeze and Cherry in 1979. All the waters of the study area recorded silica concentration levels ranging from 10 mg/l to 100 mg/l and with a mean of 58.8 mg/l (Tables 4.1 and 4.2). The high silica concentrations are shown in (Table 4.1 and Fig Iii in Appendix II). The relationship of geology and the water chemistry appears significant, the leaching of the volcanic terrains in the study area to enable the release of SiO₂ into water is apparent.

Iron (Fe)

Most water resources contain iron, because iron is common in many igneous rocks and is found in trace amounts in practically all sediments and sedimentary rocks. In sedimentary strata iron occurs in its ferrous (bivalent) form, or as ferric (trivalent) hydroxide or oxide in a mixed ferric-ferrous form. Ferrous iron is a common constituent of bog and swamp deposits, lignites and coal (Driscoll, 1986, Mandel and Shiftan, 1981). Some of the important mineral and mineral groups, which may obtain large amounts of iron, are pyroxene, amphiboles, magnetite, hematite and siderite (Hem, 1959; Walton 1970). When water is exposed to air, the dissolved iron rapidly oxidises, turning the water dark. Dissolved ferric iron precipitates in the form of floccules Fe (OH)₃ that are difficult to remove. For this reason, minute amounts of iron in water are undesirable, which occurs in water at the two levels of oxidation (either as bivalent ferrous iron or as total dissolved iron).

During this study, it has been observed that most waters have an iron concentrations ranging from 0 - 0.89 mg/l. According to WHO (1984) the highest desirable level of iron for drinking water is set at 0.3 mg/l. According to the recommended levels of iron, only five borehole water samples exceeded the recommended limit. These high concentration levels are found at C12902 (Yaya Centre), at S75 (Shade Hotel), at S 38 (Vet farm U.O.N), at C13148 (Forest View Academy) and at C 12664 (Brae bun School) (Table 4.1 and Fig IIj in Appendix II). High iron content in groundwater could indeed also be attributed to the process

of infiltration through which the rainwater passes through the extensive lateritic capping within the study area.

Fluoride

The principal independent fluoride mineral of igneous rocks is fluorite (calcium fluoride). This mineral is a source of fluoride in water but its solubility is low (Hem, 1959). There are a considerable number of complex fluoride-bearing minerals, the most important of which is apatite. Fluoride is found in igneous, metamorphic and sedimentary rocks as a component of amphiboles, such as hornblende, and of the mica and certain other types. In these minerals it replaces part of the OH-groups in the mineral structure (Rankama and Sahama, 1950). Fluoride is often associated with volcanic fumarolic gases, and in some areas it is probably added to water by such emanations. Fluoride is an important constituent of drinking water because it is taken up by the human body and incorporated into teeth and bones. Excessive fluoride concentrations, however, are toxic.

In water and in particular groundwater fluoride concentrations of 10 mg/l or more are rare (Hem, 1959). Such rare concentrations were recorded in water from different boreholes at different locations in the study area may not be related to the geological factors since different boreholes penetrating an identical formations as assumed by Njenga (1982) had different concentrations although being very close to each other.

Here in this study area, the same problem exists, as far as some neighbouring boreholes exhibit different fluoride concentrations (Table 4.1). Therefore, it is not easy to point out the real cause of the problem, but it can be assumed to be related to a certain fluoride-bearing strata, which penetrate into different formations of different depths, whereby the water extraction depth changes along these formations, which result the different fluoride contents within neighbouring boreholes.

The U.S. Public Health Services (1962) has recommended 1.5 mg/l as the safe maximum concentration of fluoride in water for human consumption. Higher concentrations may cause fluorosis. The recommendation has been adopted by WHO (1984). In this study, the fluoride content varies from 0.19 mg/l to 13.0 mg/l (Table 4.0 and Fig IIk in Appendix II). The statistical analyses of fluoride in these waters generally indicate high fluoride levels. A quite significant number of (61) boreholes of the study area, however, recorded values falling above the recommended range of 1.5 mg/l. The remaining nineteen (19) boreholes of the study area are suitable for human consumption.

5.2 Relationship of the groundwater quality to use.

The suitability of water with respect to use, to which it is accounted for, is generally governed by the quality of the water itself. The requirements for drinking water, industrial water or irrigation water do vary widely (Todd, 1980). An analysis of the various bodies and organizations have recommended and laid down standards of permissible amounts of impurity with regard to all the above-said factors e.g.

- WHO= World Health Organisation
- USPHO=United States Public Health Organisation
- APHA=American Public Health Association
- WPCF=Water Pollution Control Federation

Comparing the laboratory and field analysis data obtained from the study area with the maximum limit levels for the various chemical constituents, the results reveal that most boreholes have cation contents i.e. (sodium, potassium, calcium and magnesium) that are within the acceptable levels of WHO (Table 4.7). High content for some of these cations, and anions are however common among groundwaters. From the above discussion and by examining the various chemical constituents, iron (Fe) has a mean of 0.2 mg/l in the study area. These values may not pose any toxicity fear to consumers.

Generally, most underground waters are known to have high fluoride concentrations. This has happened particularly in Nairobi area where most boreholes had to be sealed down. The statistical analysis of fluoride concentration levels in the study area range from 0.19 mg/l to 13.0 mg/l.

The source minerals of fluoride occur in igneous, metamorphic and sedimentary rocks. Fluoride compounds are common constituents of volcanic exhalations. Fluoride is an important constituent of drinking water for the human body. It is usually incorporated into teeth and bones. Excessive fluoride concentrations however are toxic (Mandel and Shiftan, 1981).

The fluoride contents in the study area do not agree the recommended limits in most of the boreholes in the study area, because it has a range that doesn't befit the desirable range of 0.9 mg/l to 1.5 mg/l, which is essential for, drinking purposes as given by WHO (1984). Some boreholes recorded fluoride values below the lowest permissible level of 0.9 PPM. Despite the fact that some of these values are outside of the recommended range, and they are no longer within tolerable range. Water from these boreholes may instead be used for washing or watering plants.

Basically, all the water resources in the study area are suitable for irrigation purposes. The quality of water for livestock consumption is equally important. The threshold concentration set by the California State Water Quality Control Board in 1963 (Tebbut, 1983) require that calcium should be 500 mg/l, magnesium (250 mg/l), sodium (100 mg/l) bicarbonate (500 mg/l), and sulphate (50 mg/l), and that of chloride 1500 mg/l and 1 mg/l for fluoride. Except for sodium and fluoride, which are found above the recommended level in the study area, all the other constituents in the groundwater do fall within the recommended level for livestock quality.

A comparison of the total hardness values (Table 4.4) and the water of the study area indicate that the groundwater resources of this area are generally soft to moderate. Indeed, all of the hardness values recorded are below the acceptable 500-ppm level for drinking water and also for most industrial purposes.

5.2.1 Water for domestic use (potable water)

According to AWWA (1971), potable water is one that may be consumed in any desired amount without concern for adverse effects on the health of the consumer. Water for drinking purposes must therefore meet very high quality standards of physical, chemical and biological purity. Such water must be free from pathogenic micro-organisms, minerals, and substances capable of producing adverse physical effects (APHA, AWWA and WPCF, 1980). The water must therefore be aesthetically acceptable i.e. it must be free from turbidity, colour, odours and all objectionable taste and it should also be of reasonable standard for potable water as provided by WHO (Table 4.7)

These acceptable standards vary from country to country depending on economic prosperity, experience, climate, and geographic position (Llyod and Heathcote, 1985). The standards tend to change with time as medical information becomes available, so that any set of standards can only be considered as a guide and they are rarely legally binding. Thus separate standards have been developed for certain uses. The Kenya Government water laws governing the quality of drinking and recreational waters coincide with 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 (WHO, 1992, Talsma and Philip, 1971).

Table 5.1: Water classification based on TDS (Source: APHA, AWWA and WPCF, 1989).

Type of water	Concentration of TDS (PPM)
Fresh	1000
Brackish	1000-10,000
Salinity (Saline)	10,000-100,000
Brine	>100,000

Comparing the waters of the study area with the above classification, the waters of the study are mostly fresh and brackish (Table 5.1) and thus some of the water boreholes are then suitable for the most intended domestic purposes in terms of TDS classification. But the high fluoride contents in Nairobi borehole waters, is not recommended for human consumption. But, the use of water on the farm for non-domestic purposes includes the water for livestock, irrigation and operating of machinery. Fluorides do not seem to have serious effects on livestock and irrigation water. However, the total dissolved solids and sodium-salinity hazards have been reported to have tremendous effects on livestock and irrigation respectively (Mailu, 1983).

5.2.2 Water for industrial use.

The quality requirements for industrial water supplies have a wide range and almost every industrial application has different standards from the other. In some cases, the intended use may have specific needs, which will be reflected in the water standard that is imposed. Thus, separate standards have been developed for certain industries. Although, in certain places such as single-pass condensing or, cooling, or for the concentration of ores, chemical quality is not particularly critical, and almost any water may be used (Mailu, 1983). However, water approaching the quality of distilled water is required for processes such as manufacture of high-grade paper and pharmaceuticals, where impurities in the water used would seriously affect the quality of the product. Considering the above-said requirements, Hem (1959) has suggested that reports intended for use by the specialised needs of specific types of industry, should present facts and interpretations of general nature that can be further studied by those that have special requirements. The quality of water recommended depends; therefore, upon types of industry, the use of the water and quality of product desired (Table 5.2). A single water quality standard cannot be set for water to be used for the various industrial purposes (Mathess, 1982)

Some important concerns in the quality of water for industry are generally corrosiveness, hardness content of iron, manganese and silica content, turbidity, colour and TDS. Water used for food processing must meet WHO standards for potable water (Ogege 2001). The water resources in the study area meet most fundamental requirement for the general industrial uses.

