UNIVERSITY OF NAIROBI

DEPARTMENT OF CIVIL ENGINEERING

GROUND WATER QUALITY MONITORING IN MAKUYU DIVISION OF MARAGUA DISTRICT.

MSc. RESEARCH THESIS

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F56/8344/99

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A thesis submitted in partial fulfilment for the award of Master of Science in Civil Engineering.

Declaration

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

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

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Dedication

To my parent, wife and every person whose moral support has made me accomplish my assignment.

Acknowledgments

First and foremost, I'm highly indebted to my supervisor, Professor B. N. K. Njoroge, whose continued keen interest, encouragement, advise and criticism has made this research work a success.

I appreciate the help I got from the technicians at the Environmental Health Engineering Laboratory, Civil Engineering Department. I also appreciate the assistance I got from the lecturers and technicians at the Chemistry Department, University of Nairobi.

I acknowledge the Director, Institute of Nuclear Science, University of Nairobi, for granting me the express permission to use the institute's laboratory facilities.

Last but not least, I wish to recognise the moral role played by my colleagues at the Department of Civil Engineering, University of Nairobi, for their constant encouragement and valuable advice throughout the demanding period of this study.

Acronyms

BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DDT	Dichlorodiphenyl Trichloroethane
DDE	Dichlorodiphenyl Dichloroethene
TDS	Total Dissolved Solids
WHO	World Health Organisation
T. O	Threshold Oduor Number
TCU	True Colour Units
NTU	Nephelometric Turbidity Unit
SS	Suspended Solids
AWWA	American Water Works Association
KBS	Kenya Bureau of Standards
IAEA	International Atomic Energy Agency
AXIL	Analysis of X-ray Iterative Least Square
QAES	Quantitative Analysis of Environmental Samples
MCA	Multi-channel analyser
DDTC	Sodium Diethyldithio-carbonate
XRF	X-ray Fluorescence
EDTA	Ethylene diamine Tetraacetic Acid.

Abstract

This report shows results of groundwater quality monitoring in Makuyu division of Maragua district. Analytical results have revealed that the 21 boreholes and wells water are not polluted and can be consumed readily.

In the ground water quality monitoring water samples were obtained from 21 boreholes and wells. In addition, water from three rivers in the area were sampled and tested to compare their quality with that of the groundwater. The depth of the boreholes and wells were divided into three categories. These were 0 – 50 metres, 50 – 100 metres and above 100 metres. The borehole and wells are distributed over the area.

The physical properties monitoring indicate that the temperature, conductivity, turbidity, colour, dissolved solid, suspended solids and total dissolved solid were within the WHO guidelines and Kenya Bureau of Standards limits except for dissolved and total solids for Kamahuha girls high school borehole, which has 4290 mg/l. The physical properties values ranges from 22 ^{0}C – 24 ^{0}C for temperature, 48 – 6130 Us/cm for conductivity, 0.9 – 38 FTU for turbidity and <5 – 20 ^{0}H for colour, 182 – 4290 mg/l for dissolved solids and total solids. For the river waters, the values ranged from 150 – 195 Us/cm for conductivity, temperature is 22 ^{0}C, 41 – 85 FTU for turbidity, 30 – 70 ^{0}H for colour and 1109 – 4179.8 mg/l for dissolved solids and total solids.

The groundwater quality was chemically good. The pH range between 6.39 and 7.97 for boreholes and wells, while for rivers it ranged from 7.06 – 7.34 which are within the World health Organisation Guidelines (WHO, 1993). The concentrations of fluoride ions in most of the sources were within the recommended limits except for Makuyu Secondary School borehole, which had 2.5 mg/l. The chemical properties monitoring indicated that the concentration of iron, manganese, copper, zinc, selenium, titanium, strontium, yttrium and zirconium showed no significant heavy metal pollution in groundwater. The trace metal concentrations values ranged from 0.0994 - 1.1450 mg/l for iron, 0.0046 – 1.0190 mg/l for manganese, 0 – 0.0588 mg/l for titanium, 0.0011 – 0.0142 mg/l for copper, 0.0027 – 0.1692 mg/l for zinc, 0.0011 – 0.0016 mg/l for strontium, 0.0012 – 0.0043 mg/l for yttrium, and 0.0013 – 0.0043 mg/l for zirconium.

In addition, the concentration of other parameters like chloride, calcium hardness, total hardness, total alkalinity, carbonate, fluoride, sulphate, phosphate, nitrate, and dissolved oxygen were also below the maximum permissible limits for drinking water as given (WHO 1993). Pesticides presence in water was not detected.

The biological monitoring indicated that human being or animals pollute few of the groundwater sources. The presence of feacal coliforms in some of the wells indicated biological pollution. The total coliform/100mg/l values ranged from 0 – 2500 and total feacal coliform/100mg/l values ranged from 0 – 8000 for boreholes and wells. For the river water, the total coliform/100mg/l values ranged from 100 – 600 and total faecal coliform/100mg/l values ranges from 30 – 248. Indicating the river water will need full treatment before consumption.

The deep boreholes and wells had good water quality except three boreholes. The Kamahuha Girls Secondary School borehole, Wamtega borehole and Gichuiri well, which are located within Sabasaba town. The water from these sources had high levels of total solids. In addition, Ndachi Mugo's well, Kamahuha well and Muruithia's well had high level of feacal coliforms/100mg/l ranging from 1000 – 8000 total faecal coliform/100ml. These boreholes were all located near pit latrines. Thus to prevent presence of feacal coliforms in the groundwater, the wells should be located away from pit latrines and flash floods should be diverted away from the wells. Secondly, the bucket used to draw water from the wells should be clean.

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CHAPTER 1

1.0 INTRODUCTION

1.1 BACKGROUND

Water is probably the most important natural resource in the world, since without it life cannot exist and industry cannot operate. Water plays a vital role in the development of communities and thus a reliable source of water is an essential prerequisite for the establishment of a permanent community. Nonetheless, liquid and solid wastes from such a community have a considerable potential for pollution of water. The concept of water as a natural resource, which must be carefully managed, is very necessary due to the growing populations and industrial development.

The growth of population especially in developing countries is such that unless strenuous efforts to increase water supply and sanitation facilities are made, the percentage of the world's population with satisfactory amenities would actually decrease in the future. In addition, as the knowledge of the effects of varied forms of environmental pollution increases, new potential hazards appear. For example, there is current concern about the possible carcinogenic hazards arising from the presence of minute concentrations of some organic compounds in water.

The water sources should provide an ample water supply of wholesome quality i.e. water free from:

- Visible suspended matter
- Excessive colour, taste and odour
- Objectionable dissolved matter
- Bacteria indicative of faecal pollution, and
- Chemical pollutant.

There is a vast amount of water present in the earth and its surrounding atmosphere. About 7% of the earth's mass is made up of water. However, 97% of all the water is saline water found in the oceans and much of the 3% freshwater is incorporated in the polar ice caps. And, only about 7% of the earth's water occurs in freshwater lakes and rivers, in accessible aquifers and in the atmosphere (Tebbutt, 1983).

In the semi-arid and arid areas, groundwater is widely exploited as the major source of water. In the other zones it is exploited to supplement existing water sources. The intensive use of natural resources and the large production of wastes in modern society often pose a threat to groundwater quality. Degradation of groundwater quality can take place over large areas and from various sources.

Pollution can impair the use of water and can create hazards to public health through toxicity of heavy metals or the spread of diseases. Most pollution originates from the disposal of wastewater following the use of water for any of the wide variety of purposes. A complex and interrelated series of modifications to natural water quality is created by the diversity of human activities impinging on the hydrologic cycle.

The possible pollutants in ground water are varied in quantities and types. But generally, they can be classified according to chemical, biological, physical and radiological types. Because groundwater tends to move very slowly, many years may elapse before affected water shows up in an abstraction point. For this same reason, many years may be required to rehabilitate polluted aquifers after the source of pollution has been eliminated (Allan and Cherry, 1979). The groundwater sources are not unlimited. Thus, they must be well managed to protect undue exploitation and contamination by pollutants.

1.2 Description of the study area

1.2.1 Location of study area

The study area is located in the lower part of the Maragua District in Central Province of the republic of Kenya. Its bounders are Thika, Murang'a and Kirinyaga districts. Some parts of the area are semi-arid and receive water supplies from surface water and groundwater through natural springs, rivers and private boreholes. Water obtained from wells and private boreholes are used for domestic, industrial and agriculture purposes. The area has a population of approximately 80,000 people (Population Council, 1999).

1.2.2 Geology and hydrogeology

The geology of the study area is dominated by Archaean gneisses of the basement System. (Hydrogeological report for Murang'a district, 1979). The basement rocks throughout the area are covered in the higher parts by sandy alluvium and red-sandy soils, while in lower parts black cotton soils predominate. The basement rocks in the area comprise quartzo- felspathic gneisses and the Biotite gneisses hidden beneath a layer of recent soils. A thin layer of Kapiti phonolites, basalts and basaltic agglomerates that in turn overly basement rocks system covers the lower parts of this area.

The Precambrian rocks have suffered advanced metamorphism and include granitoid gneisses of replacement origin. No economic minerals were recorded from the Precambrian apart from small deposits of magnetite and kaolin. The volcanic succession contains tuff-beds providing considerable reserves of building-stone and also carries ground water reserves giving good borehole yields and are capable of further development.

In the study area, most of the aquifers are semi confined: that is, water in a borehole rises to a level higher than that at which it was struck. There are different types of aquifer encountered in basement rocks. Those associated with fault and fractures are better than those associated with weathered rock, usually encountered beneath the soil cover and overlying compact, or unweathered rock.

These latter aquifers, located in the regolith, are highly variable in terms of potential yield. This is because the physical transmission of water within the aquifer body itself is dependent upon the total clay fraction present after weathering of the parent rock, which itself depends on the chemical constituents of the parent rock and the mechanism of weathering. Faults and fractures associated with major movements of the Earth's crust and often accompanied by volcanic activity, lead to the formation of coarser material. This, together with the larger volume of potential storage brought about by the fault, leads to rather better potential yields, especially where a borehole is sited so as to intersect fault features at depth.

Groundwater occurrence is dependent upon geology, rainfall, erosion, and recharge. The best aquifers are found when a conjunction occurs of optimum recharge (rainfall and soil permeability), storage (porous rock) and transmissivity.

1.2.3 Rainfall and climate of study area

The temperature vary with altitude, the climate on the higher volcanic part in the west is generally cooler than that of the lower lying basement system of the Tana and Thika valleys. Rainfall over much of the area is fairly high. It is controlled by altitude, being lowest in the area east of Kakuzi Hills south of Tana River, and increasing northwards and westwards towards the lower slopes of Mount Kenya and the Aberdares. The average mean annual rainfall ranges from 890mm to 1270mm. The infiltration of this rainfall forms the recharge of the aquifer. There are two rainy seasons per annum. The long rain is between the month of March and May and short rains between October and December. Temperatures are highest in the months of January to mid-March before the rain season and lowest in the months of July to August.

If no rainwater is able to percolate to a sandy weathered basement aquifer due to the presence of an aquitard (impermeable layer) probably clay the actual potential is very low. Both Basement and Volcanic systems have the same limitations so far as recharge is concerned. If rainfall is low the volume of water that may eventually percolate to a suitable aquifer is likely to be relatively small, and possibly mineralized due to high evaporation.

Percolation is dependent on soil structure, vegetable coverage and the erosion state of the parent rock. Rocks that weather to clayer soils will naturally inhibit percolation e.g. black cotton soils. Recharge is the term applied to the whole mechanism, and includes all the aspects of parent geology, effective rainfall and percolation. Some aquifer systems are recharged by water falling a substantial distance away - this is for instance the case where recharge apparently occurs laterally, from west to east, through the volcanic dipping down from Aberdare Mountains.

1.2.4 Source of water

There are three rivers in the study area. These are SabaSaba, Ndera and Thaara. The rivers can be considered as an input of the aquifer system as they flow even during the dry seasons. Conversely, rivers participate also to the recharge of the groundwater resource in some sections at certain periods of the year and thus induce recharge, which can be linked to borehole abstraction.

There are several private and community owned wells and boreholes. A total of 12 boreholes and nine wells were identified in the study area. They provide water to several people. The groundwater is greatly exploited in the area and thus there is need for groundwater quality monitoring.

1.3 Study objective

The objectives of the study were: -

- To monitor, measure and evaluate the quality of groundwater obtained from wells and boreholes in Makuyu Division of Maragua district, Central Province. The research aimed to check the physical, chemical and microbiological quality of the water sample drawn from the wells and boreholes, over a period of time.
- To assess whether groundwater source is a suitable alternative to the surface water source.

1.4 Study hypotheses

The Makuyu borehole and well water is polluted by physical, chemical, and biological agents of pollution and thus should be considered for human consumption after treatment only.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 GROUNDWATER

2.1.1 Introduction

Ground water is that portion of the water beneath the surface of the earth that can be collected in wells, tunnels, borehole or that which flows naturally to the surface via seeps or springs. Groundwater is also defined as part of the Earth's water cycle that flows underground. The rocks or soil materials that hold groundwater are called "aquifers". Groundwater can also be defined as water occurring in the saturation zone. The geological condition of the ground determines the paths that the water follows. Groundwater can be found in rock formation e.g. in limestone area and are formed during rock formation. This water is highly mineralised and of less use.

The principal source of groundwater is meteoric water, that is, precipitation (rain, sheet, snow and hail). Part of this water enters the ground by infiltration whilst the remainder is lost either as runoff on the surface or by evaporation and transpiration to the atmosphere. The main conditions, which influence the relationship between infiltration, runoff, evaporation and transpiration, are climate, topography, vegetation and geology.

Groundwater supply is much more widely distributed than surface water, but local variations are found as a result of the variety of soils, rock and geological structures located beneath the land surface. Groundwater is a major source of fresh water for public consumption, industrial uses, and crop irrigation. Groundwater storage volumes and transmission rates are affected by soil properties and geological conditions, and these are often highly variable in space and not amenable to simple quantification.

Most ground water is constantly in motion. It is pulled by gravity from higher aquifers to lower, where it may appear in springs and streams. Gravity attracts water from the skies, pulls it beneath the surface of the ground, distributes it among permeable layers of the earth and influences the direction in which it flows.

Rainwater seeps downward through the soils until it is blocked by rock or non-porous layers such as clay. The proportion of water that sinks into the ground varies with the character of the soil. The groundwater itself occurs in pores, voids or fissures in the ground material. Pores are the spaces between the mineral particles in sedimentary ground layers and in decomposing work formations.

Groundwater can be found in hardrocks, sedimentary rocks or unconsolidated formation. Hardrocks include igneous and metamorphic rocks. These rocks have low permeability. The pores in such rocks are not interconnected. Fracturing leads to formations of fissures through which groundwater may penetrate. Water bearing formation in hardrocks may occur in areas with fracture due to earth movements or in areas with intense weathering. As study of aquifer test usually reveals such area in hardrocks, yields from aquifer may be 50 – 100 m^3/day or as high as 300 m^3/day (Babbitt, 1967).

In sedimentary rocks, the possibility of finding groundwater is minimised because they have very small pore sizes thus low permeability e.g. clay, stones and shale. Permeability is the ability of the formation to transmit water through its pores when subjected to pressure difference or head. In areas where they are fractured or weathered, permeability is high. Sedimentary rock formed from sandstone may have high porosity and permeability depending on the particle size arrangement. Wells found in sedimentary rock are very good in water formation.

2.1.2 Occurrence of Groundwater

Groundwater occurs in geological formation referred to as aquifers. The word aquifer comes from the two Latin words aqua (water) and ferre (to carry). An aquifer is a geological formation, which contains and transmits ground water in significant quantities. The quality of water that a given piece of saturated earth can contain depends on the earth's porosity, the total measure of the spaces among the grains or in the cracks that can fill with water. If the grains of sand or gravel are all about the same size or "well sorted", the spaces between them account for a large proportion of the total volume of the aquifer. If the grains however are poorly sorted, the spaces between them account for a large proportion of the total volume of the aquifer. Poorly sorted rocks therefore do not hold as much water as well sorted rocks.

If water is to move through rock or other material, the pores must be connected to one another. A rock or underground material that is good source of water must contain many interconnecting pore spaces or cracks. Ground permeability is a measure of the freedom with which water moves through it.

Typical examples of good aquifers include: -

- Unconsolidated sands and gravel.
- Heavily sheltered quartzite.
- Granites with fissures and cracks.
- Weathered gneisses and schists.
- Limestone with cavities and vesicular basalts.
- Marbles with fissures and cracks.

The surface of the groundwater exposed to atmospheric pressure beneath the groundwater surface is known as the groundwater table or the free surface. The groundwater table rises and falls according to the amount of rainfall, the rate at which water is withdrawn from or added to it, the barometric pressure and other conditions. The groundwater table is seldom static or horizontal. Groundwater occurs also as a lens of fresh water supported above the level of adjacent salts water, and as perched water, that is, water held in porous material supported by an impervious basin like underground stratum.

In the aquifer, groundwater occupies spaces known as pores or voids or interstices. The amount of water in an aquifer depends on its porosity, which is a measure of the contained voids expressed as the ratio of the volume of interstices to the total volume. Groundwater distribution may generally be categorized into zones of aeration and saturation. The saturated zone is one in which all voids are filled with water and under hydrostatic pressure. In the zone of aeration, the interstices are filled partly with air and partly with water. The saturated zone is commonly called the ground water zone.

The saturated zone is subdivided into several subzones. These include:

1. Soil water zone – a soil water zone begins at the groundwater surface and extends downward through the major root band. Its total depth is variable and dependent on soil type and vegetation. The zone is unsaturated except during period of heavy infiltration. It has three categories of water classification, which are encountered in this region. Hydroscopic water; which is adsorbed from the air; capillary water, held by surface tension; and gravitational water, which is excess soil water draining through the soil.
2. Intermediate zone – this belt extends from the bottom of the soil – water zone to the top of the capillary fringe and may change from non-existence to several hundred feet in thickness. This zone is essentially a connecting link between a near ground surface region and the near water table region through which infiltration fluids must pass.
3. Capillary zone – a capillary zone extends from the water to a height determined by the capillary rise that can be generated in the soil. The capillary band thickness is a function of soil texture and may fluctuate not only from region to region but also within a local area.
4. Saturated zone – in the saturated zone, groundwater fills the pores spaces completely and porosity is therefore a direct measure of storage volume. Part of this water (specific retention) cannot be removed by pumping or drainage because of molecular and surface tension forces. Specific retention is the ratio of volume of water retained against gravity drainage to gross volume of the soil.

   Water that can be drained from a soil by gravity is known as the specific yield. It is expressed as the ratio of the volume of water that can be drained by gravity to the gross volume of the soil. Its values depend on the soil particle size, shape and distribution of pores, and degree of compaction of the soil (Warren Viessman Jr. et al, 1989).

There are two types of aquifers, confined aquifers and unconfined aquifers.

Confined aquifers.

These occur where groundwater is confined under pressure greater than atmospheric by overlying relatively impermeable strata. If water comes to the surface under pressure it is known as a free flowing or artesian well.

Unconfined aquifers

These are like underground lakes in porous materials. There is no restricting material at the top of the groundwater so that groundwater levels are free to rise or fall. The top of these aquifers is the water table. It is open to infiltration of water directly from the ground surface.

2.1.3 Sources of groundwater

The main source of groundwater is precipitation, which may penetrate the soil directly to the ground or may enter surface streams and percolate from these channels to the groundwater. Interception, depression, storage and soil moisture must be satisfied before any large amount of water can percolate to the groundwater. The path taken by ground water to the zone of saturation depends on the geological conditions. Relatively impermeable layers above the water table may prevent direct percolation.

Miscellaneous sources of groundwater include water from deep in the earth, which is carried upward in intrusive rocks, and water that is trapped in sedimentary rocks during their formation. Normally the quantities of such water are small and are highly mineralized.
The groundwater source should be as remote as possible from any source of pollution, such as latrines, septic tanks, sewerage discharges, agricultural drainage – water discharges, etc

2.1.4 Types of Ground water sources.

Borehole
Borehole is a hole drilled or bore into the earth, usually for exploratory or economic purposes, a hole into which casing, screen, and other materials may be installed to construct.

Well
A well is any excavation that is drilled, cored, washed, fractured, driven, dug, jetted, or otherwise constructed when the intended use of such excavation is for the location, monitoring, dewatering, observation, diversion, artificial recharge or acquisition of ground water or for conducting pumping or aquifer tests. The artesian well is one in which the water rises above the level at which it is encountered in the aquifer because of pressure in the

confined water of the aquifer. A flowing well is an aquifer well where the pressure raises the water above the casing head. The various types of wells include: -

- Open shallow wells

These are wells, which are hand-dug down into the water table. In a shallow well, a bucket and rope are used to raise water to the surface. They are subjected to gross contamination and to often yield water of unacceptable quality. They have cover slabs made of wood or concrete to prevent the dangers to children, animals and foreign objectives falling into the well. Open shallow wells are readily subject to contamination by humans, animals etc. Contamination of the bucket is reduced by hanging it on the windlass handle or a special bucket hook attached to the windlass support.