Table 5.2: Water quality criteria for industrial use (Source: Driscoll, 1986).

Food Product	Turbidity NTU	Colour TCU	Hardness PPM CaCO ₃	Alkalinity as (PPM) CaCO ₃	Fe ⁺ + Mn (PPM)	TDS	Others
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
Confectionery	-	-	-	-	0.2	100	A
Ice	5	5	-	30-50	0.2	300	A,C
Laundering	-	-	50	-	0.2	-	C
Manufactured products							
Lather	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	5	20	20	-	0.25 0.5	- -	F -

Legend

- SHD - Some hardness desirable
- A - Must conform to standards for potable water
- B - NaCl-- - 275 ppm
- C - SiO₂, Ca - and Mg - HCO₃ are troublesome, Sulphate and Chlorides for Na, Ca and Mg each – 300 ppm
- D - No slime formation
- E - Non - corrosive
- F - Constant composition, residual aluminium not more than 0.5 ppm.
- NTU - Nephelometric turbidity unit
- TDS - Total Dissolved Solids
- TCU - True colour unit

5.2.3 Water for Agricultural Use.

The largest single agricultural use of water is irrigation (Camp, 1963) in the agricultural sector water can also be used for watering and caring for livestock and poultry. Water for agricultural use depends on the influence of the waters on the soil and on the crop, on climatic factors, and on irrigation methods.

According to the U.S. Salinity Laboratory Staff (1954), low-salinity water zone (C1 in Fig 5.1) can be used for irrigating most crops on most soils with little likelihood that soil salinity will develop, but none of the water samples of the study area correspond to this zone.

Medium-salinity water zone (C2 in Fig 5.1) can be used if leaching is moderate. Plants having a moderate salt tolerance can be generally be grown without special salinity control, but none of the study water samples fall in this zone.

High-salinity water zone (C3 in Fig 5.1), to which only two samples of the study area belong to, can't be used on soils having restricted drainage. Even with adequate drainage, special salinity control may be required, and plants having high salt tolerance should be selected.

Very-high salinity water zone (C4 in Fig 5.1) is not suitable for irrigation under ordinary conditions, but it may be used occasionally under very special circumstances. The soils must be permeable, the drainage must be adequate, the irrigation water must be applied in excess to provide considerable leaching, and the water can be used to irrigate only those crops that have very high tolerance for salt. All the water samples of the area with the exception of two samples of the study area belong to this class.

The Low-sodium Water zone (S1 in Fig 5.1), to which most of the water in Nairobi area belongs to, can be used for irrigation on almost all the soils with little danger of the development of harmful levels of exchangeable sodium, but sodium sensitive crops may accumulate injurious concentration of sodium.

Medium-sodium Water zone (S2 in Fig 5.1) presents an appreciable sodium hazard on the fine-textured soils having high cation exchange capacity, especially under low-leaching conditions, unless used on coarse-textured or organic soils having a moderately high permeability.

High-Sodium Water zone (S3 in Fig 5.1) may produce harmful levels of exchangeable sodium in most soils and requires special soil management, good drainage, high leaching, and addition of organic matter. Gypsiferous soils may not develop harmful levels of exchangeable sodium from this water.

The very-high-Sodium Water zone (S4 in Fig 5.1), which is represented in Nairobi water, is generally unsatisfactory for irrigation except at low and perhaps medium-salinity, where solutions of calcium from the soil or the use of gypsum other amendments may make the use of these waters feasible. The irrigation water may sometimes dissolve sufficient calcium from calcareous soils to decrease the sodium hazard appreciably, and this possibility should be taken into account in the use of (C1- S3 and C1- S4 in Fig 5.1) water. For calcareous soils of having high pH or for non-calcareous soils, the sodium status of water in classes C1- S3 and S4 – and C2 – S4 may improved by the addition of gypsum. It may also be beneficial to add gypsum to the soil periodically if C2 – S3 and C3 – S2 water is used for irrigation. It will be noted that the major constraint of the ground water in most parts of the Nairobi City is its high salinity hazard as the sodium hazard is predominantly high. This water cannot be used on soils having restricted drainage. Even with adequate, special salinity control may be required; and plants having high salt tolerance should selected.

High sodium concentrations are undesirable in water because sodium adsorbs onto soil cation exchange sites, causing soil aggregates to break down (deflocculation), sealing the pores of the soil, and making it impermeable to water flow. The tendency for sodium to increase its proportion on cation exchange sites at the expense of the other types of cation is estimated by the ratio of sodium content to the content of calcium plus magnesium in the irrigation water.

This is called the sodium adsorption ratio (SAR), and is defined by the relationship:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

Where Na, Ca, Mg are in mg/litre.

5.2.4 Water for livestock use

Table 5.3 summarises the salinity limits and daily consumption for stock as derived from the recommendations of the New South Wales Department of Agriculture (Berkman, 1976)

The water quality standard for animals may vary depending upon the types of stock, the size or age and the feeding habits.

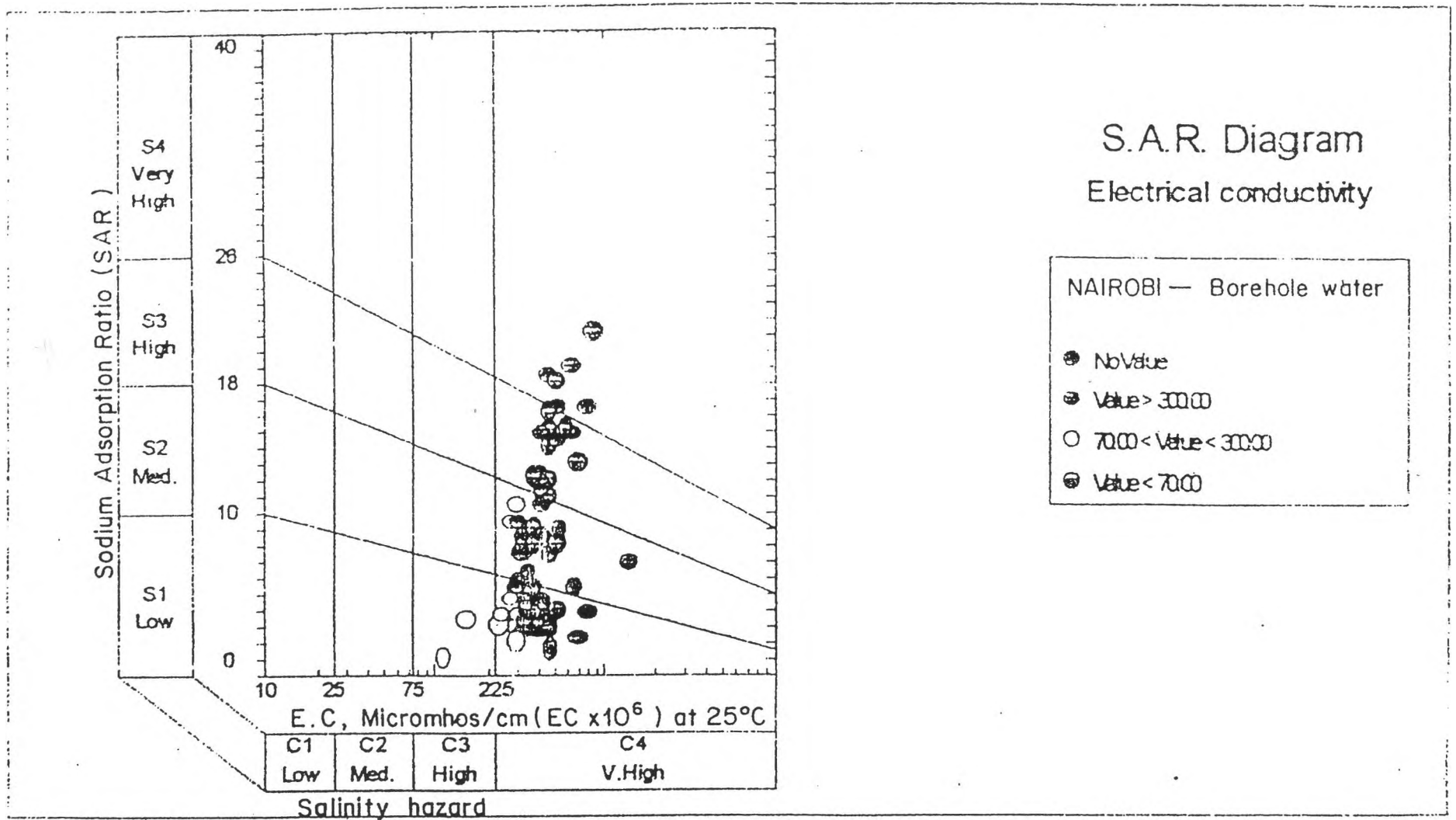


Fig. 5.1 Classification of irrigation waters based on S.A.R and conductivity.

Table 5.3 - Salinity Limits and Daily consumption for Stock (Source Robert, 1996).