Open shallow wells do not require maintenance, especially when they are lined with concrete. It may also happen that in the course of a prolonged drought period water levels go down and wells run dry._More frequently, sediment will accumulate in the bottom of the well, possibly up to the water table. This happens mainly in sandy areas. Sand may be blown into wells by wind, or may be brought slowly but steadily by the humid extraction ropes, which may collect it on the ground.

- Dug wells

They are the oldest and most widely used ground water wells for domestic water supplies throughout the Country. The wells are shallow and Cylindrical in shape with varying diameter and depth. The cylindrical shape is used because of the wall stability to collapsing. Private wells are mostly smaller in diameter and shallower in depth than public wells.
The dug wells provide water from relatively shallow aquifer close to the soil surface and can therefore be rather easily contaminated, most commonly by leachates from excreta disposal facilities and animal excrement. It should have a sufficient internal diameter (approx. 1.25m) to allow people to work inside, for cleaning or deepening the well. It should be dug through to at least 3m below the top of the aquifer, so that enough water will be available, even with a poor aquifer.

When hand–dug wells are not covered, the quality of the water inside the well becomes generally poor. This is due to pollution of the well from outside. The quality will be particularly poor if the wells are situated close to contaminant sources like pit latrines, sanitary landfills, animal stables and feedlots.

Wells dug during the wet season dry up during long dry seasons. So, hand-dug wells must be dug during the driest period to ensure an adequate yield at all seasons.

- Drilled wells and Boreholes

Drilled wells mostly reach deep aquifers that are far from the soil surface. It is less liable to be affected by contamination. The groundwater is normally free from microbial pollution and directly usable as drinking water. Drilled wells and boreholes require greater expertise to dig, since they penetrate much deeper aquifers, which often lie in rock formations.

Boreholes are deep ground water wells that are constructed by conventional methods of well drilling. Important design considerations in connection with this type of wells are: well diameter, drilling methods, casing, well screen, gravel pack, pumping, grouting and well completion. When boreholes are properly designed, constructed and operated, they are a good ground water source for medium to large communities. This is because the water is relatively free from pollution and also more reliable in quality.

Groundwater has some advantages and disadvantages: -

The advantages include: -

- Good quality.
- The temperature of water is constant throughout the year.
- The bacteriological quality is good.
- Requires little or no treatment except chlorination.
- Availability hardly depending on season.

The disadvantages include: -

- Presence of sufficient quantities of groundwater not always easy to determine.
- Often pumping required.
- Water may contain excessive salts, iron, hydrogen sulphide, etc.
- Moderate to high construction costs involved.

2.1.5 Groundwater movement

Groundwater is not stagnant, but rather moves from areas where water recharges aquifers (recharges area) to areas where it leaves aquifers (discharge area). Groundwater moves from areas of higher elevation or higher pressure/hydraulic head (recharge areas) to areas of lower elevation or pressure/ hydraulic head. This is where the groundwater is released into streams, lakes, wetlands, or springs (discharge areas). Discharge areas are lakes, streams and wetlands.

The base flow of streams and rivers, which is the sustained flow between storm events, is provided by groundwater. The quantification of the volume and rate of flow of groundwater in various regions is a difficult task because volumes and flow rates are determined to a considerable extent by the geology of the region. The characters and arrangement of rocks and soils are important factors, and these are often highly variable within a groundwater reservoir. The direction of groundwater flow normally follows the general topography of the land surface.

Many aquifers have been contaminated, at least locally by the improper disposal of chemical and other wastes by leachates from solid waste disposal sites, and from infiltrating storm water discharges. Boundaries to groundwater flow system may be fixed geological structures or free water surfaces that are dependent for their position on the state of the flow. Porous media through which groundwater flow may be classified as: isotropic, anisotropic, heterogeneous, homogeneous or several possible combinations of these.

An isotropic medium has uniform properties in all directions from a given point. Anistropic media have one or more properties that depend on a given direction. For example, permeability of the medium might be greater along a horizontal plane than along a vertical one. Heterogeneous media have non-uniform properties of autotrophy or isotropy, while homogeneous media are uniform in their characteristics.

Groundwater flow is the rate of movement of water through the ground and is of an entirely different magnitude than that through natural or artificial channels or conduits. Typical values range from 1.5 m/day to a few metres per year. Groundwater flow is the movement of water through openings in sediment and rock that occurs in the zone of saturation.
The volume of groundwater replaced annually through natural mechanisms are relatively small because of the slow rates of movement of groundwater and the limited opportunity for surface waters to penetrate the earth's surface.

The rate of flow of water through the ground is higher following heavy rains compared with periods of lighter rain and dry spells. During heavy rains, bacteria held in the water are also carried through greater distances. The closer the groundwater is to the surface, the greater the effect of heavy rain in carrying bacteria and other organisms through the soil. Pathogenic bacteria do not find the soil a suitable medium in which to survive, and die off as they pass through it.

The movement of groundwater is governed by established hydraulic principles. Except in large caverns and fissures, groundwater flow is almost exclusively laminar. The flow through aquifers can be expressed by the Darcy's Law (1856). Darcy's law states that the velocity of flow through a porous medium is directly propositional to the hydraulic gradient, for laminar flow and inertia being neglected. The Darcy's Law:

$$V= ks$$

Where

V = Velocity (specific discharge) in metres per second.

s = Slope (hydraulic gradient)

k = coefficient of permeability (hydraulic conductivity) in metres per second.

And $V = Q/A$

Where

Q = Flow rate (volume per unit time)

A = Cross – sectional area though which flow occurs

Thus, $Q = Aks = AV_{Actual}$

On the average, the actual velocity at which water move through an aquifer is given by

$$V_{Actual} = V/P$$

Where P is the porosity of the aquifer medium.

Groundwater movements thus depend on the type of aquifer and its properties (geological properties).

2.2 Sources of groundwater pollution.

Groundwater not only contains the hydrogen and oxygen atoms that form water (H_2O), but it also contains naturally dissolved gases from the atmosphere and dissolved minerals and gases from the soil and rock through which it passes. The soil filters the water and absorbs and removes many contaminants though some will pass through unimpeded. But if the soil layer is thin, it has high permeability, or if the water table is close to the land surface, then the soil is less likely to adequately remove the contaminant. The excess contaminants may pass through the zone of aeration and enter the groundwater in the zone of saturation.

If this happens, a plume forms. A plume is an underground pattern of contaminant concentrations created by the movement of groundwater beneath a contaminant source. The contaminant spreads mostly laterally in the direction of groundwater movement. The site of original contamination has the highest concentration of contaminant and the concentration decreases as it moves further away from the source (Fetter, 1994). The extent of contaminant spreading depends on the nature and types of interactions between the contaminant and the aquifer materials.

Groundwater normally does not contain many bacteria since the effects of filtration, exposure to unfavourable environment, will eliminate most of them, including those of sanitary significance. Groundwater pollution is a modification of the physical, chemical and biological properties of water, restricting or preventing its use in the various applications where it normally plays a part. It can also be defined as the artificially induced degradation of natural groundwater quality. Shallow groundwater is also susceptible to non-point or diffuse sources of contamination from various activities, such as the unregulated use of chemical fertilizers and pesticides combined with excessive irrigation practices, and the application, disposal and storage of animal wastes on land.

Many groundwater quality problems emanate from inappropriate land-use practices directly over susceptible aquifers e.g. over-application and runoff of agricultural fertilizers and chemicals which may result in high nitrates and pesticides in groundwater; land disposal of sewage effluent; chemical spills or leakage from storage tanks and transportation facilities; poorly sited landfills; and incorrect waste disposal practices at former industrial sites. Infiltration of rainfall, snowmelt and stream flow in groundwater recharge areas may carry contaminants to groundwater especially in sensitive areas where water tables are shallow and surface soils consist of permeable sand and gravel deposits. Areas of groundwater discharge and immediate environs surrounding these sites (e.g., natural springs and wetlands) need to be protected from sources of contamination.

The mineral content of groundwater reflects its movement through the minerals, which make up the earth's crust. Groundwater in arid regions is harder and more mineralised than water in regions of high annual rainfall. Deeper aquifers are more likely to contain higher concentrations of minerals in solution because the water has more time to dissolve the mineral rocks.

Some aquifers show evidence of groundwater contamination to a point of being impaired or unfit for use, particularly for drinking water purposes. Sources of contamination may be due to natural levels of constituents or from human-induced sources. From an allocation perspective, groundwater use without provisions for adequate treatment should not be allowed in areas of known risk to human health. Areas of known or suspected contamination need to be identified and designated as such.

The main possible groundwater pollutants and pollution indicators include: Nitrogen, detergents, phenols, oxygen, sulphates, nitrates, nitrites, ammonium, free carbon dioxide, bicarbonates, iron, manganese, sodium, potassium, calcium, magnesium, total hardness, chloride, fluoride, phosphate, zinc, lead, copper, arsenic, titanium, SiO_2, temperature, pH, conductivity and redox potential.

Origin of groundwater pollution.

The sources of groundwater pollution include: -

1. Industrial pollution that is carried to the aquifer by used water, which contains chemical compounds and trace elements, for example: -

- Rain infiltrating through waste disposal.
- Accidents like leakages from pipeline.

2. Domestic pollution carried to the aquifer by: -

- Rain water infiltrating through waste disposal.
- Accidents like the breaking of septic tanks.

3. Agricultural pollution is due to irrigation water or rain carrying fertilizers, minerals, salts, herbicides and pesticides.

4. Environmental pollution due to seawater intrusion in coastal aquifer.

5. Poor well construction practices, resulting in degradation of groundwater quality and contamination.

6. Health risks, public safety and environmental hazards associated with uncapped and abandoned wells.

2.2.1 Sources of Municipal pollution.

(i) Sewer Leakage

- Although sanitary sewers are intended to be watertight, in reality, leakage of sewage into the ground is a common occurrence, especially from old sewers. Leakage may result from poor workmanship, defective sewer pipe, breakage by the tree roots, rupture from heavy loads or soil slippage, fractures from seismic activity, loss of foundation support, shearing due to different settlement at manholes, etc.

- Suspended solids in sewage tend to clog sewer cracks and because the surrounding soil tends to become clogged due to aerobic conditions, leakage from minor sewer openings is often small.

- Sewer leakage can introduce high concentrations of biochemical oxygen demand, chemical oxygen demand, nitrate, organic chemicals and pathogens into groundwater.

- Where sewers serve industrial areas, heavy metals such as arsenic, cadmium, chromium, cobalt, iron, lead, manganese and mercury may enter the wastewater.

The normal ranges of inorganic constituents from water supply to domestic sewage are shown in Table 2-1.

Table 2-1: Normal Range of increase in mineral constituents found in domestic sewage (Miller et al., 1967)

Mineral	Range of increase, mg/l
Dissolved solids	100 – 300
Boron (B)	0.1 – 0.4
Sodium (Na)	40 – 70
Potassium (K)	7 – 15
Magnesium (Mg)	3-6
Calcium (Ca)	6-16
Total nitrogen (NO_3)	20-40
Phosphate (PO_4)	20-40
Sulphate (SO_4)	15-30
Chloride (Cl)	20-50
Alkalinity (as $CaCO_3$)	100-150

(ii) Liquid Wastes

In an urban area, wastewater may originate from domestic uses, industries or storm run – off. In most cases, these waters receive some degree of treatment before being discharge into surface waters. There is a trend for treated wastewater to be recharge into the ground where it mixes with naturally occurring groundwater and subsequently becomes available for re-use. These include: -

(a) Irrigation

(b) Overland flow

(c) Infiltration – percolation.

Irrigation method is where water is applied by spraying or flooding for agricultural purposes in which case some water percolates to groundwater. Overland flow technique involves spraying over the upper reaches of sloped terraces and allowing to flow across vegetated surface to run- off collection ditches. And lastly, Infiltration – percolation method involves effluent application by spreading in basins or by spraying. Almost all of the water so applied reaches the groundwater.

(i) Solid Wastes

Solid waste (mostly garbage and industrial waste) is disposed in landfills where it decomposes and produces leachate that can pollute underlying groundwater. A landfill may be defined as any land area serving as a depository of urban or municipal solid waste. Leachate from a landfill can contaminate groundwater if precipitation, surface water infiltration, percolation from adjacent land moves through the fill material. This hazard can be reduced by proper landfill design, construction and operation. (Tchobanoglous et al., 1977)

Pollution from landfills is greatest where high rainfall and shallow water tables occur. The main pollutants frequently found in leachate include: -

- Biological oxygen demand (BOD). This is a measure of the dissolved oxygen consumed by microbial life while assimilating and oxidising the organic matter present in water.

- Chemical oxygen demand (COD). This is the amount of oxygen consumed under specific conditions to chemically oxidize a sample of wastewater under stated laboratory condition (refluxed at 100 ^{0}C for 2 hours, concentrated in sulphuric acid and strong oxidizing agent and a catalyst).
- Manganese, nitrates, chlorides, iron and other heavy metals.

Table 2-2 – shows composition of typical landfill leachate.

Table 2-2 Chemical composition of landfill leachate. (Tchobanoglous et al., 1977)

	NORMAL RANGE Mg/l	**UPPER LIMITS** Mg/l
Calcium	240 – 2330	4080
Magnesium	69 – 410	15600
Sodium	85 – 3800	7700
Potassium	28 – 1700	3700
Iron	0.1 – 1700	5500
Manganese	-	1400
Zinc	0.01 – 0.8	1000
Nickel	0.01 – 0.8	-
Copper	0.1 – 9	9.9
Lead	-	5.0
Chloride	47 – 2400	2800
Sulphates	20 – 730	1826
Phosphates	0.3 – 130	472
BOD	21700 – 30300	54610
COD	100 – 5100	89520
pH	3.7 – 8.5	8.5
Hardness ($CaCO_3$)	200 – 7600	22800
Alkalinity ($CaCO_3$)	730 – 9500	20890
Total dissolved Solids. (TDS)	-	422276

2.2.2 Industrial sources of groundwater pollution

Liquid wastes.

Water from industrial plants is mainly used for cooling, sanitation, manufacturing and processing. Groundwater can undergo pollution where industrial wastewater is discharged into pits, ponds or lagoons and thereby enabling the wastes to migrate down to the water table. Hazardous and toxic industrial wastes can sometimes be disposed off by the means of deep injection wells that place the fluids into saline water formation far below developed freshwater aquifers.

Oil leaks and spills

For industrial and commercial installations, underground storage and transmission of a wide variety of fuels and chemicals are common practices. These tanks and pipelines are subject to structural failures so that subsequent leakage becomes a source of groundwater pollution.

Gasoline and other petroleum products can enter soils and aquifers from leaking pipelines or storage tanks and even from accidents involving tank trucks or railroad cars. The main problem of petroleum pollution of ground water is taste and toxicity. The water is undrinkable due to taste and odour with even small concentration.

2.2.3 Agricultural sources of groundwater pollution

In the modern world, agriculture is based on extensive use of fertilizers and pesticides to obtain high crops yields. Some of the chemicals applied to farmland, however, move down with the deep-percolation water from the root zone and can contaminate underlying groundwater.

Agriculture is a major source of groundwater pollution and some of the pollutants are: -

- Pesticides

Pesticides are chemical by virtue of their toxicities (poisonous properties) used to kill pest organisms. Pesticide is a term of wide application, which includes all the more specific applications – insecticide, acaricide, bactericide, fungicide, herbicide, molluscicide, nematicide, rodenticide, etc. (Jones, 1974)

Large scale production of synthetic pesticides began in the 1940's. In addition to agriculture, industry and homeowners also use pesticides. Most of the pesticides are chlorinated hydrocarbons. These have been synthesized in various laboratories since 1930. They contain carbon, hydrogen and chlorine thus their name " chlorinated hydrocarbons".

Pesticides constitute a recognised class of chemical compounds. Some are commonly known by their trade name such as DDT, aldrin, chlordane, dieldrin, endrin, malathion, fenthion, parathion, menazon and heptachlor. DDT was banned because of it universal poisons, slow degradation and fat – solubility. These pesticides kill not only the insects, but also fish, birds, invertebrates and mammals (including man).

Chlorinated hydrocarbons are soluble in fat but insoluble in water or blood. If small amounts of these compounds enter the body, they will concentrate in fatty tissue and cannot be washed away very efficiently by the blood. Thus, pesticide concentrations slowly build up in the bodies of animals, and are harmful.

The other group of pesticides is the organic phosphates, and includes malathion, parathion, chlorthion, diazinon, guthion, diptherex and demeton. In addition, organic phosphates decompose in less period than DDT but they are non-selective poisons. Non-target animals (including man) have been killed, many insects have become resistant, and predator and parasite insect populations have been decimated.

Pesticides contamination of surface and groundwater is a present concern and has stimulated researching on them in order to understand the fate and redistribution of these chemicals in water environments. The pesticide comes to surface water through runoff events and to groundwater through leaching. Whether pesticides that leach into the groundwater pose a hazard to humans or animals depends on the toxicity and concentration of the compounds and how they 'degrade' or break down as they move through the soil.

In Italy (Pavia), attrazine was detected in wells with maximal values of about 4 υ*g* /litre (Leistran and Boesten, 1989). The impact of pesticides on groundwater quality depends on the properties of the pesticides, rainfall or irrigation rates and soil characteristics. The chance for pesticide contamination is much greater for surface water than for groundwater because pesticides tend to be adsorbed by soil particles. But adsorption can result to a potential long term source of pollution.

Pesticides are also used around homes, and on turf and gardens. The most commonly used pesticide around households is the 2,4-D contained in "weed and feed" lawn fertilizer formulations. Also used around households are malathion, carbaryl, and diazinon. Organic pollutants from fuels, solvents, etc (excluding pesticides) - common pollutants in this category include benzene, toluene, dichlorethane, trichloroethylene, and others. Instances of this pollution are relatively rare, usually cover small areas, and frequently are related to accidents. Most are due to old spills around gas stations, dry cleaners, industrial sites, and pipelines.

- Animal waste

The animal wastes are point sources of pollution that can contaminate groundwater via leachate that infiltrates directly into the soil below the waste or via surface run- off that infiltrates elsewhere. This occurs due to confinement of animals or damping (heaping) of waste from animals at a point. Animal waste may transport salts, organic and bacteria into the soil. The nitrate is the most important persistent pollutant that may reach the water table, as it is soluble in water.

- Fertilizers

Application of fertilizers in agricultural land leads to the leaching of a portion of the fertilizers through the soil and the water table. Primary fertilizers are compounds of nitrogen, phosphorous and potassium. Nitrogen in solution is the primary pollutant. The nitrate ion derived from nitrogenous fertilizers and other sources like animal wastes, atmosphere (through nitrifying bacteria) is completely mobile and can be leaching out of the upper soil layers by infiltrating water to the underlying groundwater. At higher nitrate levels in water, young infants (less than 4 months old) could die of methemoglobinemia or blue- baby disease. Since gastric juices of such infants lack sufficient acidity, nitrate – reducing bacteria can grow in their upper intestinal tracts, which reduce the nitrates ingested to nitrites. The nitrites react with haemoglobin to form mathemoglobin.

In adults, the nitrate may play a role in the production of nitrosamines in the stomach, which are well known carcinogens (Wolff and Wassermann, 1972). Since the nitrate is a contaminant whose repercussions are lethal its concentrations in public water supplies should be seriously monitored and should not exceed 10 mg/l (WHO, 1993). Lime, gypsum and sulphur are applied as soil amendments to alter physical or chemical properties of soil. Substantial amounts of these may leach to the groundwater thereby increasing salinity.

2.2.4 Low cost sanitation.

The unavailability of piped water, scattered housing, local customs, and slow economic and technological development may make low cost alternative methods of excreta and wastewater disposal more feasible at a particular point in time. In considering the technologies for excreta disposal to be used for rural areas and fringe urban areas as well, evidently the conventional public water-borne sewerage system is not feasible because of the cost of the pipe and the appurtenances, in-house pumping, quantities and cost of water required. Instead there are a series of options at hand including the following: -

1. Household facilities:

- Pit latrines.
- Composting toilets.

- Aqua privies and septic tanks.

2. Community facilities

- Bucket latrines, cart collection etc.

Cultural and institutional factors also play an extremely important role in obtaining user acceptance of sanitary latrine facilities. Latrines if properly located, constructed, and maintained can be acceptable, economical and sanitary devices for the disposal of human excreta where waterborne sewerage disposal systems are not provided or not practical.

Public sewers and treatment plants are not necessarily the indicated or universal solution for all situations, particularly in developing areas of the world. Their construction, operation, maintenance and repair cost can be prohibitive or impractical. (Michael, 1978)

2.2.5 Pit latrine.

Pit latrine normally consists of a hole dug in the ground, a covering slab made of wood, concrete overlying wood, and some sort of structure built for privacy. The structures are often well built with brick walls and are fitted with doors and a roof above the hard bedrock. Most pit latrines smell or emit offensive oduors and act as breeding site for flies. Pit latrine remains to date one of the most widely used technologies for excreta disposal in the tropics though in many developing countries it still takes second place to indiscriminate defecation in the fields. Open –pit latrines, private as well as communal, are often unpleasant and unhealthy places (Shelat and Mansuri, 1971).