Stock Type	Upper Limit of Salinity in mg/l	Daily consumption L/head
Sheep (dry pasture)	14000	6.8
Sheep (irrigated pasture)	14000	3.4
Lambs (dry pasture)	<14000	2.3
Lambs (irrigated pasture)	<14000	1.1
Beef cattle (irrigated pasture)	10000	45.5
Calves	<10000	22.7
Dairy cattle (Lactating)	5000	68.2
Dairy cattle (dry)	7000	45.5
Horses (working)	6000	54.5
Horses (grazing)	7000	36.4
Sows	6000	22.7
Pigs	6000	11.4
Poultry (100)	4000	3.2

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Introduction

The previous chapters have examined and discussed the various aspects of the groundwater geochemistry, as stipulated in the objectives of this study. This chapter, therefore, reviews and summarises the various conclusions that have been arrived at and further attempts to put forth some recommendations with respect to water quality in this area.

6.1.1 Conclusion.

Generally, the geology of the area consists mainly of the Athi Tuffs and Lake Beds, which are overlain by the Nairobi phonolites and trachytes respectively. This sequence is again overlain by volcanic tuffs. The amount of water held by a given formation in this area is dependent upon the amount of groundwater recharge and the extent of permeable rock outcropped. It has been observed that, basically, recharge occurs locally in all parts of the study area where rocks of favourable permeability are exposed and where rainfall is substantial. The major aquifers are the Athi River and Lake Beds at the bottom of the series. Other sources of the water are in the weathered zones representing old land surfaces and also superficial deposits overlying the lakes at the top of the series. The trachytes, phonolites and tuffs give no water supply unless they are weathered and fractured. The tuffs may to some extent be porous but they do not transmit water. Depths of water as evidenced in borehole data indicate the groundwater profile is closely related to topography of the area. The flow direction of groundwater varies from recharge to discharge areas, which is controlled by the geology and topography of the area except for cases where faulting may have occurred.

The chemical data obtained from this study have been subjected to statistical analysis. Correlation coefficient, factor analysis and principal component analysis have been used in order to interpret and characterise the groundwater behaviour. Based on the above analyses, the study area has been established to be having a groundwater composition of (field number 2) except two samples, which fall on field (1) (see Fig 4.7). Trilinear (or piper) diagrams have been used to indicate the types of water in this area. A plot of the concentrations of the major constituents on the trilinear diagrams has revealed that the groundwater of this area may be termed as sodium-bicarbonate waters. Statistical analyses of the results using

PCA/FA component revealed that the first two components could be represented to determine the completely chemical environment driving the entire system.

The first chemical association contains (Na^+ and HCO_3^-) which are positively correlated to each other and accounts for 79% of the total variance. The 2nd chemical association consists of HCO_3^- , Cl^- and NO_3^- , which are negatively correlated to each other but inversely correlated to above-said ions.

The groundwater resources in this area are found to be suitable for most intended purposes of agricultural and industrial uses though there are high fluoride contents, which are troublesome for human consumption.

From the results and discussions, it has been established that geology and climatic factors can in general, determine either directly or indirectly, the type and content of the chemical constituents of the water. Many of the boreholes sampled in this study recorded fluoride concentrations above 1.5 mg/l. Indeed, the mean concentration of fluoride in the waters was 5.5 mg/l, which exceeds the WHO (1984) recommended limit for drinking water. Minor cases of surface and groundwater pollution involved the decomposition of vegetation residues, animal wastes, detergents, human dirt and to some extent, agricultural inputs through fertilisers.

Man-made sources of nitrate pollution are likely to have come from agricultural fertilisers, urban effluents, solid waste disposal, and concentrations of livestock. Sometimes the mere lowering of the water table may expose organic matter, such as bog deposits, to air and thus induce nitrogen pollution.

Some of the important objectives of water analysis in any given area are:

- To determine the suitability of the water for its intended use and to establish the degree of treatment necessary prior to its uses and generally,
- To provide information on the present quality of the water resources of the area which can then be used to demonstrate future changes in the quality.

Based on the principle objectives outlined above, there is evidence for traces of contamination by anthropogenic activities in the area. As the area of the study gets more urbanised and developed, interference on the environment is inevitable and this may affect the water quality in time.

However, with time and space, and with increasing human intervention on the environment (through farming, exploitation of mineral and water resources, human settlement, industrialisation, etc.), the groundwater physico-chemical properties and quality in this area are bound to change. In the event of future investigations of the geochemical

properties of groundwater resources in this area, the results of the present study area envisaged to provide useful base information.

6.1.2 Recommendation

Some chemical constituents such as fluoride and TDS do occur in excess of the recommended WHO levels for drinking water in some cases. Such boreholes where levels of these constituents exceed the required standards need some kind of treatment to check the level of the elements. Most values for fluoride of the study area are above the WHO (1984) recommended range of 1.0 to 1.5 ppm for drinking water quality. These high concentration levels pose serious health problems to the consumers, and require remedial measures to be taken to correct the accepted healthy fluoride levels in the waters. This can be done by using resins to remove toxic ions from the aqueous phase through ionic exchange processes with relatively harmless ions held by the ionic species from water including anionic or cationic soluble metallic elements, inorganic anions, organic acids if at an alkaline pH, and organic amines when solution acidity is favourable for the formation of the acid salt. Excessive fluoride causes mottling of tooth enamel, brittle teeth and if acute, may cause skeletal fluorosis. These effects are more evident in children who drink too much fluoridated water while their permanent teeth are still growing (Driscoll, 1986). However, it should be noted that optimum levels of fluoride are known to be beneficial in preventing tooth decay.

Sodium level should also be checked in some boreholes, which have SAR levels reaching between 26 – 40. These high values indicate that the waters are unsuitable for irrigation use. Groundwater containing high concentration of sodium is alkaline (pH values of 9 or more). The pH can however be reduced by use of water treatment pH stabilisers. Precipitation of suspended sediments in water may also be speeded up by addition of “alum” [$\text{Al}(\text{SO}_4)_3 \cdot 18 \text{H}_2\text{O}$ or $\text{Al}(\text{OH})_3$, or even $\text{Fe}(\text{OH})_3$] water treatment coagulants that are commonly used in water treatment works for sedimentation.

Silica, even though it occurs in levels below the recommended limits for drinking and irrigation water, it should all be monitored if the water is intended for industrial purposes. In the case of silica, the eminent problem is in scale build-ups. It is important to note that silicate scale cannot be removed by dissolution with acids or other chemical used for such treatment. Colloidal materials such as aluminium silicates and other hydrous metal oxides and suspended substances may be treated by sodium zeolite softening if their concentrations are not high [because removal of multivalent cations in softening processes stabilises the

colloids]. If the concentration of colloids is high, then a combination of coagulation, purification and filtration methods can be used. Ultra filters can also be adopted in the removal of colloids (Ogege, 2001).

Therefore if groundwater is being used as the only source of water for households and stock watering, as is the case in many rural areas, care should be taken to understand its quality. Groundwater is different from surface water in that if it is polluted it is often difficult or impossible to clean it and pollution problems may persist for many hundreds of years.

Many remediation attempts in various parts of the world have been extremely costly. At present, in many countries the approach is to prevent pollution from occurring rather than, allowing limited degradation and trying to maintain the water quality at a given standard, or trying to clean up the groundwater after pollution has occurred. Therefore monitoring forms of groundwater is essential whenever the water forms an important source or where there are human activities that may generate substances that are harmful to groundwater. Hence the following steps of monitoring should be taken:

1. Water level monitoring: this is the collection of groundwater depth measurements over time.
 - Water level draw down and groundwater use
 - Recharge relationships with rainfall.
 - Shape of the water table and groundwater directions (minimum of three boreholes are necessary)
2. Water quality monitoring: this is the collection of groundwater quality data over time.
 - Ambient trend – this involves time and space trends in a groundwater basin.
 - Source – measurements of effluent quality and quantity from discharge sources, which may affect the groundwater. The most important sources must be identified. This implies that connection or relationship between surface water and groundwater exists. Tracer studies may be needed to prove or show the extent of this relationship.
 - Research – into groundwater, pollution occurrences and movement.

The fore-mentioned steps should be targeted where groundwater is being used for human consumption e.g. Nairobi City to ensure that the water quality remains as desired. In some cases it may be necessary to monitor water quality for animal consumption as well. Monitoring is also necessary in the vicinity of waste disposal dumpsites; to monitor possible

leachate that may be entering the groundwater from such dumps. Other sources that may need to be monitored include industrial petroleum refinery areas. Therefore monitoring wells should be constructed with specified information of:

- Well diameter
- Well depth
- Piezometer installation
- Casing and screens

The monitoring frequency of the wells should depend on the seriousness of the expected identified problem and the budget. Because many parameters in the natural environment vary seasonally, it is important to synchronise monitoring with season. Once the frequency is decided on, sampling should be taken at the same time each year to eliminate seasonal influences for example; monitoring results from the season can be compared for a number of years. This is also important for comparison with other data such as rainfall and recharge characteristics, which may influence the chemistry of the groundwater.

It is of great importance in the planning and developing of our water resources to carry out by carrying such detailed studies in order to improve the environment problems of the City of Nairobi. It should be noted that such detailed studies are essential in the facilitation provisions of potable water in good quantities to our people as well as towards sustaining our environmental balance. Future hydrogeochemical studies in this area and the surrounding regions are recommended.

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Appendix I

Table AI: River-water Discharge values of Nairobi area (After Masibo, 1990)

River	Variation of Discharge values along rivers and their causes	Amount Discharged
NGONG (upper Reach)	At Kibera	0.0403 m ³ /sec
NAIROBI (upper Reach)	At Westland	0.204 m ³ /sec
GITAHURU (upper Reach)	At spring valley	0.124 m ³ /sec
RUIRUAKA (upper Reach)	Ruaka	0.097 m ³ /sec
NGONG (upper Reach)	Between Ngong and Kibera Between Ngong and South B It is possible that the river has lost some of its water to groundwater at the contact between the tuffs and phonolites between the two stations leading to reduction of discharge values	2.05 m ³ /sec 0.161 m ³ /sec
NGONG	Between Ngong and Doonholm after the river had flowed through the industrial area. There was an increase of discharge value which could be attributed to the factory effluents	0.803 m ³ /sec
NGONG (Lower Reach)	Between Ngong and Kayole	0.817 m ³ /sec
"	Between Ngong and Njiru There was another decrease in the mean discharges value in the lower reaches of the Ngong river between Kayole and Njiru and it is probable that the river has lost some of its water to groundwater in the Athi Lake Beds as Gaverts (1950) suggested that the Athi Lake Beds possibly acquired some of their recharge from river influents.	0.353 m ³ /sec
NAIROBI (Middle Reach)	Between Nairobi R. and Chiromo	0.396 m ³ /sec
"	Between Nairobi R. and Kariobangi South Part of this increase may have resulted from domestic water discharges into the river in the Eastland region.	0.886 m ³ /sec
NAIROBI	Immediately after the sewage outfall at Kariobangi the mean discharge value increased further to about	1.18 m ³ /sec
NAIROBI	Before the confluence with the Ngong River at Njiru Here the increase may be from small springs derived from	2.031 m ³ /sec

River	Variation of Discharge values along rivers and their causes	Amount Discharged
	shallow groundwater especially in Dandora area.	
RUIRUAKA	At Thika Road bridge	0.444 m ³ /sec
"	About 1.5 km downstream from Thika Road bridge The decrease of discharge values between these two stations is due to some waters being diverted into or gardens for small scale agricultural use and this is may have partly contributes to the decrease in the mean discharge value.	0.270 m ³ /sec
RUIRUAKA	Immediately after the outfall of the Kenya Breweries factory effluent.	0.389 m ³ /sec
"	This slight decrease at Kasarani is because some water was diverted into gardens for small-scale irrigation activities were under taken. It is also possible that river has lost some of its water to groundwater at the contact of the tuffs and the Nairobi phonolites between the two stations.	0.348 m ³ /sec
GITATHURU	At Muthaiga	0.072 m ³ /sec
"	At Kariobangi The increase may have been partly due to domestic effluents, which were observed in the Mathare, Huruma and Kariobangi areas. An indication confirming this view was the dark-grey unnatural appearance of the river water.	0.925 m ³ /sec

N.B: The highest discharge values were recorded during the wet month of March (0.045 - 3.8 m³ /sec)) when the rivers had larger volumes of flow and generally higher velocities. In addition, there was a contribution from run-off water and also from small streams derived from shallow groundwater.

The Nairobi River generally had the highest mean discharge values (0.0204 - 2.03 m³ /sec) while the Ruaraka had the lowest 0.097 - 0.444 m³ /sec to 2.03 m³ /sec

Appendix II

901.