Pit latrine remains one of the few technologies afforded by the rural population. The 'dry' pit privy, which receives only faece and urine, can become 'wet' through the additional of water. The two major disadvantages of wet pits are the increase in fly and mosquito breeding caused by excessive water in the pit and the possibility of infiltration of contaminated water into the surrounding soil. Early research on pit latrines in the U.S (Caldwell, 1938) showed that the presence of water significantly increased the distance that coliform organisms traveled, up to 10 m from the pit. In contrast, coliforms from a dry pit in sandy soil contaminated a distance around the pit of only 30 cm.

On the other hand, increased moisture in the wet pit enhances decomposition of the excreta. Digestion of solids is more rapid and more complete in wet pits, which increases the life of the pit privy by a factor of almost two (Wagner and Laneix, 1958). When designing the pit privy, consideration must be taken of such factors as water use practices, subsoil characteristics, population densities, and location of the nearest dug-well water supply.

Earlier research findings (Baars, 1957) confirmed observations of Caldwell that as the soil around the pit becomes saturated with fine faecal particles movement of water is retarded through this 'filter' and the death rate of faecal organisms increases. Thus in homogeneous soils the chance of groundwater pollution is greatly minimised if the bottom of the latrine is more than 1.5 m above the water table. (Wagner and Lanoix, 1958).

Septic tanks

The most widely distributed potential source of groundwater pollution is septic tanks. They consist of compartmentalized vault within which settlement and some liquefaction of the solids will take place and leaching field where most of the biological treatment of the septic tank effluent occurs. All of the household wastewater goes into the tank in addition to the excreta and flushing water.

Cemeteries

The bodies in graveyards decompose producing fluids that can leak to underlying groundwater. Groundwater in areas with high rainfall and high water tables are most vulnerable. Abstraction points close to graveyards experience water with a " sweetish taste and infected odour" (Van haaren, 1951).

A human corpse on average contains 10 kg protein, 5 kg fat and 0.5 kg carbohydrate. Observations under Dutch climatic conditions showed average chemical parameters of shallow groundwater as shown in Table 2.3. (Van haaren, 1951)

Table 2-3 Chemical parameters of shallow groundwater

Parameter	Concentration, Mg/l
COD	95
Chloride	500
Sulphate	300
Bicarbonate	450

2.3 GROUNDWATER CHARACTRISTICS

2.3.1 INTRODUCTION

Practically all types of water, i.e. runoff water, groundwater and even rainwater, contain some dissolved salts and impurities. If certain elements are present in quantities above maximum allowable limits, the application of the water to domestic use or other purpose may have adverse effects. The quality of groundwater is of great importance in determining the suitability of a particular groundwater for a certain use e.g. irrigation, drinking and industrial applications, etc. Groundwater quality is influenced by the quality of its source.

The quality of groundwater is the resultant of all processes and reactions that have acted on the water from the time it condensed in the atmosphere to the time it is discharged by a well or a spring. The composition of groundwater is dependent on natural factors such as geological, topographical, biological, meteorological and hydrological processes in the drainage basin. Water to be used for a public supply must be portable. It should not be chemically pure because water devoid of dissolved and suspended matter is both unpalatable and unhygienic.

The water pollution can be classified as follows:

- Polluted water is defined as otherwise inoffensive water fouled by sewage or other liquids or suspensions rendering it offensive to sight, smell, unsatisfactory for drinking and domestic or industrial purposes.
- Contaminated water is that polluted specifically by the introduction into otherwise potable water of toxic materials, bacteria, or other deterious substances that make the water unfit for use.
- Infected water is that contaminated with pathogenic organisms.

Groundwater water may be hard, high in dissolved CO_2, and relatively high in dissolved minerals.

Generally, basement complex waters are permanently hard, with low total dissolved solids (TDS) and fluoride content seldom exceeding World Health Organisation limits (WHO 1985). However, at local level significant peak concentrations of chloride, sulphate, fluoride, sodium, calcium and potassium ions can occur, especially where groundwater is shallow, groundwater flow is low or absent and the evaporation rate is high.

The factors that determine the degree of salinity in Basement Rocks are: -

- Evaporation and Transpiration

Direct evaporation by the heat of the sun and preferential uptake of certain mineral ions by plants can, in certain environments, lead to salinition.

- Dissolution of Evaporates

The process of evapotranspiration may, in arid conditions, lead to the precipitation of salts in the unsaturated zone. These salts may then be carried down to the groundwater store during periods of rain, thus leading to high ion concentrations in space and time. This process is exacerbated in an intensely seasonal climatic regime. Dissolution is a function of solar radiation, difference in vapour pressure between a water surface and the overlying air, temperature, wind, atmosphere pressure and the quality of evaporating water.

- Dissolution of host rock

Given relatively long residence times and fairly high ambient temperatures in groundwater systems, progressive salinity of groundwater can be expected via the host rock. This will vary according to local geology, local structures (which may speed the passage of water through an aquifer by means of faults, etc, and so limit retention time), local climate and so on. Human intervention also has significant effects on water quality. More obvious are the polluting activities, such as the discharge of domestic waste, solid waste disposal in landfills and wide spread use of chemicals on agricultural activities. To establish quality criteria, measures of chemical, physical, biological and radiological constituents must be specified.

2.3.2 Physical characteristics

These relate to the quality of water for domestic use and are associated with the temperature, appearance of water, turbidity, taste, odour and its colour. They are relatively easy to measure and some may be readily observable by a layman.

Temperature

It is important for its effect on the other properties e.g. speeding up or retarding of chemical reactions, reduction in solubility of gases, amplification of tastes and odours. Temperature is normally measured immediately after sample collection. At higher temperature, the biological activity is high. Temperature is a rough indication of biological activity in water. Water having a temperature between $10^0C - 15^0C$ is most palatable. Identification of source of water supply, such as deep wells, often is possible by temperature measurements alone.

Groundwater temperature for the first hundred or so feet below ground level is approximately that of the local average annual air temperature. Impoundment that leak or are meant to recharge will recharge warmer than ambient groundwater in hot weather and cooler than ambient groundwater in the cold weather.

Taste and oduor

Taste and odour in water are caused by dissolved impurities, often organic in nature e.g. phenols and chlorophenols. Alkaline material impacts a bitter taste to water, while metallic salts may give a salty or bitter taste. These salts include magnesium sulphate (Epsom salt), sodium sulphate (Glauber's salt) and sodium chloride (common table salt). Consumers find taste and oduor esthetically displeasing for obvious reasons. Oduors produced by organic substances may pose more than a problem of simple aesthetics, since some of those substances may be carcinogenic.

Taste and odour are subjective properties, which are difficult to measure. Oduor evaluation is dependent on the olfactory senses of the tester and on the ability to distinguish between different levels and kinds of oduors.

Odour is recognised as a quality factor affecting water in several ways. These include: -

1) Acceptability of drinking water (and foods prepared there from).
2) Tainting of fish and other aquatic organisms.
3) Aesthetics of recreational waters.

Most organic and some inorganic chemicals contribute taste and odour. Taste is simpler than odour. There are four true taste sensations: sour, sweet, salty and bitter. Dissolved inorganic salts of copper, iron, manganese, potassium, sodium and zinc can be detected by taste.
The standard test method for odour and taste is the threshold dilution method whose result is expressed in terms of the threshold oduor number (T.O). The test temperature is also reported.

Colour

Pure water has a pale green- blue tint in large volumes. It is necessary to differentiate between true colour due to material in solution and apparent colour due to suspended matter. Water containing natural colour are yellowish- brownish in appearance. Natural yellow colour in water from upland catchments is due to organic acids, which are not in any way harmful being similar to tannic acid from tea.

Nevertheless, many consumers object to highly coloured water on aesthetic grounds and coloured waters may be unacceptable for certain industrial uses e.g. production of grade art papers.

The guideline value is true colour Units (TCU). Most people can detect levels of colour above 15 TCU in a glass of water. (WHO, 1993)

Turbidity

Turbid water contains suspended matter that interferes with passage of light through the water or in which visual depth is restricted. Turbidity occurs due to a wide variety of suspended materials, which range in size from colloidal to coarse dispersion depending on the degree of turbulence.

The presence of colloidal solids gives liquid a colour appearance, which is aesthetically unattractive and may be harmful. It is caused primarily by clay, salt, organic matter and other fines, which enter a well. The natural filtration produced by unconsolidated aquifers largely eliminates turbidity. It is usually expressed in terms of reduced light transmission by water Nephlometric Turbidity Unit (NTU). Absolute turbidity is the fractional decrease of incident monochromatic light through a 1-cm layer of a sample, integrating both scattered and transmitted light. Nephelometric turbidity is an empirical measure of turbidity based on measurement of the light scattering characteristics (Tyndall effect) of the suspended matter in a sample. It is determined by reference to a chemical mixture that produces a reproducible refraction of light.

Suspended Solids

These may be present in suspended and/or in solution and they may be divided into organic and inorganic matter. Total dissolved solids (TDS) are due to soluble materials whereas suspended soluble (SS) are discrete particles, which can be measured by filtering a sample through a fine paper. Inorganic solids such as clay, silt and other soil constituents are common in surface water. Because of the filtering capacity of the soil, suspended material is seldom a constituent of groundwater.

Suspended material may be objectionable in water for several reasons. It is aesthetically displeasing and provides adsorption sites for chemical and biological agents. Biological active (live) suspended solids may include disease- causing organisms as well as organisms such as toxin producing strain of algae. Settable solids are those removed in a standard settling procedure using a 1-litre cylinder. They are determined from the difference between suspended solids in the supernatant. Suspended materials are large enough to settle out at reasonable rates and to be retained by many common filters. They are also large enough to absorb light and thus make the water they contaminate look cloudy or murky.

Total solids

The residual left in a drying dish after evaporation of a sample of water or wastewater and subsequent drying in an oven. It can also be defined as the total concentration of dissolved constituents in solution, usually expressed in milligrams per litre. The total solids determination is used to determine the suitability of potential supplies for development. A case in which water softening is needed, the type of softening procedure used may be dictated by the total solids content.

Water with a total solids content of less than 500 mg/l are most desirable for domestic use. In many areas, it is impossible to find natural waters with solids content under 500 mg/l; consequently it is impossible to meet this desired level without some form of treatment. Standards generally recommend an upper limit of 1000 mg/l on potable waters (Sawyer et al., 1994).

Dissolved solids

Dissolved solids can be defined as weight of matter in true solution in a stated volume of water, including both inorganic and organic matter. Dissolved solids are the solids that pass through the glass–fiber and are calculated from total and suspended solids analyses. Total dissolved solids equals total solids minus suspended solids.

Electrical conductivity

The conductivity of a solution depends on the quality of dissolved salts present. The total dissolved salts should not exceed 1500 mg/l (WHO, 1993). Conductivity is a numerical expression of the ability of a water sample to carry an electric current. It is an indirect way of determining total dissolved solids.

For inorganic species, the electrical conductivity of the water is directly proportional to the total dissolved salt. Because specific conductance is an electrical measurement, solutes not contributing ionic species (most organic compounds) will not be reflected in the measurement.

Conductivity is usually measured in microsiemens per centimetre (υS cm-1) is equivalent to specific conductance, that is, the capacity of a 1cm cube of a substance at 25 ^{0}C to conduct an electric current. In most natural waters the value of constant A is between 0.55 and 0.75 (Hem 1970). Although there are no exact relationship between conductivity and total dissolved solid. But in polluted groundwater, where the ionic composition is more complex, the relationship between conductivity and total dissolved solid is more variable. As a general rule the higher the conductivity, the greater the concentration of dissolved solids. Conductivity can therefore be used as a rapidly determined broad indicator of groundwater quality

The Table 2.4 below shows the comparison of maximum contaminant levels. The figures are adopted from American Water Works Association (AWWA, 1998) and the Kenya Bureau of Standards (KBS, 1985).

Table 2.4 Maximum contaminant levels and goals

CONTAMINANT	AWWA Goals	KBS Requirements
Turbidity	5 FTU	< 0.1 FTU
Colour	15 °H	< 3 °H
Oduor	Unobjectionable	None
Taste	Unobjectionable	Unobjectionable

In addition, the world health organisation water acceptable characteristics are given below.

Table 2.5 Water acceptable physical characteristics (WHO 1993).

Physical constituents	**Concentration mg/l**
Colour	5 °H
Odour	Not odourless
Turbidity	5 FTU
Total solids	1000 mg/l

2.3.3 Chemical characteristics

The common parameters in this category include - Alkalinity, hardness, pH, suspended solids, acidity and the various ions like calcium, manganese, magnesium, sodium, potassium, fluoride, chloride, etc.

pH

It is the intensity of acidity or alkalinity of a solution. It actually measures the concentration of hydrogen ions present. Groundwater is alkaline in nature due to the presence of mineral salts. If the water is highly alkaline, it is unpalatable, and consumers tend to seek other supplies. The pH of water in its natural state varies from 5.5 to 9.0. But for a neutral solution, the pH is numerically equal to 7.

Alkalinity

Alkalinity of water is a measure of its capacity to neutralise acids. The compounds result from the dissolution of mineral substance in the soil and atmosphere. Materials that exhibit a pH of greater than 7 are alkaline. In groundwater and other natural waters, it is produced by salts of weak acids. Carbonate and bicarbonate ions and hydroxyl ions represent the major form of alkalinity. Alkalinity is expressed as the equivalent concentration of $CaCO_3$. The amount of acid reacting with hydroxide, carbonate and bicarbonate represent the total alkalinity.

As groundwater is commonly in the range pH 6 to 8, the contribution to total alkalinity by OH^- and CO_3^{2-} is negligible, and alkalinity due to the bicarbonate ion is the only capacity actually measured, for this reason total alkalinity is often (inaccurately) referred to as bicarbonate concentration. Determination of alkalinity is of importance in water softening as it helps in calculating the amount of lime and soda ash required and corrosion control. In large quantities, alkalinity imparts a bitter taste to water.

Hardness

This results from the presence of divalent metallic cations of calcium and magnesium. Due to their presence, hard water results, which is a menace to most of household activities. Hard water retards the cleansing action of soaps and detergents. Hard water when heated deposits a hard scale in kettle, heating coils or cooking utensils with a consequent waste of energy.

The degree of hardness in water is commonly based on the classification in Table 2.6

Table 2.6 degree of hardness.

Degree of hardness	Hardness, mg/l as $CaCO_3$
Soft	0 – 75
Moderately hard	75 – 150
Hard	150 – 300
Very hard	Over 300

(Sawyer & McCarty, 1994)

Dissolved oxygen

It is present invariable quantities in ground water. The amount of oxygen that water can hold is small and is affected by the temperature, the higher the temperature, the smaller is the amount required for saturation. Dissolved oxygen should be differentiated from the oxygen that is chemically united with hydrogen to form water.

Chlorides

The presence of chlorides in a concentration higher than is found in natural waters in a region is an indication of pollution. High chlorides are undesirable for some industrial purposes and may increase corrosiveness of the water. Chloride concentration in excess of 250mg/l usually produces a noticeable taste in drinking water. There are no adverse human health effects from the presence of large quantities of chlorides. However, it is important to note that large amounts of chloride where calcium and magnesium are also present increase water's corrosiveness and may adversely affect metallic equipment.

Fluoride

The natural occurring form of fluoride is commonly found in trace amounts in most soil and rock. Fluorine forms 0.078% of the earth's crust and is thus more abundant than chlorine 0.055% (Elrashidi, 1986). Groundwaters usually contain fluoride ion dissolved from geologic formations. Fluoride has some notable chemical as well as physiological properties of great importance to human health. The chemical activity of fluoride ion makes the ion physiologically very reactive. With low concentrations of fluoride ion, enzymatic processes may be either inhibited or stimulated while interaction with other organic or inorganic body components may occur (WHO, 1970).

The maximum limit permitted under the public health services standard is 1.5 mg/l (KBS, 1985). Low levels of fluoride result in increasing incidence of carries in children's teeth. A minimum amount of fluorides is desirable in potable water to aid in the prevention of dental carries. The maximum amount is limited to the need for the prevention of fluorosis, a defect of the enamel of the teeth.

Phosphate

Phosphate – phosphorus appear exclusively as phosphate (PO_4^{3-}) in aquatic environment. There are several forms of phosphate, e.g. orthophosphate, condensed phosphates (pyro-, meta-, and polyphosphates), and organically bound phosphates. Phosphates are constituent of soils and are used extensively in fertilizer to replace and/ or supplement natural quantities on agricultural lands. Phosphate is also a constituent of animal waste and may become incorporated into the soil in grazing and feeding areas.

Concentration of phosphate as low as 0.2 mg/l interferes with the chemical coagulation of turbidity. Phosphates are measured directly, while condensed forms must be converted to orthophosphate by acid hydrolyzation and organic phosphates must be converted to orthophosphate by acid digestion. Results of the analysis are reported as milligrams per liter of phosphate as phosphorus.

Nitrates

Nitrate (NO_3) is a compound that contains nitrogen and oxygen. Nitrogen comes from decomposing organic materials like manure, plants, and human wastes. Often the nitrogen (N) comes from ammonia (NH_3) or ammonium (NH_4). Basically, plants need nitrogen to make amino acids and proteins, which are essential for plant growth. Plants cannot use organic nitrogen directly. "Microorganisms in the soil convert the nitrogen locked up in crop residues, human and animal wastes or compost to ammonium (NH_4). A specific group of microorganisms convert ammonium to nitrate (NO_3)" (Jackson Gary and Webendorfer Bruce, 1983). Since nitrate is water-soluble, excess nitrate not used by plants can leach through the soil and into the groundwater.

The drinking water standard (10 ml/l as nitrate-nitrogen) is based on the risk of methemoglobinemia (blue baby disease) to infants. Other countries have adopted similar standards. Other concerns over health risks associated with nitrate in drinking water have been expressed regarding non-Hodgkins lymphoma, gastric cancer, hypertension, thyroid disorder, birth defects, and miscarriage. Besides human health, concerns about nitrate include toxicity to livestock, fish eggs and fry, amphibian eggs and tadpoles, and the formation of the "Dead Zone" in the Gulf of Mexico.

Sulphates

Concentration of sulphates in excess of 250 mg/l may restrict the use of water by certain industries. The sulphates of calcium and magnesium cause hardness, which forms a hard and troublesome scale in steam boilers and water heaters. The presence of sulphur compounds may be a factor in the corrosive qualities of water since certain bacteria, may utilise sulphates in the production of sulphuric acid to corrode exposed materials.

Heavy metals

Heavy metal are metallic elements including the transition series, which include many element required for plant and animal nutrition in trace concentrations but which become toxic at higher concentrations. Heavy metals are generally defined to include those metals of atomic weight higher than that of sodium and having a specific gravity in excess of 5.0. The concept of toxicity is usually associated with these terms and consequently may be applied so as to include iron, zinc, selenium, titanium, manganese, copper, vanadium and lead. These are essential elements because they are necessary for biological functions i.e. without them life does not exist or exists at unhealthy level.

Arsenic, barium, cadmium, chromium, mercury, nickel, selenium and thallium are toxic metals affecting the internal organs of the human body. Arsenic is widely distributed in waters at low concentrations, with associated instances of higher concentration in well waters. Chromium is amphoteric and can exist in water in several valence states. The content in natural waters is extremely low because it is held in rocks in essentially insoluble trivalent forms. Acute systemic poisoning can result from high exposures to hexavalent chromium. Presence of metals in potable waters is a matter of serious concern because of the toxic nature of these materials.

Iron and Manganese

The presence of iron and manganese is common in groundwater. Iron is widespread in nature, and is very abundant occurring at concentrations of about 50,000 mg/kg in the earth's crust (Oehme, 1974.) Iron occurs in minerals like biotite, magnetite, pyroxenes, ferric oxides and hydroxides. In groundwater, the common form of iron is the soluble ferrous ion (Fe^{2+}). When exposed to atmosphere it is oxidized to the ferric state (Fe^{3+}), which is insoluble and causes brown discolourations of water.

Iron bacteria capable of using dissolved compounds containing iron include crenothrix, leptothrix, pirophyllum, gallionella and others. The organism utilises iron and deposit ferric hydroxide. Iron bacteria oxidise ferrous iron to ferric iron and precipitates ferric hydrate. Some sulphur bacteria increase acidity and this tends to dissolve iron. Under specific conditions insoluble iron sulphate may be produced. Sulphate reducing bacteria may cause the precipitation of the iron by the production of sulphate from the reduction of sulphate. These bacteria also affect the aerobic corrosion of iron.

Copper

It is widely distributed in the environment and is essential to human life, but potentially toxic at elevated levels of exposure. Copper is essential to humans. Copper acts as a catalyst in the formation of haemoglobin and is also involved in haemopoisis, maintenance of vascular and skeletal integrity, structure and function of central nervous system (Norconsult, 1975). As an indicator of corrosivity, has a no- action level of 1.3 mg/l in first- flush samples.

The metal is readily adsorbed onto the particulate material, very little being present as free Cu^{2+} ion except stability constants of these complexes. Most copper complexes are labile and equilibria are readily established. The main pollution sources of copper are power plants, municipal wastewater discharge, industrial processes and agriculture.