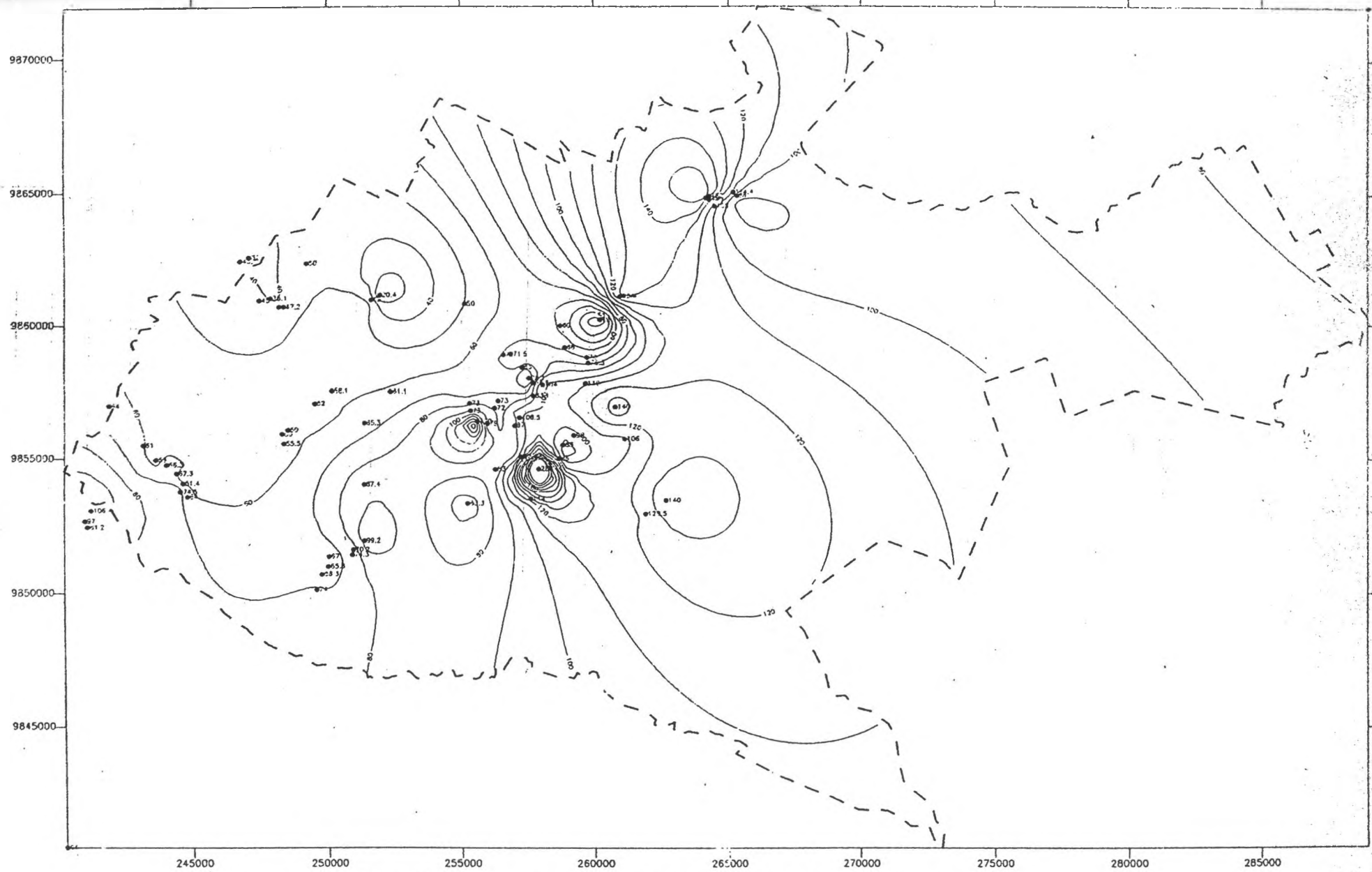


Fig. IIa: Distribution of Sodium (mg/l) in the Groundwater of Nairobi Area

95

107

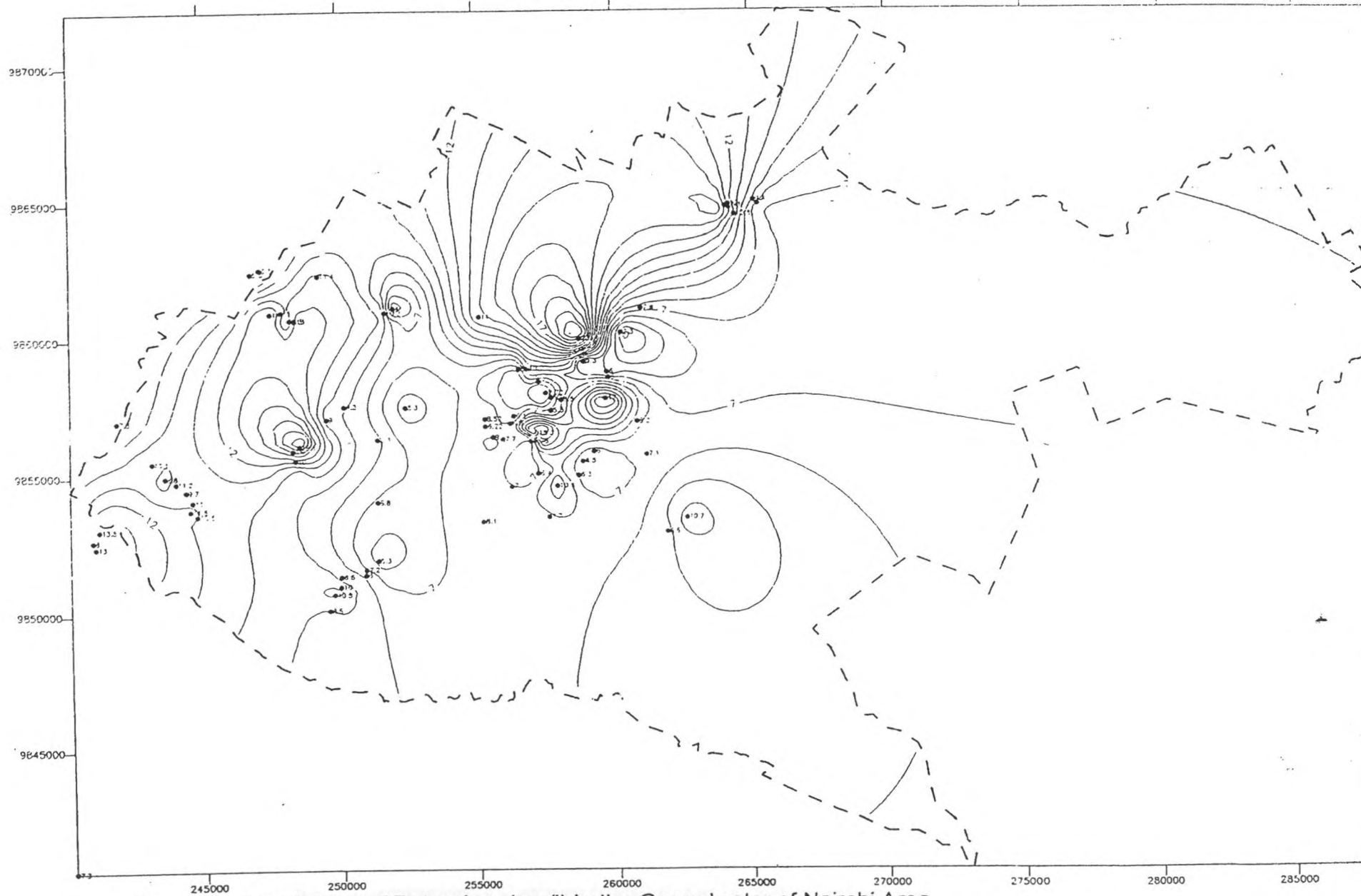


Fig IIb: Distribution of Potassium (mg/l) in the Groundwater of Nairobi Area

108

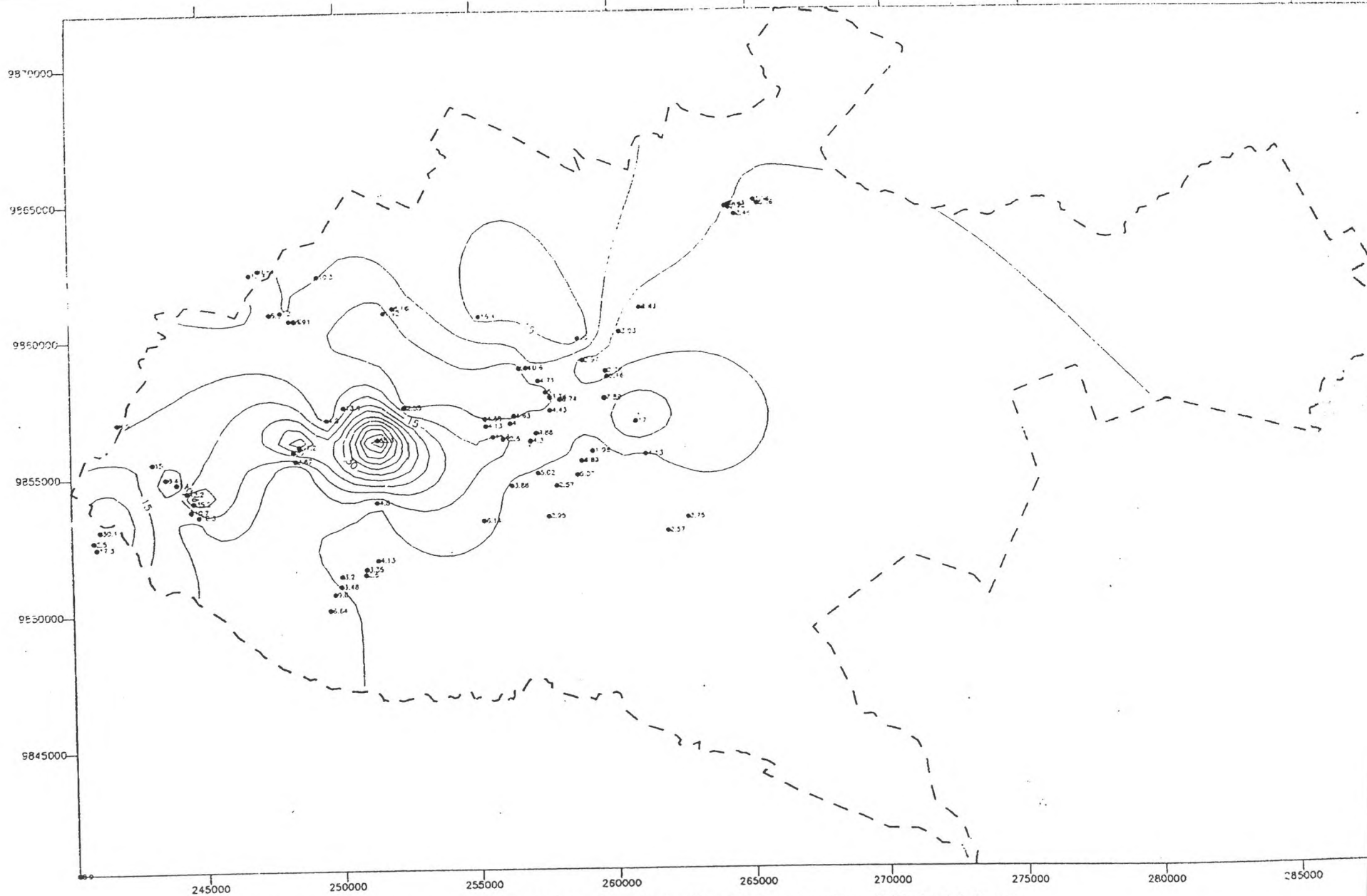