Selenium

Selenium is a trace metal naturally occurring in soils derived from some sedimentary rocks. Selenium has a toxic effect on man and animals comparable with that of arsenic giving rise to similar symptoms. Selenium also has been suspected of causing dental carries in man and of being a carcinogenic agent. The selenium concentration of most drinking water is less than 0.01 mg/l. Concentrations exceeding 0.5 mg/l are rare and limited to seepage from seleniferous soils.

Strontium

Strontium chemically resembles calcium and causes a positive error in gravimetric and titrimetic methods for the determination of calcium. Because strontium has a tendency to accumulate in bone, radioactive strontium 90, with a half – life of 28 years presents a well recognised peril to health. The natural occurring strontium is not radioactive. For this reason, the determination of strontium in a water supply should be supplemented by a radiological measurement to exclude the possibility that the strontium content may originate from radioactive contamination.

Zinc

Zinc is non-cumulative, and the amount absorbed is thought to be inversely prepositional to the amount ingested. Zinc was first demonstrated to be essential element for mammals over 45 years ago. Zinc is an essential and beneficial element in body growth. The clinical symptoms of zinc deficiency are anorexia, pica, impaired taste acuity, menstrual lethargy and disturbances, viz: rough, dry skin, impaired wound healing and increased susceptibility to infection, chronic deficiency in pediatric and adolescent age group causes growth retardation and delay of sexual maturation (Casey, 1980). Acute zinc toxicity results in haemodialysis, characterised by nausea, vomiting, fever and severe anaemia. However, concentrations above 5mg/l can cause a better astringent taste and opalescence in alkaline waters (Gallery et al, 1972).

Titanium

Titanium occurs rather abundantly in the earth's crust and is used in large variety of industrial processes (Mason, 1966). Titanium mainly interferes with two types of enzyme action. It inhibits bone growth and interferes with the carbohydrate metabolism (Braunwald et al, 1987).

Table 2.7 shows the limits of some water characteristics parameter.

Table 2.7 Water acceptable chemical characteristics (WHO, 1993)

Chemical constituents	**Concentration mg/l**
Dissolved oxygen	5.0 mg/l
pH	7 –8.5
Chloride	200 mg/l
Copper	0.05 mg/l
Iron	0.1 mg/l
Manganese	0.05 mg/l
Fluoride	1.5 mg/l
Sulphates	200 mg/l
Zinc	5.0 mg/l
Selenium	0.01 mg/l

2.3.4 Radiological Characteristics

Radionuclides are elements that undergo nuclear decay. Nuclear decay is the process by which atoms split to form other atoms and in the process emit potentially harmful radiation. A number of radioactive elements - radium, radon, uranium, thorium, and others - occur in the bedrock aquifer, particularly at greater depths. The USEPA is in the process of revising standards for radioactivity in drinking water. The current standards are: "combined radium 226/228 of 5 pCi/L; a combined standard of 4 mrems for beta emitters; and a gross alpha standard for all alphas of 15 pCi/1, not including radon and uranium" (USEPA, http://www.epa.gov/ogwdw000/standard/radionuc.html).

2.3.5 Microbiological Characteristics

Water for domestic use must be free from disease causing pathogens. These include viruses, protozoa, bacteria and helminthes (worms). Microbiological agents are very important in their relation to public health and may also be significant in modifying the physical and chemical characteristics of water. Microorganisms (bacteria, viruses, and others) are everywhere in the environment, including aquifers and groundwater. Most are harmless or even beneficial, but some can cause disease and others create nuisance conditions.

Coliform bacteria and fecal coliform bacteria are frequently analyzed in water samples. Coliform bacteria are a broad group that has members who live in soil, water, vegetation, and in the gut of animals. Feacal coliform bacteria are members of the group who specifically live in the gut. Most members of the coliform group do not cause disease, however, they are good indicators that a breach exists in the sanitary condition of a water system. Generally, coliform bacteria are usually not present as a groundwater contaminant, but rather, enter wells via a defect (missing well cap, a cracked casing, poor well construction) or an unsanitary condition adjacent to a well (e.g., a privy near a shallow well).

Drinking water should be free from bacteria indicative of excremental pollution. To ensure that a supply of drinking water satisfies these guidelines, it is important that samples should be examined regularly for indicators of faecal pollution. Contamination of drinking water by human or animal excrement constitutes the most directly, but also indirectly, through food preparation. The primary objective of the bacteriological examination of portable water is thus the detection of faecal pollution. For water to be portable, the total Coliform counts per 100ml of samples taken from a representative point in water supplies should be less than one. The faecal Coliform Count should always be zero (WHO, 1993).

The biological analysis of water gives an indication of the quality of water in relation to its potability, wholesomeness and the degree of treatment required to render water safe for human consumption.

3.0 MATERIALS AND RESEARCH METHODOLOGY.

3.1 Introduction.

The research was carried out through conducting several tests in the laboratory. Water samples for tests were obtained from the various boreholes and wells within the region. The water samples for various water sources were analysed and results tabulated. The precision of measurements was obtained by carrying out several tests on each source. The work was carried out in five months between July and December 2002. Four samples were tested and average obtained for each month. The water samples were obtained during the morning hours and afternoon hours.

3.2 Parameters to be investigated.

Table 3.2.1 – 3.2.3 shows the parameters that were investigated in water samples from 12 boreholes, nine wells and three rivers.

Table 3.2.1 Physical parameters.

ITEM	PARAMETERS
1	Temperature, ^{0}C
2	Conductivity, Us/cm
3	Turbidity, FTU
4	True colour, ^{0}H
5	Apparent colour, ^{0}H
6	Dissolved solids, mg/l
7	Suspended solids, mg/l
8	Total solids, mg/l

Table 3.2.2 Chemical parameters.

ITEM	PARAMETERS
1	Ph
2	Chlorides, mgCl/l
3	Calcium hardness as $CaCO_3$,
4	Total Hardness as $CaCO_3$
5	Total Alkalinity as $CaCO_3$
6	Carbonate Alkalinity as $CaCO_3$
7	Fluorides, mg/l
8	Sulphate, mg/l as SO_4^{2-}
9	Phosphates, mg/l as PO_4^-
10	Dissolved oxygen, mg/l
11	Nitrates, mg/l as NO_3^-
12	Iron mg/l as Fe
13	Manganese mg/l as Mn
14	Titanium, mg/l as Ti
15	Copper, mg/l as Cu.
16	Zinc, mg/l as Zn.
17	Strontium, mg/l as Sr.
18	Yttrium, mg/l as Y
19	Zirconium, mg/l as Zr.

Table 3.2.3 Microbiological parameters.

ITEM	PARAMETERS
1	Total coliform/100 mg/l
2	Total Faecal coliform/100mg/l

3.3 Water samples

The water samples were fetched from the sources using well-rinsed containers and sterilized bottles. The water samples were transported to the laboratory using hired vehicles. The water samples for microbiological and pesticides test were stored in a potable refrigerator. The water samples were obtained from the sources given below. The depth of each well was measured and recorded. For the boreholes, the depth recorded at drilling time was taken. The water sources were categorized into three groups according to depth. These categories are: 0 – 50 metres, 50 – 100 metres and above 100m.

The boreholes and wells depths are given below according to category.

A. 0 – 50 metres deep boreholes and wells.

1. Kirimiri shops' well – 0.8 m
2. Kamahuha well – 1.0 m
3. Muruithia's well - 13.8 m
4. Waweru's well at Iganjo sub-location – 14.4 m
5. Mburu Kamathi well at Igikiro – 14.7 m
6. Ndachi Mugo plot well near Kamahuha market - 16.0 m
7. Esbon's well at Iganjo Sub-location – 19.5 m
8. Gikungu's well in Iganjo sub-location – 27.0 m
9. Gichuiri's well at Sabasaba town - 27.9 m

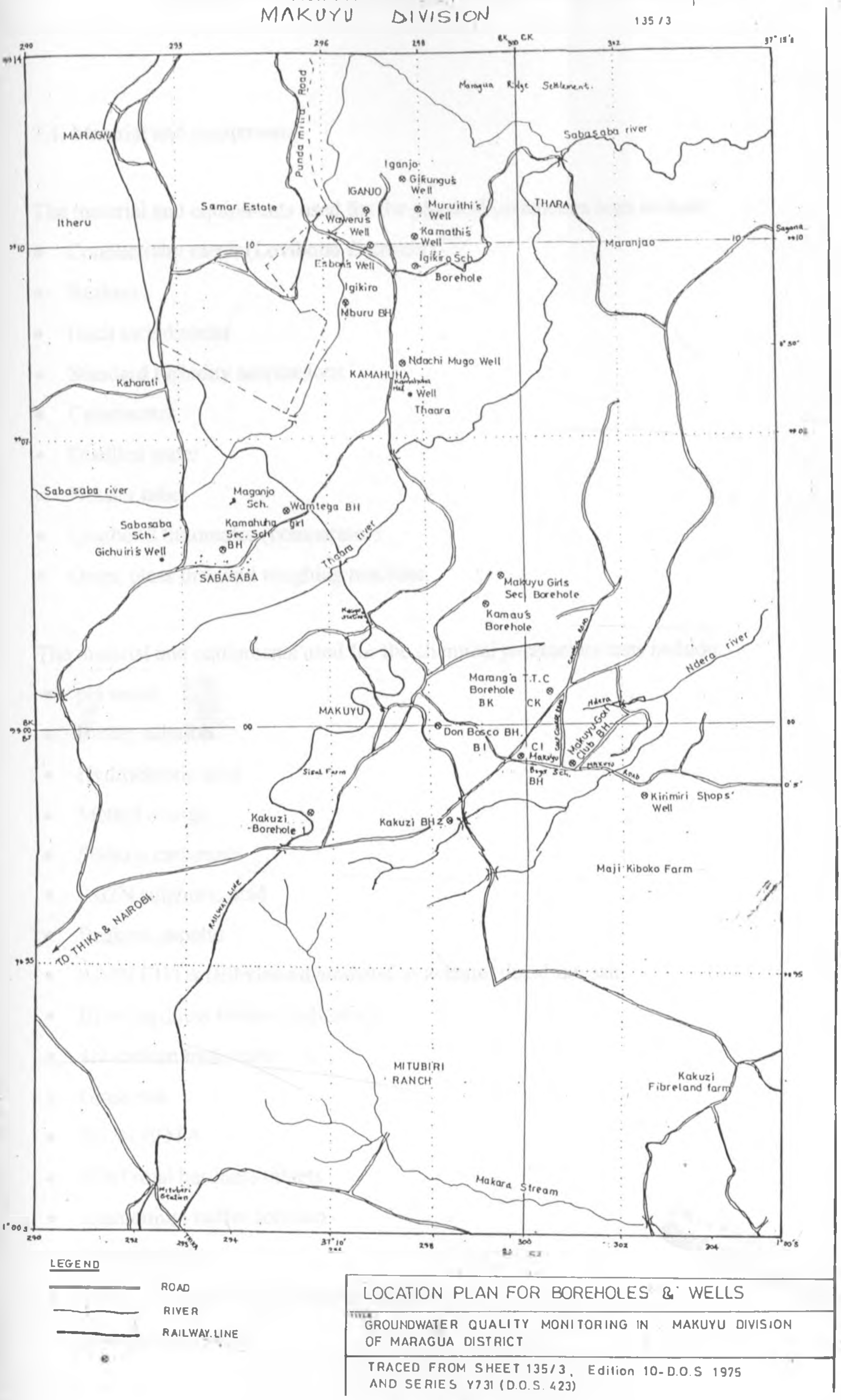
B. 50 - 100 metres deep boreholes.

1. Mburu's borehole – 50 m
2. Murang'a Teachers' Training College borehole – 75m
3. Igikiro secondary school – 80 m
4. Kamau borehole at Mohrem – 81 m
5. Makuyu Girls Secondary School borehole – 97 m
6. Kakuzi borehole 1 near Makuyu town – 98 m

C. 50 - 100 metres deep boreholes.

1. Don Bosco borehole at Makuyu – 101 m
2. Kakuzi borehole 2 near Makuyu town – 104 m
3. Makuyu Golf Club borehole – 105 m
4. Kamahuha Girls High School borehole – 108 m
5. Makuyu Boys Secondary School borehole – 120 m
6. Wamtega borehole near Sabasaba town – 187 m

The site plan of the wells, boreholes and rivers is shown in Figure 1.



LOCATION PLAN FOR BOREHOLES & WELLS

GROUNDWATER QUALITY MONITORING IN MAKUYU DIVISION OF MARAGUA DISTRICT

TRACED FROM SHEET 135/3, Edition 10-D.O.S 1975 AND SERIES Y731 (D.O.S. 423)

Figure 1. Site plan of the wells, borehole and rivers

3.4. Material and equipments

The material and equipments used for the physical parameters tests include:

- Conductivity meter (Lovibond Datronix)
- Beakers
- Hach turbidimeter
- Standard turbidity suspensions
- Calorimeter
- Distilled water
- Nessler tubes
- Lovibond tintometor (comparator)
- Oven, glass dish and weighing machine.

The material and equipments used for the chemical parameters tests include:

- pH meter
- Buffer solution
- Hydrochloric acid
- Methyl orange
- Sodium carbonate
- 0.02N sulphuric acid
- Beakers, pipette
- 0.02N EDTA (Ethylemediaminetetra- acetate) disodium salt
- BDH hardness tablets (indicator)
- 4N sodium hydroxide
- Grass rod
- 0.02N EDTA
- BDH total hardness tablets
- Ammonium buffer solution
- Conical flask
- 0.0141N standard silver nitrate solution
- Potassium chromate

- Salicylic acid solution
- Sodium hydroxide
- Spectrometer
- Gum acacia (0.5%)
- Barium chloride
- Deionised water
- HClO4 Vanado-molybdate
- Fluoride standard solution 10 mg/l
- Nessler cylinder
- 407 A Specific ion fluoride meter
- TISAB (Total ionic strength adjustment buffer)
- Glacial acetic acid and sodium chloride.
- EDPXRF spectrometer
- Ammonium pyrolidine dithiocarbonate (APDC)
- 0.45 um Millipore filter.
- Hexane
- Sodium chloride analytical grade
- Separating funnel
- Anhydrous sodium sulphate
- Gas chromatography
- Diethyl ether
- Sodium sulphate column and florisil column
- 250 ml round bottomed flask.

Lastly, the material and equipments used for the microbiological parameters tests include:

- 0.45 um Millipore filter
- Oven
- Refrigerator
- Sterilized glass.
- Petri dish
- Macorkey broth and enriched teepol.
- Pipette

3.5 Experimental procedure

The experimental procedure used was the standard methods for the examination of water and wastewater, 14th Edition 1985, except for heavy metals and pesticides.

Test for heavy metal

The test for heavy metals was done using x-ray fluorescence spectrometry (XRFS). The energy dispersion x-ray fluorescence (EDXRF) technique is a non-destructive instrumental method of qualitative and quantitative analysis for chemical elements based on measurements of the wavelength and intensities of their x-ray spectral lines emitted by secondary excitation (Bertin, 1980). The primary beam from x-ray tube or a radioisotope source irradiates the specimen (sample or standard), exciting each element to emit secondary spectral lines having wavelengths characteristic of that element. The detector receives excited lines of all the specimen elements at once and generates a pulse of electric current proportional to its photon energy.

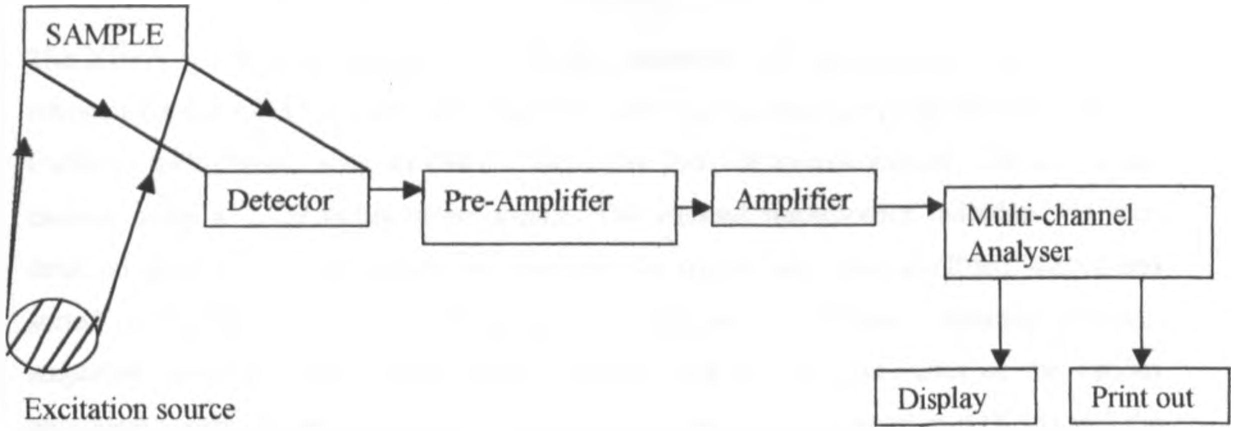
Like in all other spectrometers, the instrument has three basic parts: - the primary source unit, the spectrometer and the measuring electronics (Jenkins, 1982). The actual parts are: -

- Radioisotope source (^{109}Cd, ^{55}Fe or ^{241}Am) to act as the primary beam source. The ^{109}Cd excitation source was used in this work. It's activity was 0.218 mci. The measurement time for each filter with ^{109}Cd excitation source was 2000 seconds.
- The sample compartment. It holds the sample in a precisely defined geometry during analysis and provides for introduction and removal of the specimen during the excitation.
- Lithium – drifted silicon or germanium detector (Si/Li or Ge/Li). The Si/Li detector (Canberra S1 – 30180) was used with spectral resolution of 180 eV at Mn K alpha line and associated electronics for signal processing.
- A preamplifier and an amplifier
- The multichannel analyser (MCA) and a micro – computer.

The spectrum evaluation software was Axil IAEA QXAS whose background model was linear order 8.

Figure 2 shows a diagrammatic representation of an EDPXRF spectrometer.

Figure 2: Diagrammatic representation of an EDPXRF spectrometer.



Sample and sample preservation

The water samples were collected using well-rinsed plastic containers, which had been previously washed with hot soap solution and rinsed in deionised water. The water sample was then filtered using Whitman No. 2 filter membrane to remove suspended particles. The water samples were preconcentrated using ammonium pyrolidine dithiocarbonate (APDC) and filtered through a 0.45 um millipore filter. Standards were prepared from an analytical grade of its salt. The water used in all the work was deionised and doubly distilled.

Analytical procedures of x-ray fluorescence

Direct XRF analysis of aqueous sample is only feasible for part per million concentration of high atomic number element (Florkowski et al. 1976). The detention limits are approximately 5 to 10 part per million for such elements as copper, zinc and lead. This rather poor detection limit is due to the backscatter background and X-ray adsorption effects. To reach detection limit in part per billion ranges a preliminary chemical enrichment must be undertaken.

In this case, heavy metals were isolated by preconcentration of the solution using ammonium pyrolidine dithiocarbonate (APDC). Then, a 500 ml of the water sample was acidified to pH 3.8 using ammonium hydroxide analar or nitric acid analar and 10 ml of APDC added to it. The mixture was thoroughly shaken then filtered through a 0.45 um millipore filter. The deposit on filter paper is then analysed using XRF.

The standard solution was made from pure analytical grade salts of the elements to be tested. Adsorption correction was done on one sample using a multi-element standard and it showed that it was a thin film of sample deposited on the filter hence had negligible absorption.

The XRFA system used consisted of a 10-mci cadmium 109 radioisotope source, a liquid nitrogen cooled ORTEC, Si/Li semi-detector with a 25 micron beryllium window, an S40 Canberra multichannel analyser (MCA) and a Dec Pro-350 microcomputer. The source was excited using a ^{109}Cd radioisotope source. The emitted fluorescence radiation was then detected using a Si/Li semi conductor detector. The signals were then amplified, shaped and sorted out by the electronic system as per their energies by a system consisting of a pre-amplified, amplifier and a multichannel analyser (MCA). The intensities of the various photopeaks were determined using a quantitative x-ray analysis program (QXAS) and the corresponding concentrations calculated with the help of a pro-350 microcomputer.

QUANTITATIVE ANALYSIS OF ENVIRONMENTAL SAMPLES (QAES) PROGRAM FOR QUANTITATIVE ANALYSIS

The quantitative analysis of environmental sample (QAES), modular program of the international Atomic Energy Agency (IAEA)'s Quantitative X-ray Analysis Software (QXAS) was first calibrated for quantitative analysis by way of three sub-routines of the program available for: -

(a) Quantitative analysis of unknown samples
(b) Performing calibration of the x-ray system
(c) Calculating energy distribution of primary x-rays.

Sensitivity calibration involves determining the distribution of primary x-ray source from sub-routine (c) and intensity measurements of pure metal samples or analar compounds whose characteristic energies cover the analytical range of interest. Intensities of elements for compounds together with their real densities were input to enable the program evaluate the sensitivities and the geometrical constants.

Spectral data analysis

A Canberra S-100 PC based multi-channel analyser (MCA) was used for spectral data acquisition and storage. Both the course and fine loaded filters were irradiated for 2000 seconds using ^{109}Cd source so as to give reasonable statistics. The loaded filters were placed on the sample holder such as that the loaded side faced the source of radiation as per the recommended method (IAEA, 1996). Spectrum data analysis was done using the IAEA software, Analysis of x-ray by iterative least square fitting (AXIL). Quantitative analysis was done using quantitative analysis of environmental samples (QAES) software (Kump, 1993), which relates the spectral intensities with the elemental concentrations based on the fundamental parameter technique (Kinyua, 1982., Sparks, 1975).

Standard solutions for calibration

Standard solutions for calibration of the spectrometer were prepared before analysis. The standard used for the calibration was pure metal foil of zinc, zirconium, iron, copper, titanium, manganese, copper, strontium and yttrium. The concentration range of the standards was as per the specification of the spectrometer that is 1- 6 part per million (Shimadzu corporation, 1991). The standards were then utilized for plotting the calibration curve for the various elements to be analysed. For each element the experimentally determined geometrical constants for the measurement elements were compared with the theoretically determined value. The selected values of geometrical constants of the accepted elements were used to evaluate the average geometrical factor.

Tests for pesticides

Sample, collection, storage, processing and analysis

The water sample was collected in dark bottles from the site. The water sample was then stored in a refrigerator at 4 ^0C. On commencement of the experiment, the temperature of the water sample was restored to normal temperature i.e. 22 ^0C by giving it time to warm naturally. The water sample was neutralised to pH 7 using 0.1 M Sulphuric acid H_2SO_4. Then,

salting out was done using 100g sodium chloride analytical grade.
A 60 ml of organic solvent (Hexane) was added while shaking for two minutes and organic layer was separated using a separating funnel. This step was repeated thrice. The organic layer was then dried using 10g of anhydrous sodium sulphate in order to concentrate the content to about 5 to 10 ml. Analysis was done using Gas Chromatography. The gas chromatography has two mutually immiscible phases, which are brought into contact. One phase is stationary and the other is mobile. The water sample was introduced into the mobile phase and was carried along through a column (manifold containing a distributed stationary phase). The species in the sample undergo repeated interaction (partition) between the mobile phase and the stationary phase. When both phases are properly chosen, the sample components are gradually separated into bands in the mobile phase. Then, the gas chromatography gives the peaks at different retention times depending on pesticide detected.

A 250 ml of sample, spike and control was filtered and transferred into 500 ml separating funnel. A 5 g of anhydrous Na_2SO_4 was added and shaken vigorously for 2 minutes. Then, 50 ml of diethyl ether was added and shaken for two minutes. The phase layers were allowed to separate and the diethyl ether layer was passed through sodium sulphate column to dry.

Another 50 ml of diethyl ether was added to aqueous layer and process repeated with no addition of Na_2SO_4 The diethyl ether was collected in a round bottom flask and concentrated using the rotor vapour to remove the solvent to concentrate. Then, all the samples, control and spike solution consisting of 0.01 mix of chemicals to be analysed were made to 10 ml with hexane. Then, it was injected into the gas chromatography in the nitrogen phosphorus detector for analysis.

In addition, 100 ml of spike (Organo- chlorides and Organo-phosphates) was extracted as per method described. After extraction sample containing Organo- chlorides was cleaned. The sample was introduced in florisil column packed using 6g florisil and small cap of sodium sulphate. It was then eluted using 6%, 15%, 30% and 50% 40 ml diethyl ether and 40 ml hexane, respectively, and the fractions collected in 250 ml round bottom flask. It was then concentrated to dryness and injected into the gas chromatography in the electronic capture detector. The sample spike containing organo-phosphates was made to 10 ml with hexane before clean up and injected in nitrogen phosphate detector for analysis.

In order to verify that the technique was effective, the range of recover was calculated using a standard and a spike. The spike was 0.1 parts per million malathion. Table 3.1 shows the comparison of standard and marathion spike.

Table 3.5.1 Comparison of standard and spike.

STANDARD		SPIKE	
RETENTION TIME	PEAK AREA	RETENTION TIME	PEAK AREA
4.00	112145	4.05	117422
3.95	118221	3.88	155858
4.07	139285	4.04	149552
4.08	142336	3.90	154092
4.07	137001	3.93	155858
Average peak area	129540.67	Average peak area	146556.4

$$\% \text{ Recovery} = \frac{\text{Spike peak area}}{\text{Standard peak area}} \times 100$$

$$= \frac{146556.40}{129540.67} \times 100$$

$$= 113.14\ \%$$

The recovery was okay. It was within the range of recommended recovery in the range 70 – 120%. The standard, sample and spike were injected in gas chromatography in nitrogen phosphorus detector. There was no peak for malathion. The other pesticides and herbicides were tested in the same way.

3.6 Sampling

The sampling equipment includes resistant borosilicate glass, commonly called pyres glass, with secure fitting stoppers adequately sterilized and plastic bottle. Stopper cops and plugs used were chosen to resist the attack of material contained in the vessel. Sample bottles were cleaned carefully before each use and sterilized. Sterilization procedure for sample bottles was done using standard method (WHO, Geneva 1985).

The water samples were collected from the source during the dry and the rainy season. They were collected using well-cleaned buckets from the wells and rivers. While, for the borehole water samples were fetched from the tap after 10 - 30 minutes of pumping. In addition, for each day four samples were taken from each source. The samples were collected and stored in suitable sterilized bottles. The volume of water collected was large enough to permit an accurate analysis. Great care was taken during sampling to prevent contamination of the sample being collected by using well-cleaned buckets and sterilized bottles. Water sample details were described and the sample bottled properly labeled to avoid mixing of samples and any confusion as to the source and time of sampling. Lastly, the samples were transported to laboratory for tests.

The maximum period that was taken between sample collection and testing was 6 hours. To ensure that the water samples were not affected by the climatical conditions, they were stored in a refrigerator. The experiments were carried out between August and December 2002 because both the dry season and wet season period were well catered for. The months of August and September were very dry and the rainfall was high during the months of November and December.

4.0 RESULTS AND DISCUSSION

4.1 INTRODUCTION

The data collected was aimed at monitoring and evaluating the groundwater quality within Makuyu division of Maragua District. This was accomplished by tabulation of the results for physical, chemical and biological characteristics of the water samples obtained from the boreholes, wells and three rivers within the area. This was done within a period of five months. The following relationships were formulated from the data obtained.

- Analysis and comparison of water characteristics for borehole/wells with depth 0 - 50m with rivers water
- Analysis and comparison of water characteristics for borehole/wells with depth 50 - 100m with rivers water
- Analysis and comparison of water characteristics for borehole/wells with depth above 100m with rivers water

4.2 ANALYSIS OF RESULTS

The result obtained for the various boreholes, wells and rivers were tabulated in the tables that follow from next page. The results were divided into three categories. These were physical, chemical and microbiological characteristics. The World Health Organization Guidelines (1993) and Kenya Bureau of Standards (1985) were included in order to compare with the results obtained for the various parameters.

Physical properties

Tables 4.1.1 – 4.1.5 shows the summary of the physical properties of water samples from the 12 boreholes, nine wells and the three rivers in the study area. The data in the tables are mean of five months observation and also shown are standard deviations, World Health Organization Guidelines (1993) and Kenya Bureau of Standards (1985).

4.1 PHYSICAL CHARACTERISTICS FOR VARIOUS WATER SOURCES IN MAKUYU DIVISION OF MARAGUA DISTRICT

Table 4.1.1 Shows the physical characteristics of water samples from 0 - 50 m deep boreholes/wells and WHO Guidelines/KBS Standards.

DESCRIPTION	**KAMAHUHA SHOPS' WELL, 1.0 m**		**KIRIMIRI SHOPS' WELL, 0.8 m**		**WAWERU'S WELL, 14.4 m**		**KAMATHI'S WELL**		**NDACHI PLOT WELL, 16.0m**		**WHO GUIDE-LINES**	**KBS STDS**
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
Temperature, °C	23	0.0000	22	0.0000	22	0.0000	22	0.0000	23	0.4000	-	-
Conductivity, Us/cm	128	0.0000	121	0.4000	58	0.0102	48	0.0000	147	0.7483	-	-
Turbidity, FTU	4.0	0.0400	1.85	0.0000	1.3	0.0400	5.9	0.0400	2.0	0.0800	5	5
Apparent colour, °H	<5	0.0000	<5	0.0000	<5	0.0000	20	0.0000	<5	0.0000	5	15
True colour, °H	<5	0.0000	<5	0.0000	<5	0.0000	20	0.0000	<5	0.0000	5	15
Dissolved solids, mg/l	182	4.0000	206	4.8993	38	4.0000	52	4.0000	259	2.0000	1000	1000
Suspended solids, mg/l	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0
Total solids, mg/l	182	4.0000	206	4.8993	38	4.0000	52	4.0000	259	2.0000	1000	1000

Table 4.1.2 Shows the physical characteristics of water samples from 0 – 50 m deep boreholes/wells and WHO Guidelines/KBS Standards.

DESCRIPTION	**ESBON'S WELL, 19.5 m**		**MURUITHIA WELL, 13.8 m**		**GICHUIRI'S WELL AT SABA, 27.9 m**		**GIKUNGU'S WELL AT IGANJO, 27m**		**MBURU'S BOREHOLE, 50.0 m**		**WHO GUIDE-LINES**	**KBS STDS**
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
Temperature, °C	22	0.0000	23	0.4000	23	0.0000	23	0.4000	23	0.0000	-	-
Conductivity, Us/cm	61	0.4899	57	0.0000	820	0.4000	55	0.0000	402	0.4000	-	-
Turbidity, FTU	4.8	0.0400	2.5	0.0490	0.9	0.0400	1.0	0.0000	1.2	0.0400	5	5
Apparent colour, °H	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	5	15
True colour, °H	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	5	15
Dissolved solids, mg/l	210	0.0000	22.5	4.0000	698	4.0000	56	4.8990	597	4.0000	1000	1000
Suspended solids, mg/l	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0
Total solids, mg/l	210	0.0000	22.5	4.0000	698	4.0000	56	4.8990	597	4.0000	1000	1000

Table 4.1.3 Shows the physical characteristics of water samples from 50 – 100m deep boreholes/wells and WHO Guidelines/KBS Standards.

DESCRIPTION	**MURANG'A T. T. C BH, 75.0 m**		**KAKUZI BOREHOLE No. 1, 98.0 m**		**IGIKIRO SEC. SCH. BH, 80.0 m**		**KAMAU BOREHOLE, 81.0 m**		**MAKUYU GIRLS SEC. BH, 97.0 m**		**WHO GUIDE-LINES**	**KBS STDS**
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
Temperature, °C	23	0.4000	22.5	0.3162	23	0.000	23	0.0000	23	0.4000	-	-
Conductivity, Us/cm	249	0.4000	287	0.6325	118	1.166	227	0.0102	321	0.7483	-	-
Turbidity, FTU	0.8	0.0400	1.4	0.0000	1.5	0.0490	0.9	0.0040	0.9	0.0400	5	5
Apparent colour, °H	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	5	15
True colour, °H	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	5	15
Dissolved solids, mg/l	273	4.0000	280	6.3246	280	3.1623	313	3.7417	440	6.3246	1000	1000
Suspended solids, mg/l	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0
Total solids, mg/l	273	4.0000	280	6.3246	280	3.1623	313	3.7414	440	6.3246	1000	1000

Table 4.1.4 Shows the physical characteristics of water samples from 100 m deep and above boreholes/wells and WHO Guidelines/KBS Standards.

DESCRIPTION	**KAMAHUHA GIRLS HIGH BH, 108.0 m**		**MAKUYU BOYS SEC. BH, 120.0 m**		**WAMTEGA BOREHOLE, 187.0 m**		**DON BOSCO BOREHOLE 101.0 m**		**KAKUZI BOREHOLE No. 2, 104.0 m**		**MAKUYU GOLF CLUB BH, 105.0 m**		**WHO GUIDE-LINES**	**KBS STDS**
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
Temperature, °C	23	0.0000	23	0.0000	23	0.0000	24	0.4000	22	0.4000	22	0.4000	-	-
Conductivity, Us/cm	6130	0.4000	418	0.4000	305	0.4000	431	0.4899	290	0.9798	239	0.0000	-	-
Turbidity, FTU	38	0.4000	0.9	0.0000	5.3	0.0490	1.1	0.0400	0.9	0.0748	1.2	0.0400	5	5
Apparent colour, °H	20	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	5	15
True colour, °H	20	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	<5	0.0000	5	15
Dissolved solids, mg/l	4290	2.0000	519	2.0000	4000	0.0000	322	4.0000	380	6.3246	240	6.3246	1000	1000
Suspended solids, mg/l	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0
Total solids, mg/l	4290	2.0000	519	2.0000	4000	0.0000	322	4.0000	380	6.3246	240	6.3246	1000	1000

Table 4.1.5 Shows the physical characteristics of water samples from rivers and WHO Guidelines/KBS Standards.

DESCRIPTION	SABASABA RIVER - WATER		THAARA RIVER – WATER		NDERA RIVER-WATER		WHO Guidelines	KBS Standards
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
Temperature, °C	22	0.4000	22	0.0000	22	0.0000	-	-
Conductivity, Us/cm	190	0.4000	195	0.4000	150	0.6325	-	-
Turbidity, FTU	85	0.7483	58	0.9798	41	0.9798	5	5
Apparent colour, °H	70	0.0000	70	0.0000	30	0.0000	5	15
True colour, °H	70	0.0000	70	0.0000	30	0.0000	5	15
Dissolved solids, mg/l	4098	4.0000	2900	0.0000	1102	4.0000	1000	1000
Suspended solids, mg/l	81.8	0.8000	66	2.0000	21	2.0000	0	0
Total solids, mg/l	4179.8	4.8000	2966	2.0000	1109	4.0000	1000	1000

Chemical properties

Tables 4.2.1 – 4.2.7 shows the summary of the chemical properties of water samples from the 12 boreholes, nine wells and three rivers in the study area. Theses include several chemical parameters, heavy metals and pesticides. The data in the tables are mean of five months observation and also shown are standard deviations, World Health Organization Guidelines (1993) and Kenya Bureau of Standards (1985).

4.2 CHEMICAL CHARACTERISTICS FOR VARIOUS WATER SOURCES IN MAKUYU DIVISION OF MARAGUA DISTRICT

Table 4.2.1 Shows the chemical characteristics of water samples from 0 – 50 m deep boreholes/wells and WHO Guidelines/KBS Standards.

DESCRIPTION	**KAMAHUHA SHOPS WELL, 1.0 m**		**KIRIMIRI SHOPS' WELL, 0.8 m**		**WAWERU'S WELL, 14.4 m**		**KAMATHI'S WELL, 14.7 m**		**NDACHI PLOT WELL, 16.0 m**		**WHO GUIDE-LINES**	**KBS STDS**
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
pH	6.91	0.0110	7.34	0.0080	7.40	0.0102	7.13	0.0117	6.93	0.0098	7 – 8.5	6.5 – 8.5
Chloride, mgCl/l	24	0.4899	20.2	0.4000	16.4	0.4000	16	0.2000	36	0.8602	250	250
Calcium Hardness as $CaCO_3$, mg/l	8.2	0.4000	25.6	0.6325	4	0.4000	4	0.0000	10	0.0000	75	500
Total Hardness as $CaCO_3$, mg/l	60	0.6325	28.5	0.4899	8	0.0000	8.4	0.4000	20	0.4000	100	500
Total Alkalinity as $CaCO_3$, mg/l	78	0.4000	25.4	0.4899	30.5	0.6325	32.3	0.5100	46	0.4899	-	-
Carbonate Alkalinity, mg/l	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	-	-
Fluorides, mg/l	0.50	0.0075	0.34	0.0040	0.50	0.0040	0.36	0.0110	0.37	0.0102	1.5	5.0
Sulphate, mg/l as SO_4^{2-}	0.65	0.0110	0.17	0.0110	1.31	0.0075	1.03	0.0117	0.48	0.0102	250	400
Phosphates, mg/l as PO_4^-	1.21	0.0040	0.46	0.0049	0.55	0.0080	0.46	0.0075	1.88	0.0147	-	-
Dissolved oxygen, mg/l	8.13	0.0049	7.98	0.0040	7.78	0.0063	8.05	0.0040	7.62	0.0089	-	-
Nitrates, mg/l as NO_3^-	1.3400	0.0080	1.46	0.0063	0.3220	0.0075	0.4160	0.0102	1.22	0.0080	3	10
Iron, mg/l as Fe	0.1458	0.0193	0.0994	0.0007	0.0472	0.0012	0.5062	0.0047	0.2369	0.0053	1.0	0.3
Manganese, mg/l as Mn	0.0053	0.0000	0.0051	0.0001	0.0044	0.0001	0.0057	0.0002	0.0052	0.0005	0.5	0.1
Titanium, mg/l as Ti	0.0588	0.0049	0.0189	0.0002	0.0198	0.0024	0.0535	0.0001	0.0261	0.0004	-	-
Copper, mg/l as Cu	0.0122	0.0001	0.0131	0.0001	0.0001	0.0001	0.0116	0.0001	0.0116	0.0001	2	1.0
Zinc, mg/l as Zn	0.0027	0.0001	0.0042	0.0000	0.0001	0.0010	0.0046	0.0000	0.0148	0.0002	5	5
Strontium, mg/l as Sr	0.0011	0.0000	0.0014	0.0001	0.0001	0.0002	0.0012	0.0000	0.0013	0.0001	-	-
Yttrium, mg/l as Y	0.0013	0.0000	0.0014	0.0001	0.0001	0.0000	0.0018	0.0000	0.0017	0.0001	-	-
Zirconium, mg/l as Zr	0.0092	0.0010	0.0043	0.0000	0.0000	0.0002	0.0108	0.0002	0.0080	0.0001	-	-

Table 4.2.2 Shows the chemical characteristics of water samples from 0 – 50 m deep boreholes/wells and WHO Guidelines/KBS Standards.

DESCRIPTION	**ESBON'S WELL, 19.5m**		**MURUITHIA'S WELL, 13.8 m**		**GICHUIRI'S WELL, 27.9 m**		**GIKUNGU'S WELL AT IGANJO, 27m**		**MBURU'S BOREHOLE, 50.0 m**		**WHO GUIDE-LINES**	**KBS STDS**
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
PH	5.79	0.0110	7.97	0.0075	7.39	0.0172	7.03	0.0063	7.38	0.0172	7 – 8.5	6.5 – 8.5
Chloride, mgCl/l	13.4	0.3742	13	0.4000	98.4	0.4000	16	0.4000	26	0.2000	250	250
Calcium Hardness as $CaCO_3$, mg/l	10	0.4000	14	0.2000	83.8	0.4000	10	0.6325	41.4	0.4899	75	500
Total Hardness as $CaCO_3$, mg/l	22	0.2000	18.2	0.4000	156.8	0.4000	28	0.0000	115	0.4000	100	500
Total Alkalinity as $CaCO_3$, mg/l	43.8	0.4000	35	0.4000	305	0.6325	38.1	0.2000	121	0.7483	-	-
Carbonate Alkalinity, mg/l	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	-	-
Fluorides, mg/l	0.46	0.4000	0.40	0.0089	0.52	0.0063	0.48	0.0063	0.40	0.0040	1.5	5.0
Sulphate, mg/l as SO_4^{2-}	1.19	0.0098	0.84	0.0110	0.22	0.0102	0.81	0.0117	0.39	0.0102	250	400
Phosphates, mg/l as PO_4^-	0.35	0.0117	0.76	0.0141	0.35	0.0063	0.56	0.0098	0.42	0.0063	-	-
Dissolved oxygen, mg/l	7.91	0.0049	6.84	0.0040	6.95	0.0000	7.85	0.0040	7.24	0.0110	-	-
Nitrates, mg/l as NO_3^-	0.990	0.0476	0.2800	0.0089	0.6480	0.0117	0.7600	0.0063	0.3800	0.0080	3	10
Iron, mg/l as Fe	0.3961	0.0008	0.0853	0.0021	0.0159	0.0005	0.0261	0.0004	0.0172	0.0002	1.0	0.3
Manganese, mg/l as Mn	0.0049	0.0003	0.0053	0.0002	0.0170	0.0002	0.0054	0.0008	0.0057	0.0004	0.5	0.1
Titanium, mg/l as Ti	0.0330	0.0001	0.0147	0.0002	0.0139	0.0003	0.0150	0.0002	0.0178	0.0014	-	-
Copper, mg/l as Cu	0.0131	0.0002	0.0115	0.0000	0.0013	0.0003	0.0011	0.0002	0.0122	0.0001	2	1.0
Zinc, mg/l as Zn	0.0039	0.0000	0.0031	0.0000	0.0030	0.0009	0.0040	0.0002	0.0673	0.0002	5	5
Strontium, mg/l as Sr	0.0014	0.0001	0.0013	0.0001	0.0013	0.0000	0.0011	0.0000	0.0013	0.0000	-	-
Yttrium, mg/l as Y	0.0016	0.0002	0.0020	0.0002	0.0019	0.0001	0.0013	0.0000	0.0014	0.0000	-	-
Zirconium, mg/l as Zr	0.0132	0.0000	0.0021	0.0000	0.0019	0.0000	0.0015	0.0001	0.0015	0.0000	-	-

Table 4.2.3 Shows the chemical characteristics of water samples from 50 – 100 m deep boreholes/wells and WHO Guidelines/KBS Standards.