Fig. IIc: Distribution of Calcium (mg/l) in the Groundwater of Nairobi Area

507

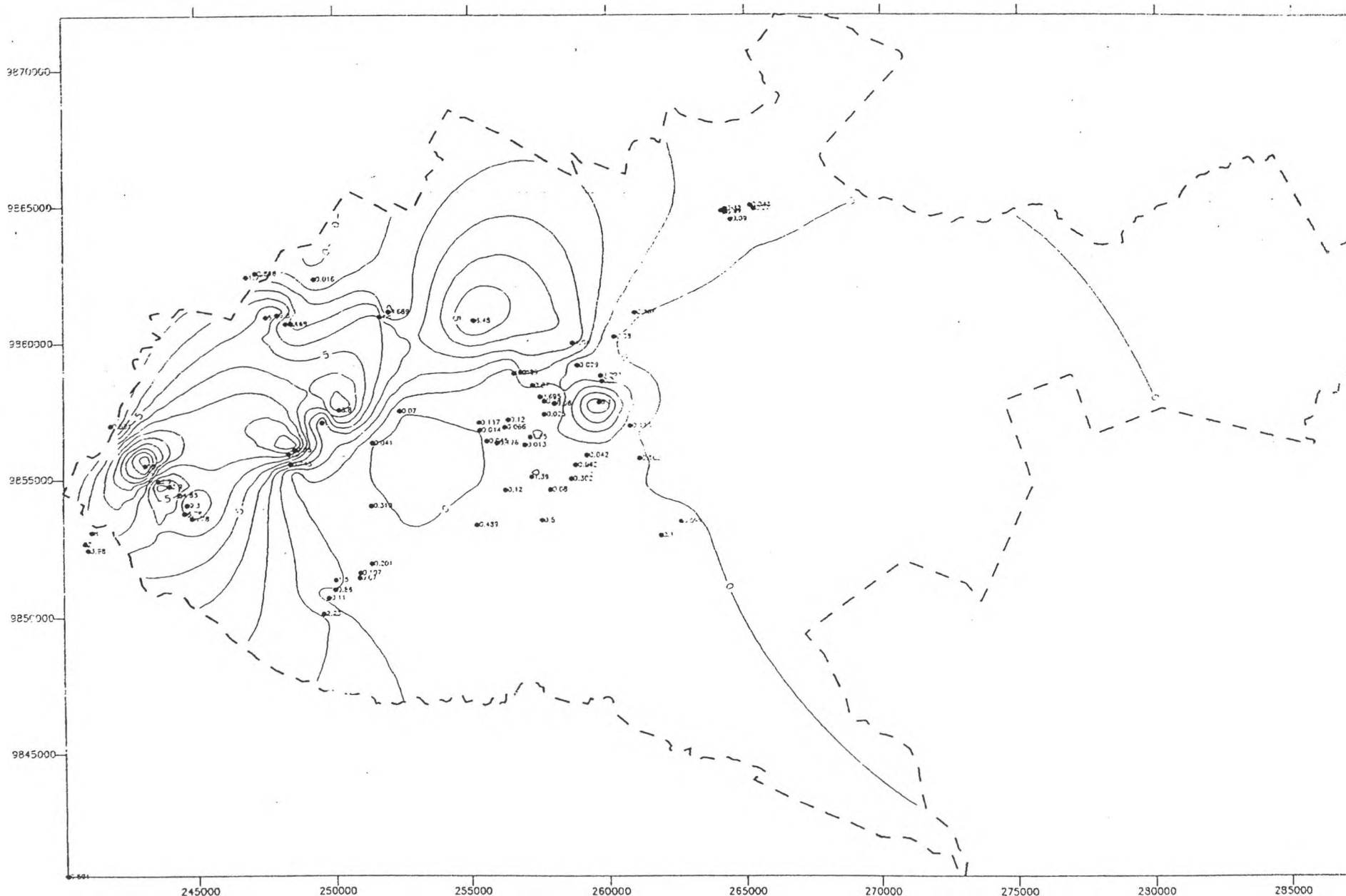


Fig. IIId: Distribution of Magnesium (mg/l) in the Groundwater of Nairobi Area

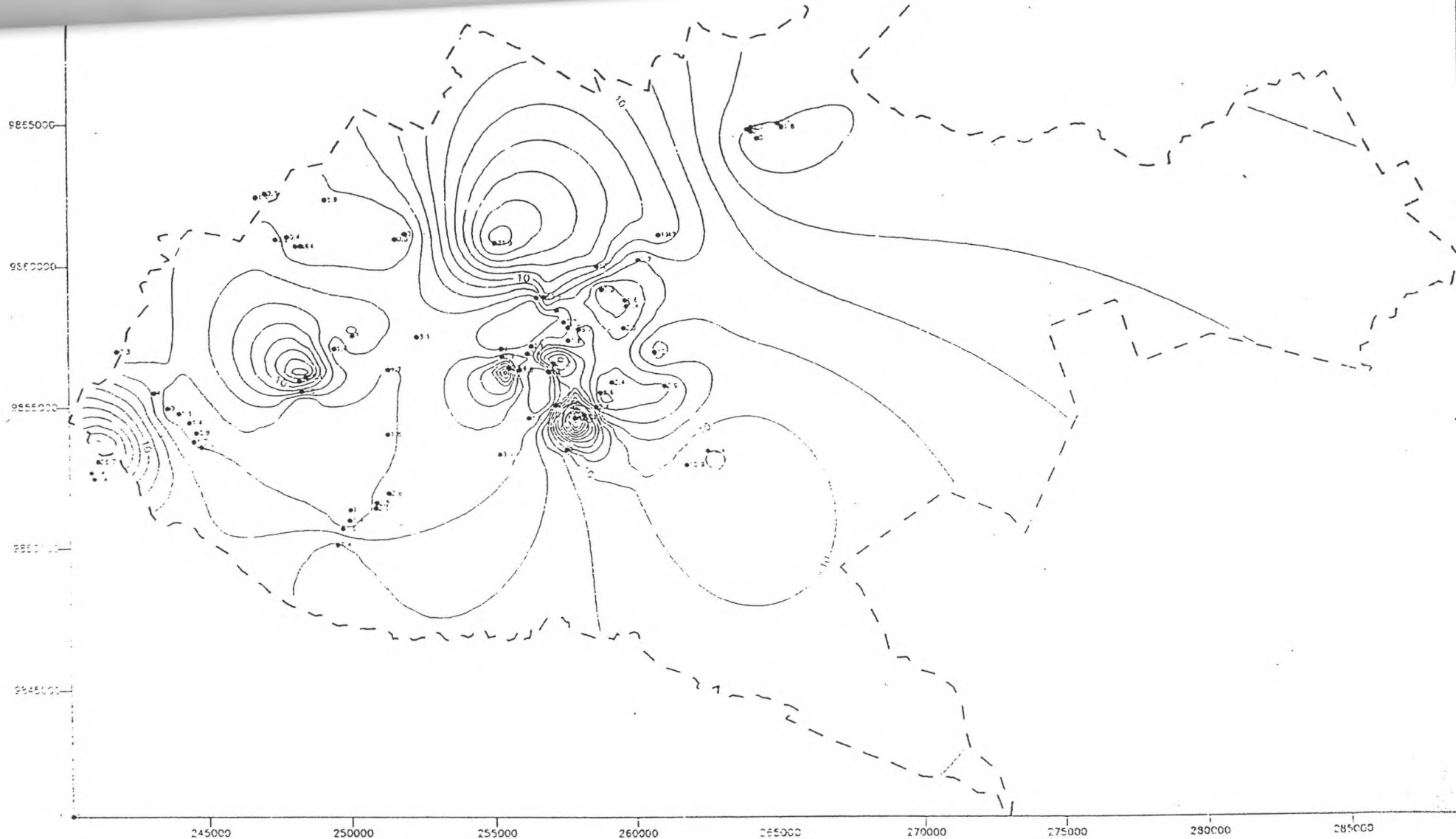


Fig. IIe: Distribution of Sulphate (mg/l) in the Groundwater of Nairobi Area