DESCRIPTION	**MURANG'A T. T. C BH, 75.0 m**		**KAMAU BOREHOLE, 81.0 m**		**KAKUZI BOREHOLE No. 1, 98.0 m**		**IGIKIRO SEC. SCH. BH, 80.0 m**		**MAKUYU GIRLS SEC. BH, 97.0m**		**WHO GUIDE-LINES**	**KBS STDS**
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
pH	7.50	0.0098	6.84	0.0102	7.02	0.0602	7.19	0.0177	7.21	0.4000	7 – 8.5	6.5 – 8.5
Chloride, mgCl/l	30	0.4000	24	0.4000	29	0.7483	21	0.5100	24	0.4000	250	250
Calcium Hardness as $CaCO_3$, mg/l	27	0.6325	35	0.8944	35	0.8000	10	0.4000	42.5	0.4472	75	500
Total Hardness as $CaCO_3$, mg/l	62.5	0.4899	97	0.8000	96	0.6325	20	0.0000	88.8	0.4000	100	500
Total Alkalinity as $CaCO_3$, mg/l	151	0.8944	199	0.8000	180	0.4000	65	0.4000	221	0.4899	-	-
Carbonate Alkalinity, mg/l	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	-	-
Fluorides, mg/l	0.58	0.0040	0.68	0.0063	0.47	0.0102	0.37	0.0060	0.62	0.0075	1.5	5.0
Sulphate, mg/l as SO_4^{2-}	0.31	0.0204	0.25	0.0117	0.37	0.0075	0.51	0.0140	0.38	0.0063	250	400
Phosphates, mg/l as PO_4^-	1.75	0.0063	1.44	0.0126	0.73	0.0117	0.37	0.0060	1.69	0.0102	-	-
Dissolved oxygen, mg/l	6.75	0.0089	7.05	0.0150	6.77	0.0075	6.98	0.0060	6.54	0.0049	-	-
Nitrates, mg/l as NO_3^-	0.51	0.0063	0.86	0.0102	0.53	0.0102	0.42	0.0080	0.5280	0.0040	3	10
Iron, mg/l as Fe	0.0203	0.0001	0.0183	0.0003	0.0162	0.0004	0.0419	0.0002	0.0483	0.0037	1.0	0.3
Manganese, mg/l as Mn	0.0051	0.0004	0.0046	0.0002	0.0049	0.0003	0.0061	0.0002	0.0070	0.0001	0.5	0.1
Titanium, mg/l as Ti	0.0226	0.0039	0.0170	0.0017	0.0156	0.0003	-	-	0.0180	0.0000	-	-
Copper, mg/l as Cu	0.0128	0.0001	0.0135	0.0001	0.0141	0.0031	0.0125	0.0001	0.0133	0.0001	2	1.0
Zinc, mg/l as Zn	0.2922	0.0003	0.0187	0.0002	0.0072	0.0004	0.1696	0.0002	0.0184	0.0001	5	5
Strontium, mg/l as Sr	0.0012	0.0001	0.0011	0.0001	0.0012	0.0000	0.0012	0.0000	0.0013	0.0001	-	-
Yttrium, mg/l as Y	0.0014	0.0000	0.0013	0.0001	0.0017	0.0001	0.0013	0.0000	0.0014	0.0001	-	-
Zirconium, mg/l as Zr	0.0014	0.0001	0.0017	0.0000	0.0014	0.0000	0.0017	0.0000	0.0013	0.0000	-	-

Table 4.2.4 Shows the chemical characteristics of water samples from 100 m deep and above boreholes/wells and WHO Guidelines/KBS Standards.

DESCRIPTION	**KAMAHUHA GIRLS HIGH SCH BH, 108m**		**KAKUZI BOREHOLE No. 2, 104.0 m**		**MAKUYU GOLF CLUB BH, 105.0 m**		**WHO GUIDE-LINES**	**KBS STDS**
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
pH	6.65	0.0063	7.00	0.0214	6.87	0.0614	7 – 8.5	6.5 – 8.5
Chloride, mgCl/l	19	0.6325	30	0.3742	25	0.4000	250	250
Calcium Hardness as $CaCO_3$, mg/l	713	0.4000	26	0.4000	18	0.2000	75	500
Total Hardness as $CaCO_3$, mg/l	716	0.4000	101	0.4000	88	0.0000	100	500
Total Alkalinity as $CaCO_3$, mg/l	4388	4.0000	178	0.4000	153.75	0.4000	-	-
Carbonate Alkalinity, mg/l	0.00	0.0000	0.00	0.0000	0.00	0.0000	-	-
Fluorides, mg/l	0.75	0.0000	0.80	0.0040	0.43	0.0075	1.5	5.0
Sulphate, mg/l as SO_4^{2-}	0.23	0.0117	0.35	0.0141	0.36	0.0063	250	400
Phosphates, mg/l as PO_4^-	0.33	0.0102	0.75	0.0063	0.79	0.0080	-	-
Dissolved oxygen, mg/l	6.39	0.0080	6.85	0.0040	6.68	0.0049	-	-
Nitrates, mg/l as NO_3^-	0.65	0.0075	0.58	0.0089	0.5600	0.0063	3	10
Iron, mg/l as Fe	1.1450	0.0340	0.0211	0.0012	0.0406	0.0052	1.0	0.3
Manganese, mg/l as Mn	1.0190	0.0301	0.0048	0.0003	0.0061	0.0003	0.5	0.1
Titanium, mg/l as Ti	0.0165	0.0001	0.0180	0.0003	0.0186	0.0002	-	-
Copper, mg/l as Cu	0.0142	0.0002	0.0138	0.0013	0.0132	0.0001	2	1.0
Zinc, mg/l as Zn	0.0032	0.0002	0.0145	0.0038	0.0091	0.0001	5	5
Strontium, mg/l as Sr	0.0013	0.0000	0.0017	0.0001	0.0014	0.0000	-	-
Yttrium, mg/l as Y	0.0021	0.0000	0.0019	0.0002	0.0015	0.0002	-	-
Zirconium, mg/l as Zr	0.0019	0.0001	0.0016	0.0002	0.0016	0.0001	-	-

Table 4.2.5 Shows the chemical characteristics of water samples from 100m deep and above boreholes/wells and WHO Guidelines/KBS Standards.

DESCRIPTION	**DON BOSCO BOREHOLE, 101.0 m**		**MAKUYU BOYS SEC. BH, 120.0 m**		**WAMTEGA BOREHOLE, SABA, 187 m**		**WHO GUIDE-LINES**	**KBS STDS**
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
pH	7.23	0.0063	7.89	0.0110	7.13	0.0075	7 – 8.5	6.5 – 8.5
Chloride, mgCl/l	30	0.5099	28.5	0.4472	61.4	0.3742	250	250
Calcium Hardness as $CaCO_3$, mg/l	18.3	0.7483	18.6	0.5831	166	0.8000	75	500
Total Hardness as $CaCO_3$, mg/l	60.3	0.7483	34	0.4000	234	0.7483	100	500
Total Alkalinity as $CaCO_3$, mg/l	260.6	0.4000	269.5	0.4899	384	1.1662	-	-
Carbonate Alkalinity, mg/l	0.00	0.0000	0.00	0.0000	0.00	0.0000	-	-
Fluorides, mg/l	1.25	0.0040	2.50	0.0040	0.72	0.0040	1.5	5.0
Sulphate, mg/l as SO_4^{2-}	0.38	0.0089	0.36	0.0098	0.24	0.0075	250	400
Phosphates, mg/l as PO_4^-	0.69	0.0117	0.57	0.0098	1.13	0.0075	-	-
Dissolved oxygen, mg/l	6.52	0.0075	6.13	0.0040	6.57	0.0063	-	-
Nitrates, mg/l as NO_3^-	0.4800	0.0089	0.56	0.0075	0.6620	0.0075	3	10
Iron, mg/l as Fe	0.0310	0.0000	0.0435	0.0002	0.0360	0.0001	1.0	0.3
Manganese, mg/l as Mn	0.0055	0.0007	0.0047	0.0001	0.0054	0.0000	0.5	0.1
Titanium, mg/l as Ti	0.0208	0.0022	0.0179	0.0012	0.0121	0.0001	-	-
Copper, mg/l as Cu	0.0002	0.0125	0.0126	0.0002	0.0101	0.0001	2	1.0
Zinc, mg/l as Zn	0.0002	0.0226	0.0036	0.0004	0.0502	0.2221	5	5
Strontium, mg/l as Sr	0.0000	0.0013	0.0012	0.0000	0.0013	0.0000	-	-
Yttrium, mg/l as Y	0.0000	0.0013	0.0013	0.0000	0.0015	0.0000	-	-
Zirconium, mg/l as Zr	0.0001	0.0016	0.0015	0.0000	0.0017	0.0000	-	-

Table 4.2.6 Shows the chemical characteristics of water samples from rivers and WHO Guidelines/KBS Standards.

DESCRIPTION	**SABASABA RIVER - WATER**		**THAARA RIVER – WATER**		**NDERA RIVER - WATER**		**WHO Guidelines**	**KBS Standards**
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
pH	7.34	0.3709	7.31	0.0185	7.06	0.0813	7 – 8.5	6.5 – 8.5
Chloride, mgCl/l	5.75	0.2245	9.0	0.3162	4.5	0.1200	250	250
Calcium Hardness as $CaCO_3$, mg/l	13.6	0.2000	12.0	0.0000	10.2	0.2450	75	500
Total Hardness as $CaCO_3$, mg/l	14.9	0.2000	14.5	0.2000	14.5	0.2577	100	500
Total Alkalinity as $CaCO_3$, mg/l	77.9	0.2000	64.8	0.4000	55	0.0000	-	-
Carbonate Alkalinity, mg/l	0.00	0.0000	0.00	0.0000	0.00	0.0000	-	-
Fluorides, mg/l	0.51	0.0049	0.42	0.0040	0.27	0.0075	1.5	5.0
Sulphate, mg/l as SO_4^{2-}	2.0	0.0400	1.2	0.0040	1.2	0.0400	250	400
Phosphates, mg/l as PO_4^-	0.22	0.0063	0.18	0.0040	0.17	0.0040	-	-
Dissolved oxygen, mg/l	8.24	0.0049	8.17	0.0098	8.03	0.0040	-	-
Nitrates, mg/l as NO_3^-	6.32	0.0400	5.34	0.0400	4.37	0.0800	3	10
Iron, mg/l as Fe	0.7033	0.0106	0.709	0.0009	0.7805	0.0445	1.0	0.3
Manganese, mg/l as Mn	0.0070	0.0009	0.0494	0.0055	0.0078	0.0013	0.5	0.1
Titanium, mg/l as Ti	0.1006	0.0056	0.1045	0.0013	0.1053	0.0050	-	-
Copper, mg/l as Cu	0.0145	0.0001	0.0275	0.0016	0.0139	0.0000	2	1.0
Zinc, mg/l as Zn	0.0048	0.0000	0.0313	0.0017	0.0057	0.0001	5	5
Strontium, mg/l as Sr	0.0018	0.0001	0.0086	0.0019	0.0015	0.0000	-	-
Yttrium, mg/l as Y	0.0014	0.0000	0.0070	0.0001	0.0012	0.0000	-	-
Zirconium, mg/l as Zr	0.0076	0.0001	0.0021	0.0001	0.0076	0.0001	-	-

PESTICIDES

In the test for pesticides, all the pesticides sought were not detected (ND).

Table 4.2.7. Shows pesticides tested in water samples from all the various sources and WHO Guidelines/KBS Standards.

DESCRIPTION	RESULTS	**WHO Guidelines υg/l**	**KBS Standards υg/l**
Diazinon	NOT DETECTED	-	-
Malathion	”	-	-
Carbofuran	”	-	-
p'p' DDT	”	2.00	1.00
p'p' DDE	”	2.00	1.00
Eldrin	”	0.03	0.03
Aldrin	”	0.03	0.03
Heptachlor	”	0.03	0.01
Atrazine	”	2.00	2.00
Chlorpyrifos	”	-	-
Methyl parathion	”	-	-
Dimethoate	”	-	-
Ethyl parathion	”	-	-
Fenalimol	”	-	-

Microbiological properties

Tables 4.3.1 – 4.3.3 shows the summary of the microbiological properties of water samples from the 12 boreholes, nine wells and the three rivers in the study area. The data in the tables are mean of five months observation and also shown are standard deviations, World Health Organization Guidelines (1993) and Kenya Bureau of Standards (1985).

4.3 BIOLOGICAL CHARACTERISTICS FOR VARIOUS WATER SOURCES IN MAKUYU DIVISION OF MARAGUA DISTRICT

Table 4.3.1 Shows the microbiological characteristics of water samples from boreholes/well and WHO Guidelines/KBS Standards.

WATER SOURCES, AND WHO GUIDELINES/KBS STANDARDS	**DESCRIPTION**				
	Depth in m	**Total coliform/100 mg/l**		**Total Faecal coliform/100mg/l**	
		Mean	SD, δ	Mean	SD, δ
KIRIMIRI SHOPS' WELL	0.8	0	0.0000	0	0.0000
KAMAHUHA SHOPS' WELL	1.0	220	4.0000	1000	0.0000
MURUITHIA'S WELL	13.8	100	4.0000	8000	0.0000
WAWERU'S WELL	14.4	10	0.0000	0	0.0000
KAMATHI'S WELL	14.7	0	0.0000	0	0.0000
NDAGHI PLOT WELL	16.0	725	4.8970	3200	0.0000
ESBON'S WELL	19.5	30	0.0000	30	0.0000
GIKUNGU'S WELL	27.0	2500	0.0000	0	0.0000
GICHUIRI'S WELL	27.9	0	0.0000	0	0.0000
MBURU'S BOREHOLE, 50.0 m	50.0	0	0.0000	0	0.0000
MURANG'A T. T. C BOREHOLE	75.0	0	0.0000	0	0.0000
MAKUYU GIRLS SEC. SCHOOL BOREHOLE	97.0	0	0.0000	0	0.0000
WHO GUIDELINES	Not detected			Not detected	
KBS STANDARDS	Not detected			Not detected	

Table 4.3.2 Shows the microbiological characteristics of water samples from boreholes/well and WHO Guidelines/KBS Standards.

WATER SOURCES AND WHO GUIDELINES/KBS STANDARDS	**DESCRIPTION**				
	Depth in m	**Total coliform/100 mg/l**		**Total Faecal coliform/100mg/l**	
		Mean	SD, δ	Mean	SD, δ
IGIKIRO SEC. SCHOOL BOREHOLE	80.0	0	0	0	0.0000
KAMAU BOREHOLE	81.0	0	0.0000	0	0.0000
MAKUYU GIRLS SEC. SCHOOL BOREHOLE	97.0	0	0.0000	0	0.0000
KAKUZI BOREHOLE No. 1	98.0	0	0.0000	0	0.0000
DON BOSCO BOREHOLE	101.0	0	0.0000	0	0.0000
KAKUZI BOREHOLE No. 2	104.0	0	0.0000	0	0.0000
MAKUYU GOLF CLUB BOREHOLE	105.0	0	0.0000	0	0.0000
KAMAHUHA GIRLS HIGH SCHOOL BOREHOLE	108.0	0	0.0000	0	0.0000
MAKUYU BOYS SEC. SCHOOL BOREHOLE	120.0	0	0.0000	0	0.0000
WAMTEGA BOREHOLE AT SABASABA	187.0	0	0.0000	0	0.0000
WHO GUIDELINES		Not detected		Not detected	
KBS STANDARDS		Not detected		Not detected	

TABLE 4.3.3 Shows the microbiological characteristics of water samples from rivers and WHO Guidelines/KBS Standards.

DESCRIPTION	**SABASABA RIVER**		**THAARA RIVER**		**NDERA RIVER**		**WHO GUIDELINES**	**KBS STANDARDS**
	Mean	SD, δ	Mean	SD, δ	Mean	SD, δ		
Total coliform/100 mg/l	210	0.0000	600	0.0000	100	0.0000	Not detected	Not detected
Total Faecal coliform/100mg/l	90	4.0000	250	4.0000	30	0.0000	Not detected	Not detected

The total coliforms are detected in wells, which are found near pit latrines like Ndachi mugo wells and Muruithia's well. The Kamahuha shops' well is 0.8 metres and it is located in adjacent to a pass that is occasionally used by livestock. This can be a factor contributing to biological pollution. The well is not protected and water users fetch the water from the well using buckets and tins. These containers can also pollute the water if they are contaminated. For the other wells in which total coliforms and feacal coliforms were detected, this can result due to contamination of wells by external forces because they were not well protected.

To assess the level of pollution in various water sources with reference to depth, the physical, chemical and microbiological characteristics of water in well boreholes and rivers water representative samples were compared as shown in Figure 4.1 to Figure 4. 9.

4.4 PHYSICAL CHARACTERISTICS FOR BOREHOLES/WELLS AND RIVERS WATER

Table 4 4.1 Well below 10 metres deep and rivers.

DESCRIPTION	KAMAHUHA SHOPS WELL	KIRIMIRI SHOPS WELL	SABASABA RIVER - WATER	THAARA RIVER – WATER	NDERA RIVER- WATER
	Mean	Mean	Mean	Mean	Mean
Conductivity, Us/cm	128	121	190	195	150
Turbidity, FTU	4	1.85	85	58	41
True colour, oH	<5	<5	70	70	30
Total suspended solids, mg/l	182	206	4179.8	2966	1109

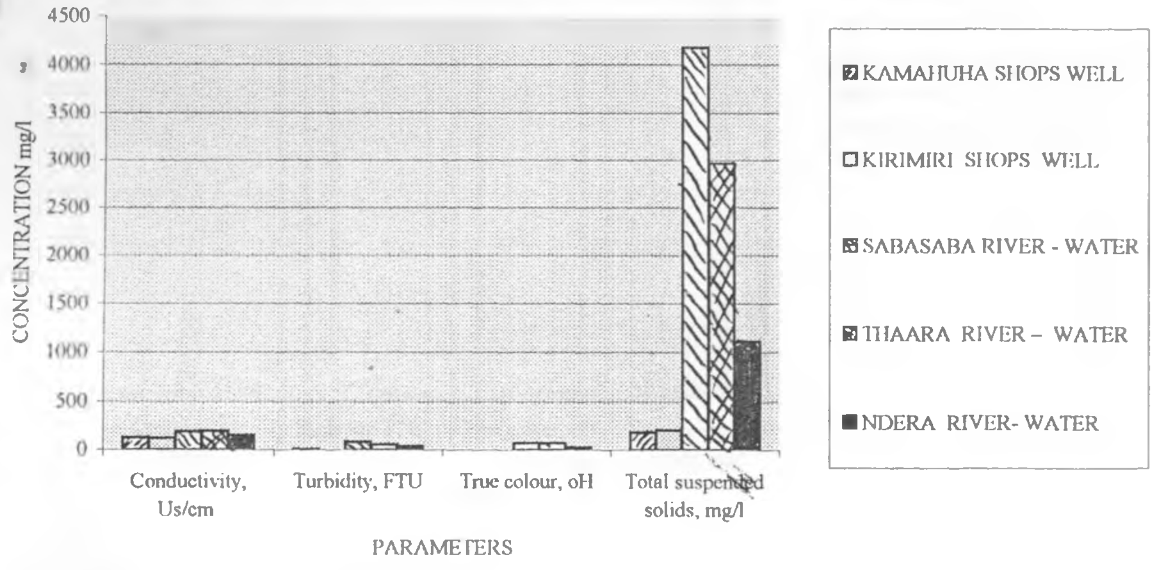


FIGURE 4.1 PHYSICAL CHARACTERISTICS OF WATER IN 0 - 10 M DEEP WELLS AND RIVERS

Table 4 4 2 Wells between 10 - 50 metres deep and rivers

DESCRIPTION	MURUITHIA WELL	NDACHI PLOT WELL	GIKUNGU'S WELL	GICHUIRI'S WELL	SABASABA RIVER - WATER	THAARA RIVER – WATER	NDERA RIVER-WATER
	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Conductivity, Us/cm	57	147	55	820	190	195	150
Turbidity, FTU	2.5	2	1	0.9	85	58	41
True colour, oH	<5	<5	<5	<5	70	70	30
Total suspended solids, mg/l	22.5	259	56	698	4179.8	2966	1109

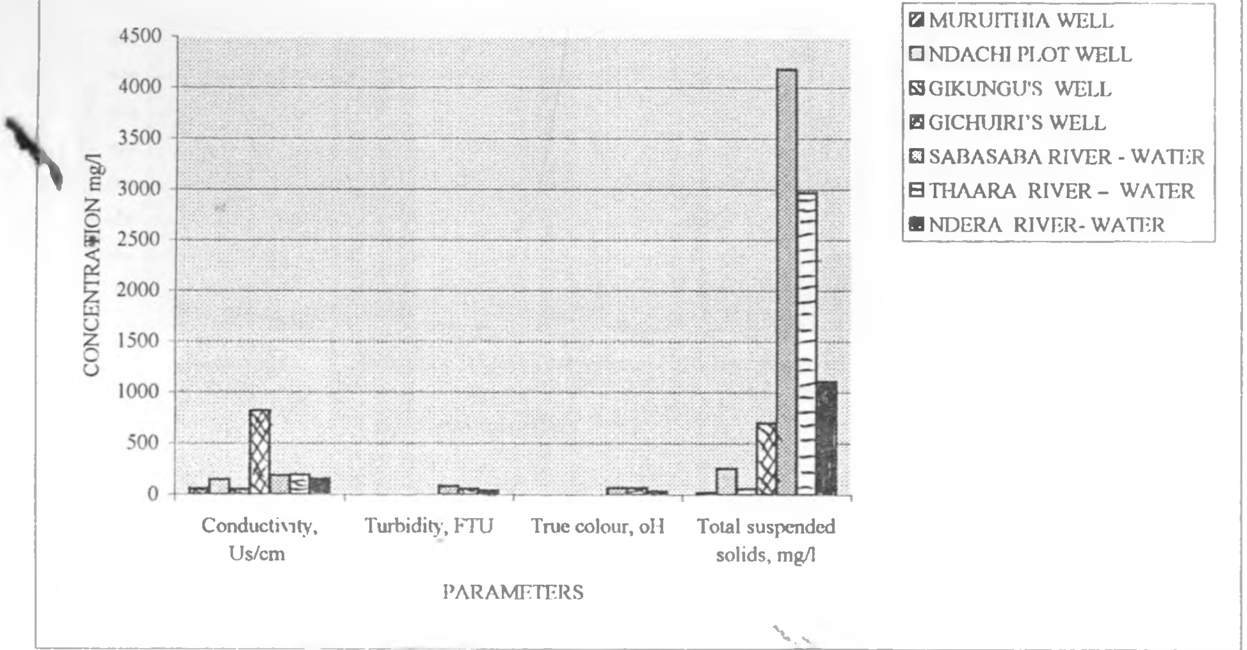


FIGURE 4.2 PHYSICAL CHARACTERISTICS OF WATER IN 10 -50 M DEEP WELLS AND RIVERS

Table 4.4.3 Boreholes between 50 - 100 metres deep and rivers

DESCRIPTION	MBURU BOREHOLE	MURANG'A T.T.C	IGIKIRO SEC. SCH.	KAKUZI BOREHOLE	SABASABA RIVER - WATER	THAARA RIVER – WATER	NDERA RIVER- WATER
	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Conductivity, Us/cm	402	249	118	287	190	195	150
Turbidity, FTU	1.2	0.8	1.5	1.4	85	58	41
True colour, oH	<5	<5	<5	<5	70	70	30
Total suspended solids, mg/l	597	273	280	280	4179.8	2966	1109

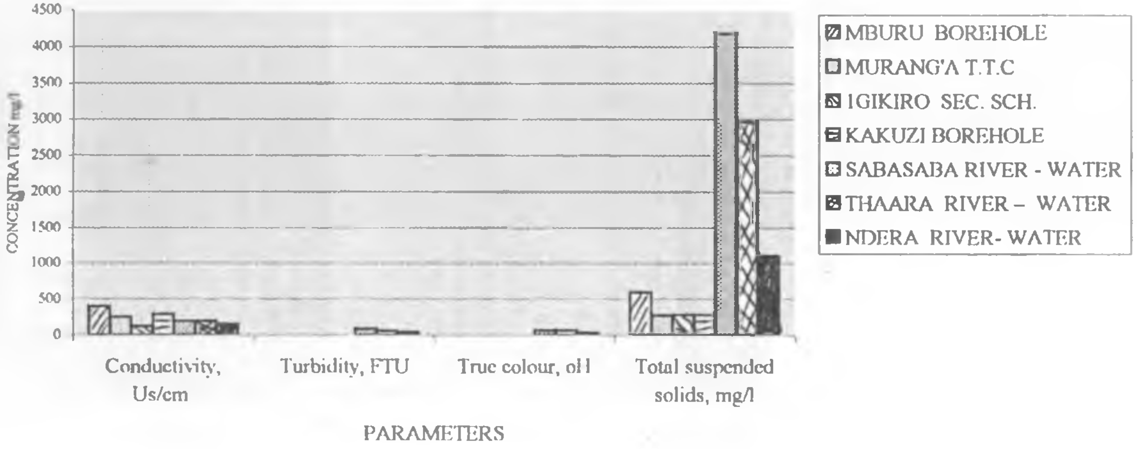


FIGURE 4.3 PHYSICAL CHARACTERISTICS OF WATER IN 50 - 100 M DEEP BOREHOLES AND RIVERS

Table 4.4.4 Boreholes above 100 metres and rivers

DESCRIPTION	DON BOSCO BOREHOLE,	MAKUYU BOYS SEC. SCH.	KAMAHUHA GIRLS HIGH SCH.	WAMTEGA BOREHOLE	SABASABA RIVER - WATER	THAARA RIVER – WATER	NDERA RIVER- WATER
	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Conductivity, Us/cm	431	418	6130	305	190	195	150
Turbidity, FTU	1.1	0.9	38	5.3	85	58	41
True colour, oH	<5	<5	20	<5	70	70	30
Total suspended solids, mg/l	322	519	4290	4000	4179.8	2966	1109

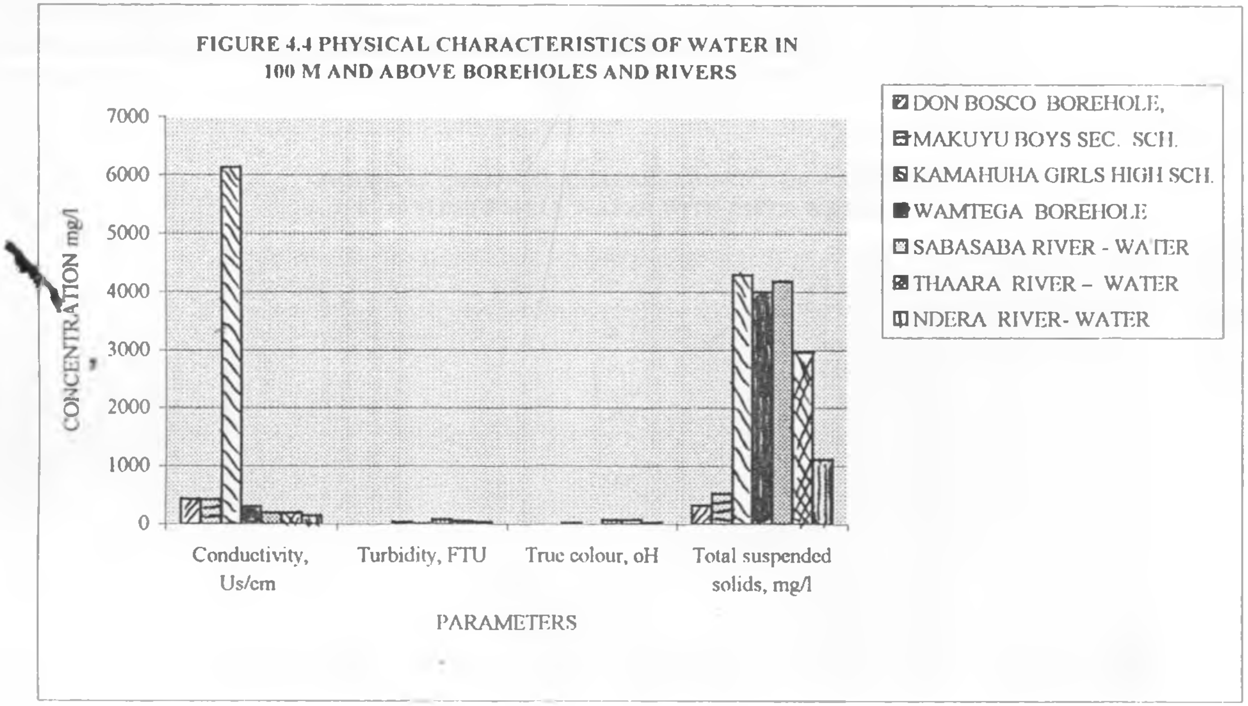


FIGURE 4.4 PHYSICAL CHARACTERISTICS OF WATER IN 100 M AND ABOVE BOREHOLES AND RIVERS

4.5 CHEMICAL CHARATERISTICS FOR VARIOUS WATER SOURCES

Table 4.5.1 Well below 10 metres deep and rivers.

DESCRIPTION	KAMAHUHA SHOPS' WELL, 1.0M	KIRIMIRI SHOPS WELL, 0.8M	SABASABA RIVER	THARA RIVER	NDERA RIVER
	Mean	Mean	Mean	Mean	Mean
Fluorides, mg/l	0.5	0.34	0.51	0.42	0.27
Sulphate, mg/l as SO42-	0.65	0.17	2	1.2	1.2
Phosphates, mg/l as PO4-	1.21	0.46	0.22	0.18	0.17
Nitrates, mg/l as NO3-	1.34	1.46	6.32	5.34	4.37
Iron, mg/l as Fe	0.1458	0.0994	0.7033	0.0709	0.7805

FIGURE 4.5 CHEMICAL CHARACTERISTICS OF WATER IN
0 - 10 M DEEP WELL WATER WITH RIVER WATER

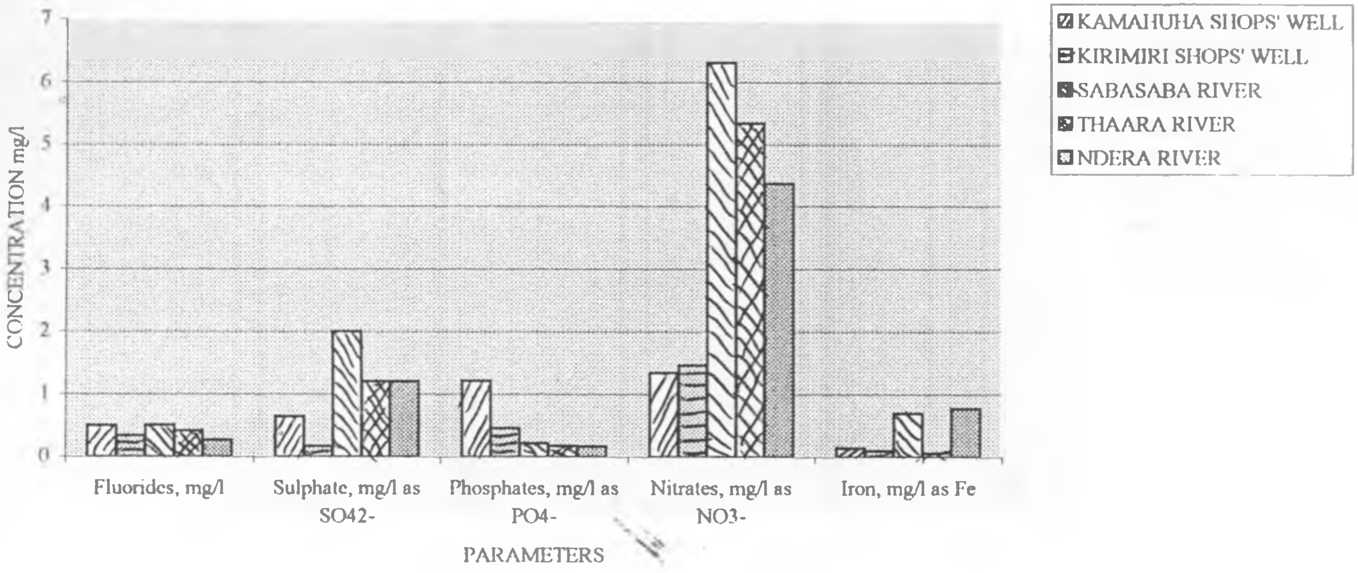


Table 4.5.2 Well between 10 - 50 metres deep and rivers.

DESCRIPTION	MURUITHIA WELL,	NDACHI WELL,	GIKUNGU WELL,	GICHUIRI'S WELL,	SABASABA RIVER	THARA RIVER	NDERA RIVER
	13.8M	16.0 M	27.0 M	27.9 M			
	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Fluorides, mg/l	0.4	0.37	0.48	0.52	0.51	0.42	0.27
Sulphate, mg/l as SO42-	0.84	0.48	0.81	0.22	2	1.2	1.2
Phosphates, mg/l as PO4-	0.76	1.88	0.56	0.35	0.22	0.18	0.17
Nitrates, mg/l as NO3-	0.28	1.22	0.76	0.648	6.32	5.34	4.37
Iron, mg/l as Fe	0.0853	0.2369	0.0261	0.0159	0.7033	0.0709	0.7805

FIGURE 4.6 CHEMICAL CHARACTERISTICS OF WATER IN 10 - 50M DEEP WELLS AND RIVERS

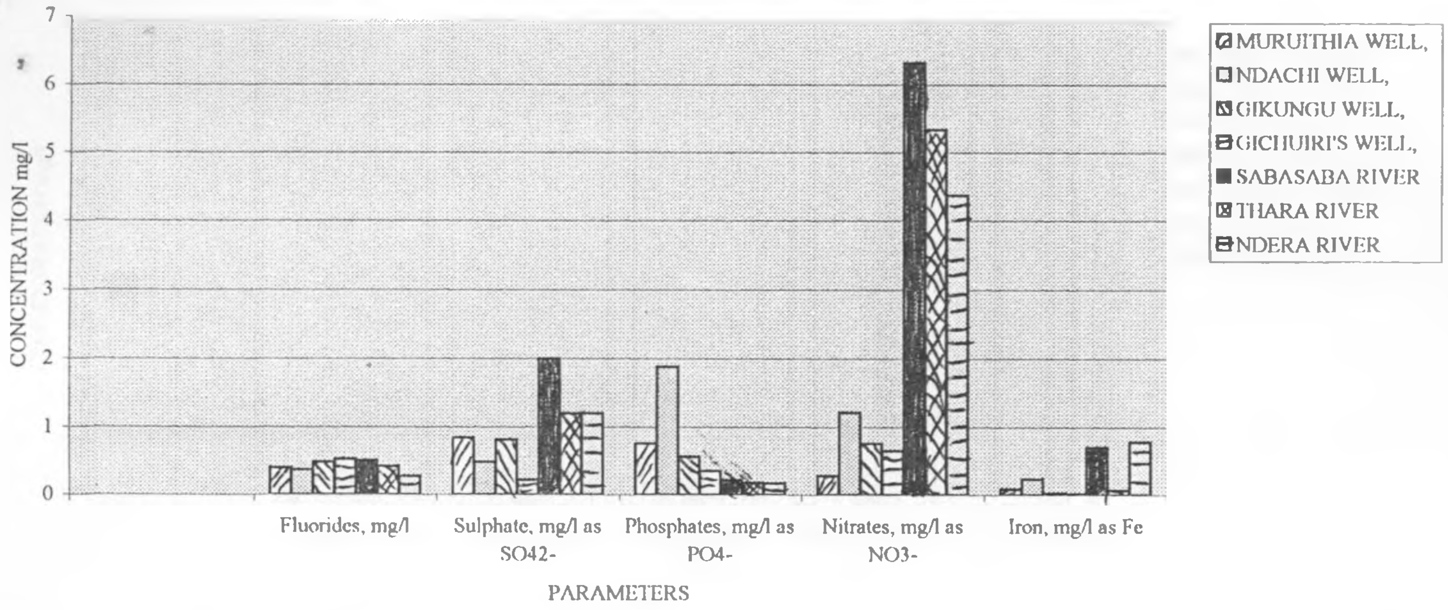


Table 4.5.3 Well between 50 - 100 metres deep and rivers.

DESCRIPTION	MBURU BOREHOLE 50 m	MURANG'A T.T.C BH., 75M	IGIKIRO SEC. SCH. BH., 80 M	KAKUZI BOREHOLE 1 98 M	SABASABA RIVER	THARA RIVER	NDERA RIVER
	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Fluorides, mg/l	0.4	0.58	0.37	0.47	0.51	0.42	0.27
Sulphate, mg/l as SO42-	0.39	0.31	0.51	0.37	2	1.2	1.2
Phosphates, mg/l as PO4-	0.42	1.75	0.37	0.73	0.22	0.18	0.17
Nitrates, mg/l as NO3-	0.38	0.51	0.42	0.53	6.32	5.34	4.37
Iron, mg/l as Fe	0.0172	0.0203	0.0419	0.0162	0.7033	0.709	0.7805

FIGURE 4.7 CHEMICAL CHARACTERISTICS IN 50 - 100 M DEEP BOREHOLE AND RIVERS

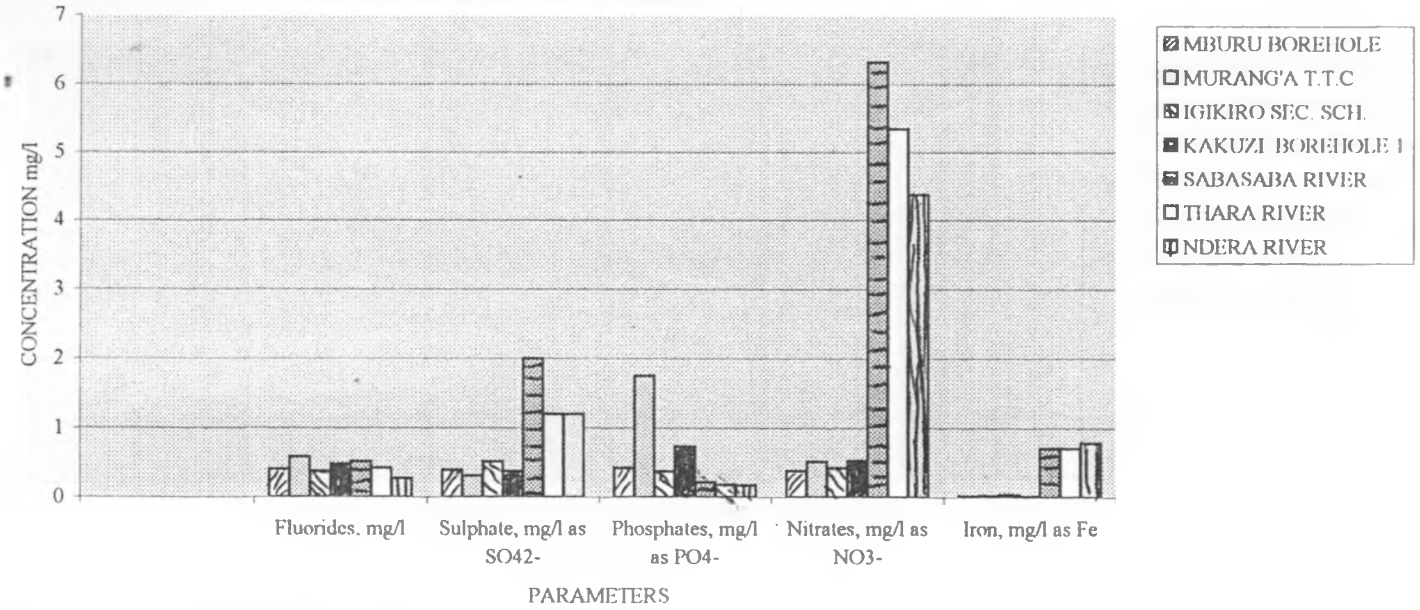


Table 4.5.4 Boreholes 100 metres deep and above and rivers.

DESCRIPTION	DON BOSCO BOREHOLE 101 m	MAKUYU BOYS SEC. SCH. 105 m	KAMAHUHA GIRLS HIGH SCH., 108 m	WAMTEGA BOREHOLE, 187 m	SABASABA RIVER	THARA RIVER	NDERA RIVER
	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Fluorides, mg/l	1.25	2.5	0.75	0.72	0.51	0.42	0.27
Sulphate, mg/l as SO42-	0.38	0.36	0.23	0.24	2	1.2	1.2
Phosphates, mg/l as PO4-	0.69	0.57	0.33	1.13	0.22	0.18	0.17
Nitrates, mg/l as NO3-	0.48	0.56	0.65	0.662	6.32	5.34	4.37
Iron, mg/l as Fe	0.031	0.0435	1.145	0.036	0.7033	0.0709	0.7805

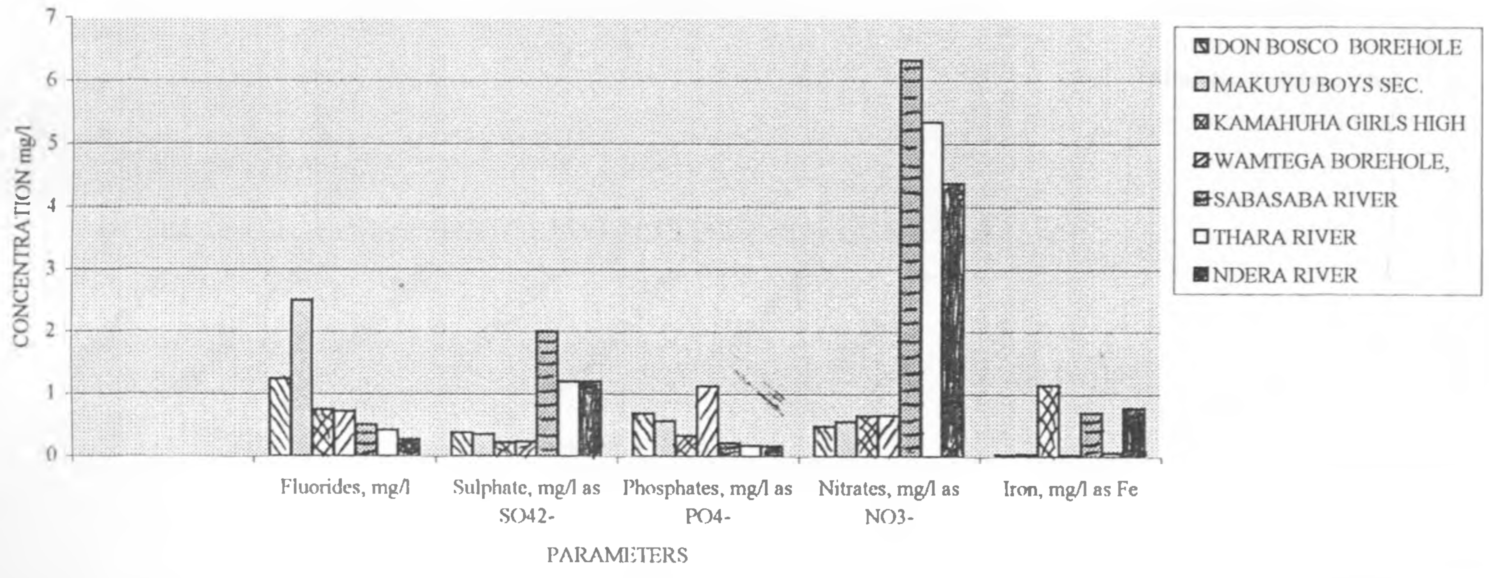


FIGURE 4.8 CHEMICAL CHARACTERISTICS OF WATER IN 100 M DEEP AND ABOVE BOREHOLES AND RIVERS

Table 4.5.5 Microbiological characteristics of water from wells below 10 metres deep and rivers.