111

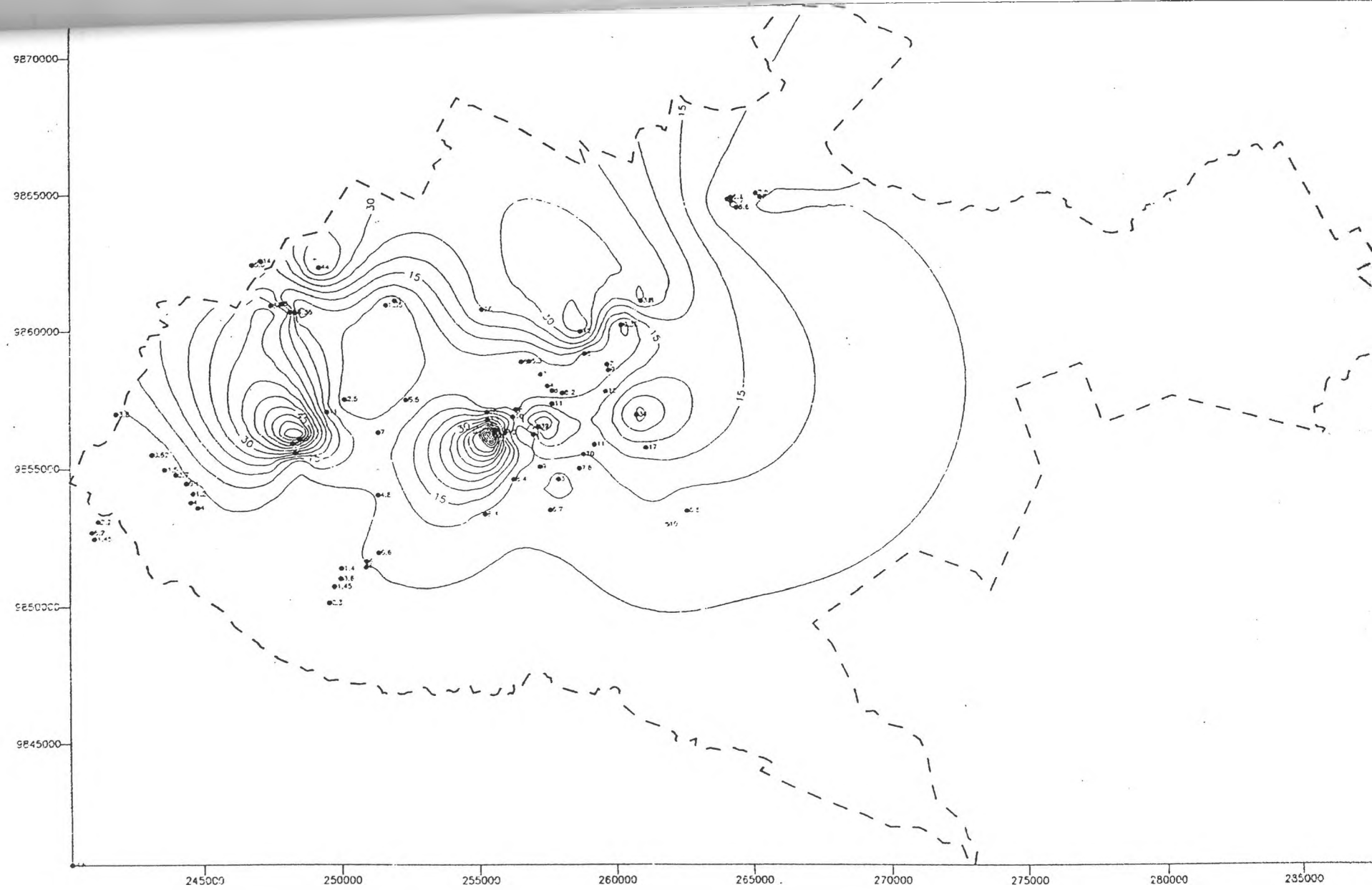


Fig. II f: Distribution of Cl (mg/l) in the Groundwater of Nairobi Area

112

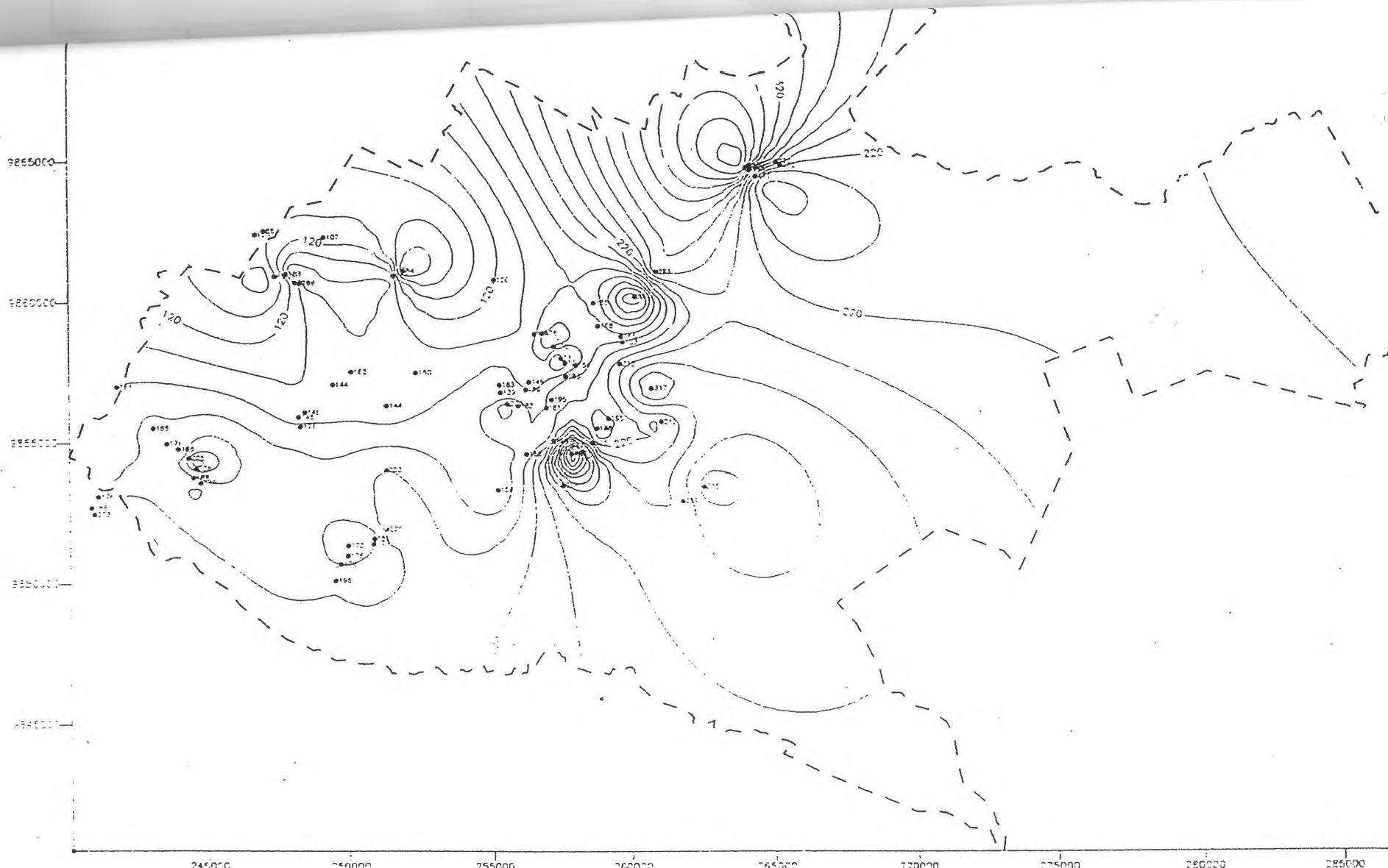


Fig. IIg: Distribution of Hydrogen Carbonate (mg/l) in the Groundwater of Nairobi Area

113

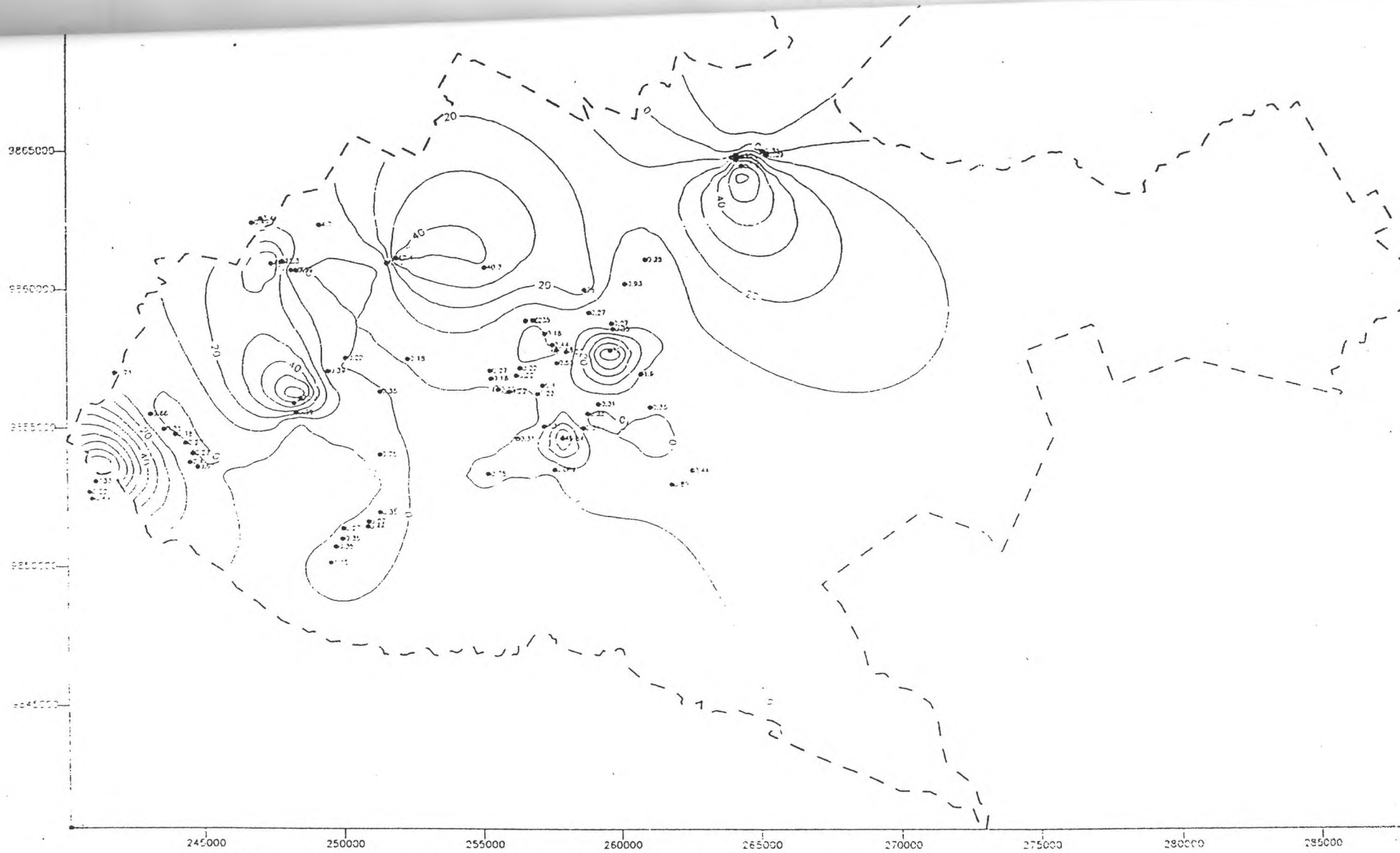


Fig. IIh: Distribution of Nitrate (mg/l) in the Groundwater of Nairobi Area

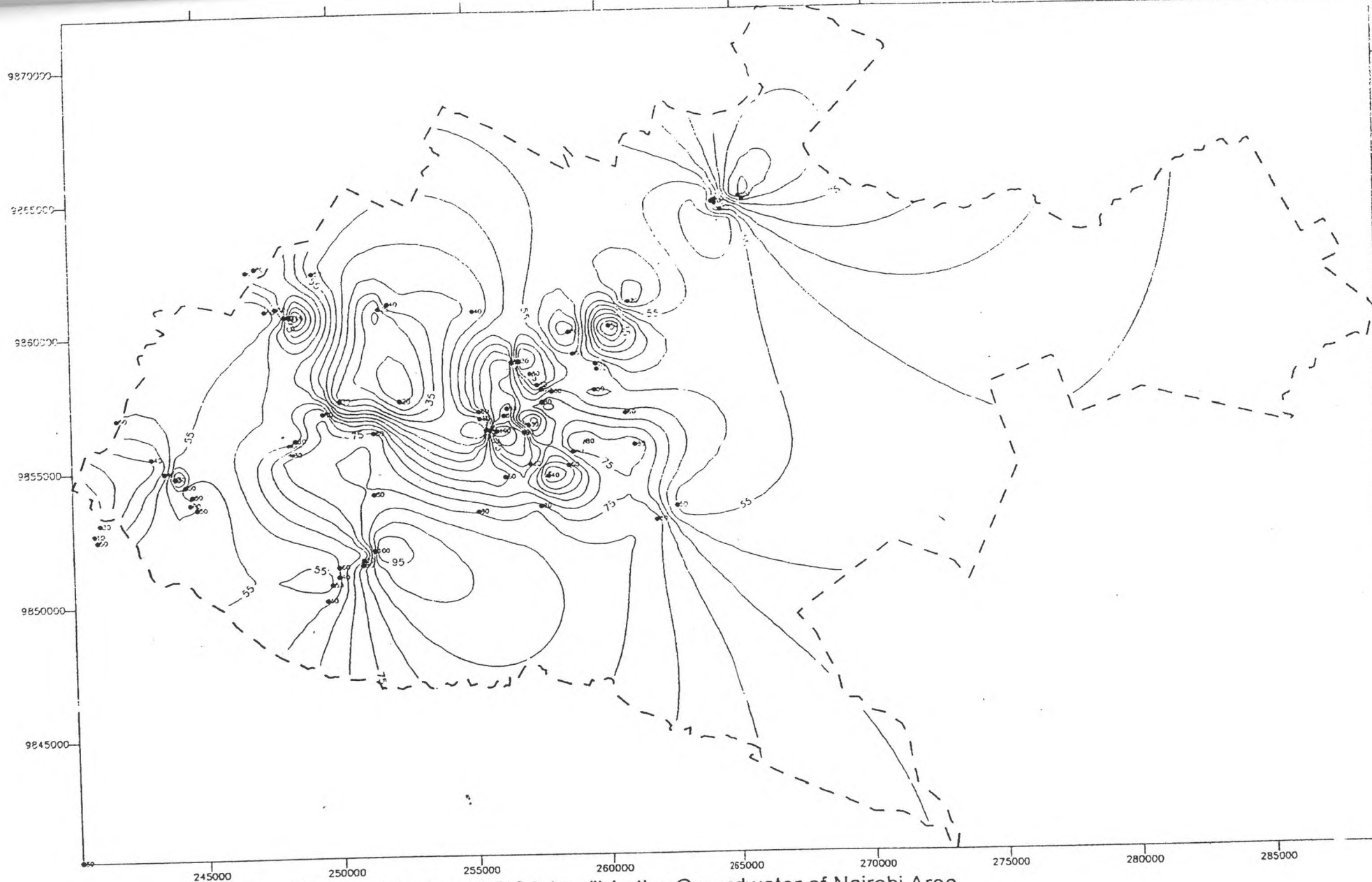


Fig. IIi: Distribution of SiO₂ (mg/l) in the Groundwater of Nairobi Area

711.

115

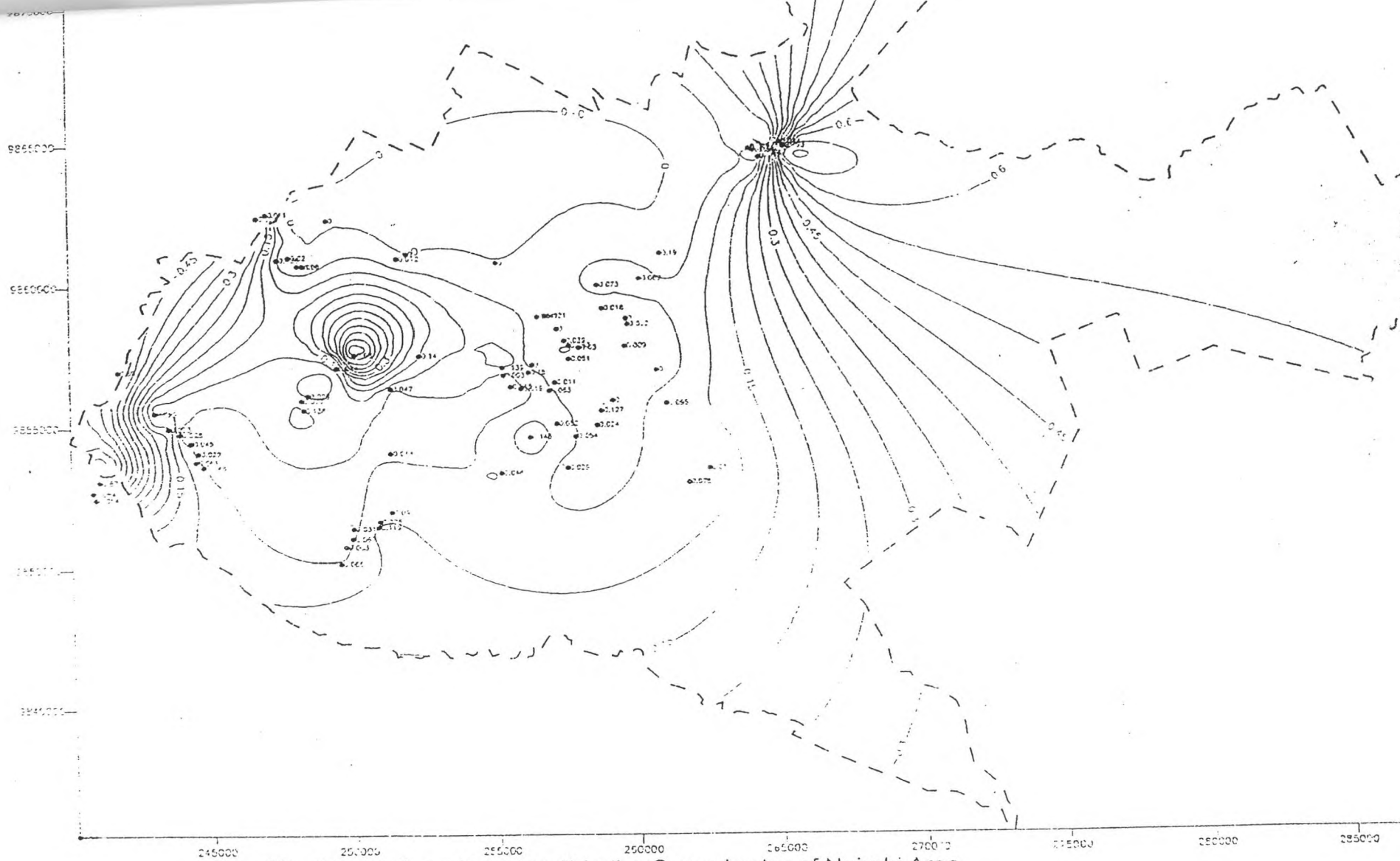


Fig. IIj: Distribution of Iron (mg/l) in the Groundwater of Nairobi Area

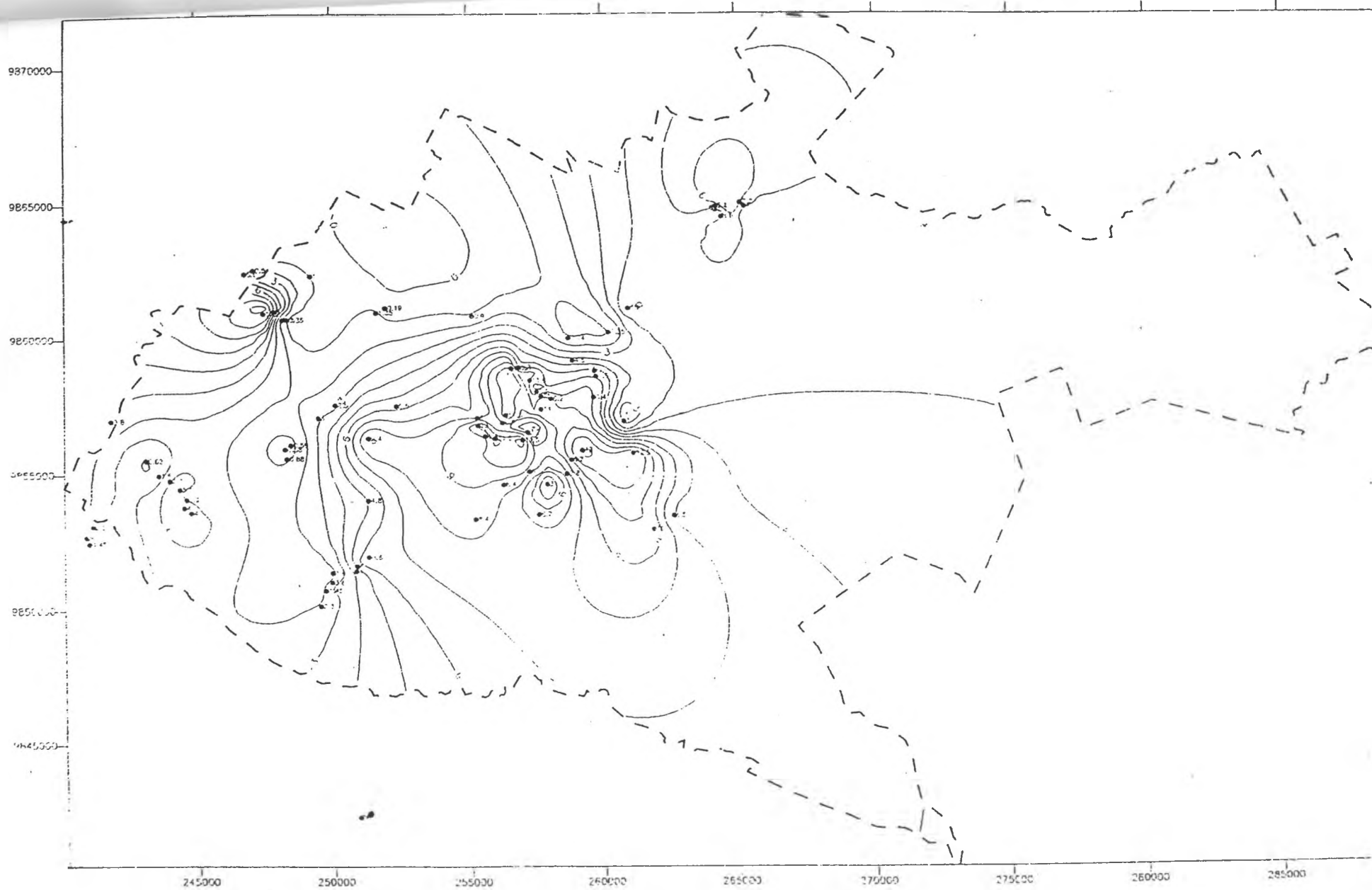


Fig. 11k: Distribution of F (mg/l) in the Groundwater of Nairobi Area

911