WATER SOURCES	Total coliform/100ml	Total feacal coliform/100ml
ESBON'S WELL	30	30
GIKUNGU'S WELL	2500	0
MURUITHIA'S WELL	100	80
NDACHI WELL	725	3200
SABASABA RIVER	210	90
THARA RIVER	600	250
NDERA RIVER	100	30

FIG.9 MICROBIOLOGICAL CHARACTERISTICS OF WATER SAMPLES FROM WELLS AND RIVERS

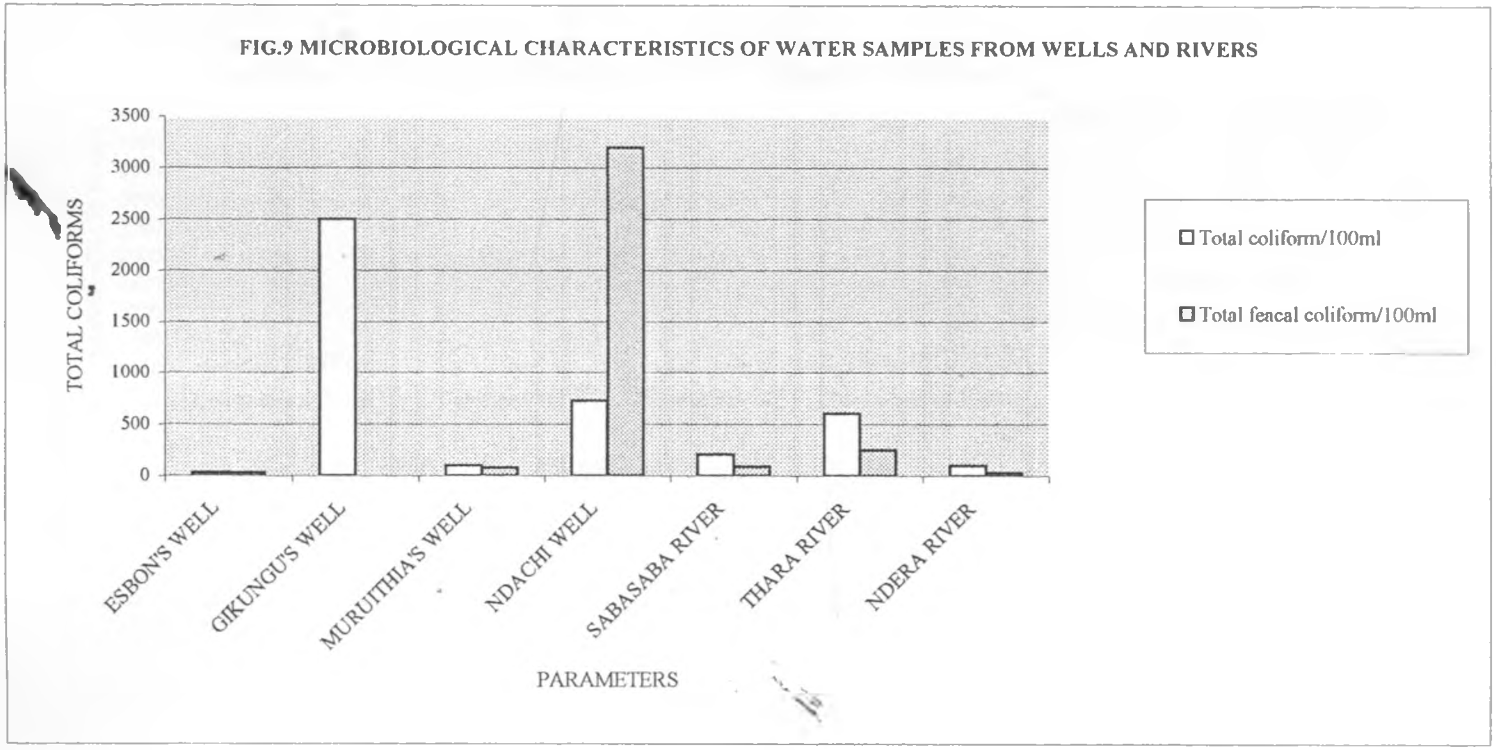


Table 4.6.1 Shows physical characteristics of water from below 10 m deep wells, 10 - 50 m deep wells and 50 - 100 m deep boreholes

DESCRIPTION	KAMAHUHA	KIRIMIRI	NDACHI	GICHUIRI'S	MBURU	MURANG'A
	SHOPS'	SHOPS	WELL,	WELL,	BOREHOLE	T.T.C
	WELL, 1.0M	WELL, 0.8M	16.0 M	27.9 M	50 m	BH., 75M
	Mean	Mean	Mean	Mean	Mean	Mean
Conductivity, Us/cm	57	147	55	829	190	249
Turbidity, FTU	2.5	2	1	0.9	85	0.8
True colour, oH	<5	<5	<5	<5	70	<5
Total suspended solids, mg/l	22.5	259	56	259	4179.8	273

FIGURE 4.10 COMPARISON OF PHYSICAL CHARACTERISTICS OF WATER FROM 10 M DEEP WELLS, 10 - 50 M DEEP WELLS AND 50 - 100 M DEEP BOREHOLES

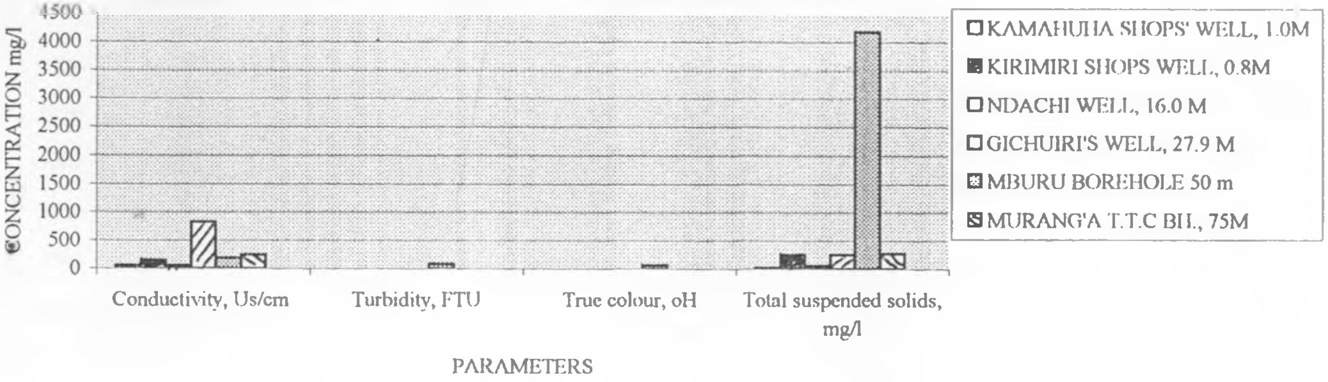


Table 4.6.2 Shows physical characteristics of water from below 10 m deep wells, 10 - 50 m deep wells and above100 m deep boreholes

DESCRIPTION	KAMAHUHA	KIRIMIRI	NDACHI	GICHUIRI'S	KAMAHUHA	MAKUYU
	SHOPS'	SHOPS	WELL,	WELL,	GIRLS	BOYS SEC.
	WELL, 1.0M	WELL, 0.8 M	16.0 M	27.9 M	SCH., 108 m	SCH. 105 m
	Mean	Mean	Mean	Mean	Mean	Mean
Conductivity, Us/cm	128	147	55	829	190	195
Turbidity, FTU	4	2	1	0.9	85	58
True colour, oH	<5	<5	<5	<5	70	70
Total suspended solids, mg/l	182	259	56	259	4179.8	2966

FIGURE 4.11 COMPARISON OF PHYSICAL CHARACTERISTICS OF WATER FROM 10 M DEEP WELLS, 10 - 50 M DEEP WELLS AND ABOVE 100 M DEEP BOREHOLES

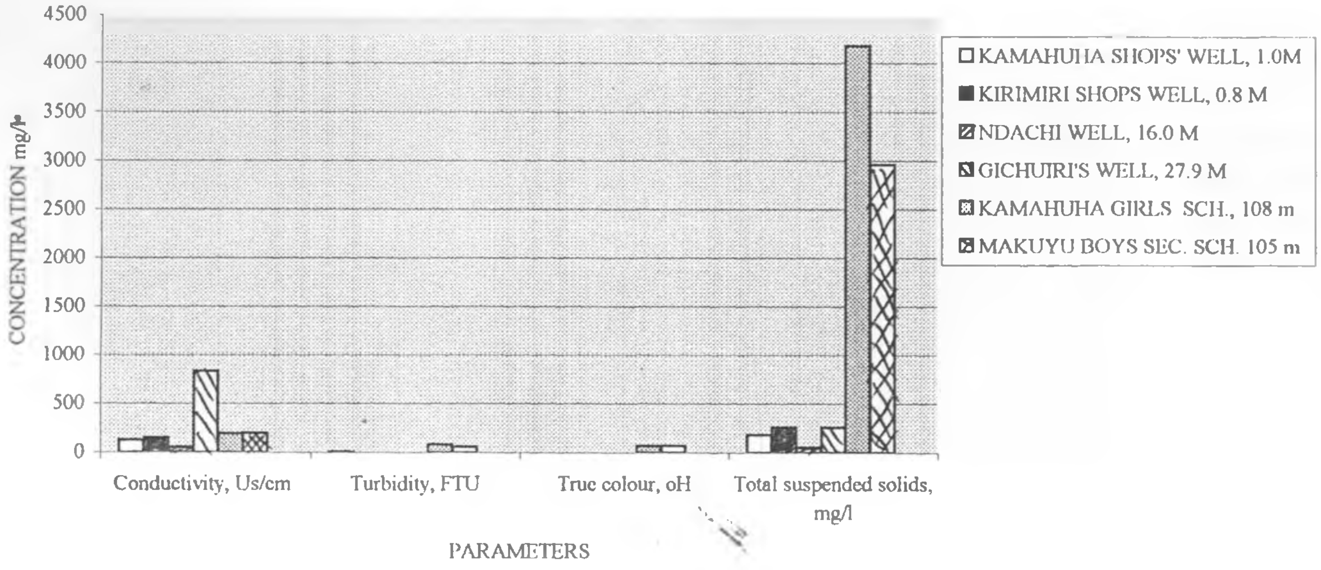


Table 4.6.3 Shows chemical characteristics of water from below 10 m deep wells, 10 - 50 m deep wells and 50 -100 m deep boreholes.

DESCRIPTION	KAMAHUHA	KIRIMIRI	NDACHI	GICHUIRI'S	MBURU	MURANG'A
	SHOPS'	SHOPS	WELL,	WELL,	BOREHOLE	T.T.C
	WELL, 1.0M	WELL, 0.8M	16.0 M	27.9 M	50 m	BH., 75M
	Mean	Mean	Mean	Mean	Mean	Mean
Fluorides, mg/l	0.5	0.34	0.37	0.52	0.4	0.58
Sulphate, mg/l as SO42-	0.65	0.17	0.48	0.22	0.39	0.31
Phosphates, mg/l as PO4-	1.21	0.46	1.88	0.35	0.42	1.75
Nitrates, mg/l as NO3-	1.34	1.46	1.22	0.648	0.38	0.51
Iron, mg/l as Fe	0.1458	0.0994	0.2369	0.0159	0.0172	0.0203

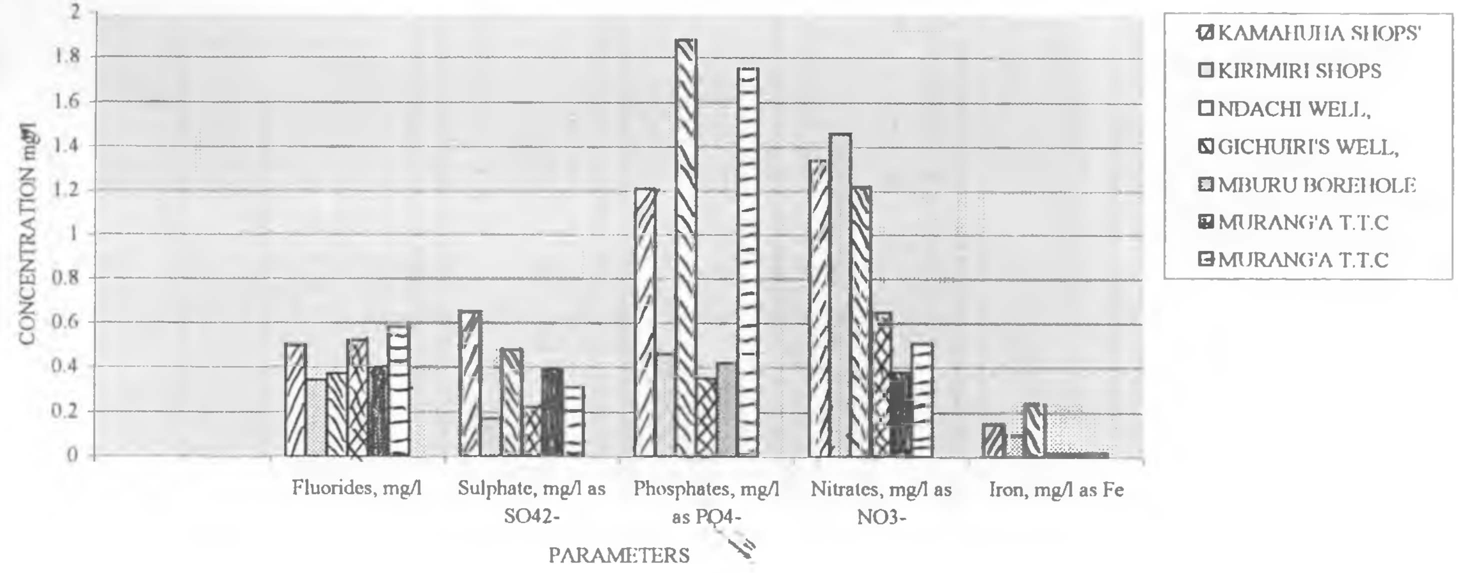


FIGURE 4.12 COMPARISON OF PHYSICAL CHARACTERISTICS OF WATER FROM BELOW 10 M DEEP WELLS, 10 - 50 M DEEP WELLS AND 50 - 100 M DEEP BOREHOLES

Table 4.6.4 Shows chemical characteristics of water from below 10 m deep wells, 10 - 50 m deep wells and above100 m deep boreholes

DESCRIPTION	KAMAHUHA SHOPS' WELL, 1.0 M	KIRIMIRI SHOPS WELL, 0.8 M	NDACHI WELL, 16.0 M	GICHUIRI'S WELL, 27.9 M	KAMAHUHA GIRLS HIGH SCH., 108 m	MAKUYU BOYS SEC. SCH. 105 m
	Mean	Mean	Mean	Mean	Mean	Mean
Fluorides, mg/l	0.5	0.34	0.37	0.52	0.75	2.5
Sulphate, mg/l as SO42-	0.65	0.17	0.48	0.22	0.23	0.36
Phosphates, mg/l as PO4-	1.21	0.46	1.88	0.35	0.33	0.57
Nitrates, mg/l as NO3-	1.34	1.46	1.22	0.648	0.65	0.56
Iron, mg/l as Fe	0.1458	0.0994	0.2369	0.0159	1.145	0.0435

FIGURE 4.13 COMPARISON OF CHEMICAL CHARACTERISTICS OF WATER FROM BELOW 10 M DEEP WELLS, 10 - 50 M DEEP WELLS AND ABOVE 100 M DEEP BOREHOLES

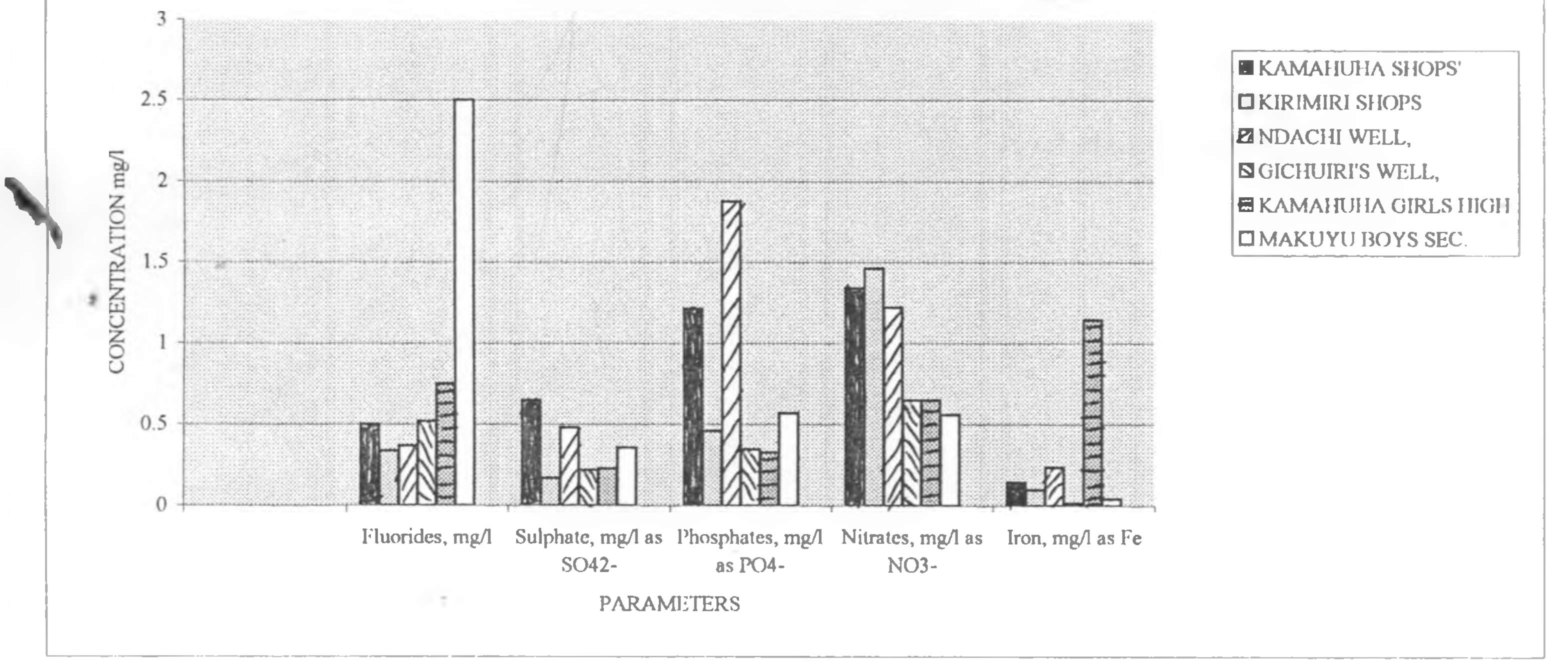


Table 4.6.5 Shows Microbiological characteristics of water from below 10 m, 10 - 50 m deep wells and 50 - 100 m deep boreholes.

WATER SOURCES	Total coliform/100mg/l	Total feacal coliform/100mg/l
KAMAHUHA WELL, 1.0m	220	725
KIRIMIRI WELL, 0.8m	0	0
NDACHI WELL,16 m	725	3200
GICHUIRI WELL, 27.9 m	0	0
MBURU WELL, 14.7m	0	0
MURANG'A T.T.C BH ,75m	0	0

FIG. 4.14 COMPARISON OF MICROBIOLOGICAL CHARACTERISTICS OF WATER FROM BELOW 10 M DEEP WELL, 10 - 50 M DEEP WELLS AND 50 - 100 M DEEP BOREHOLES

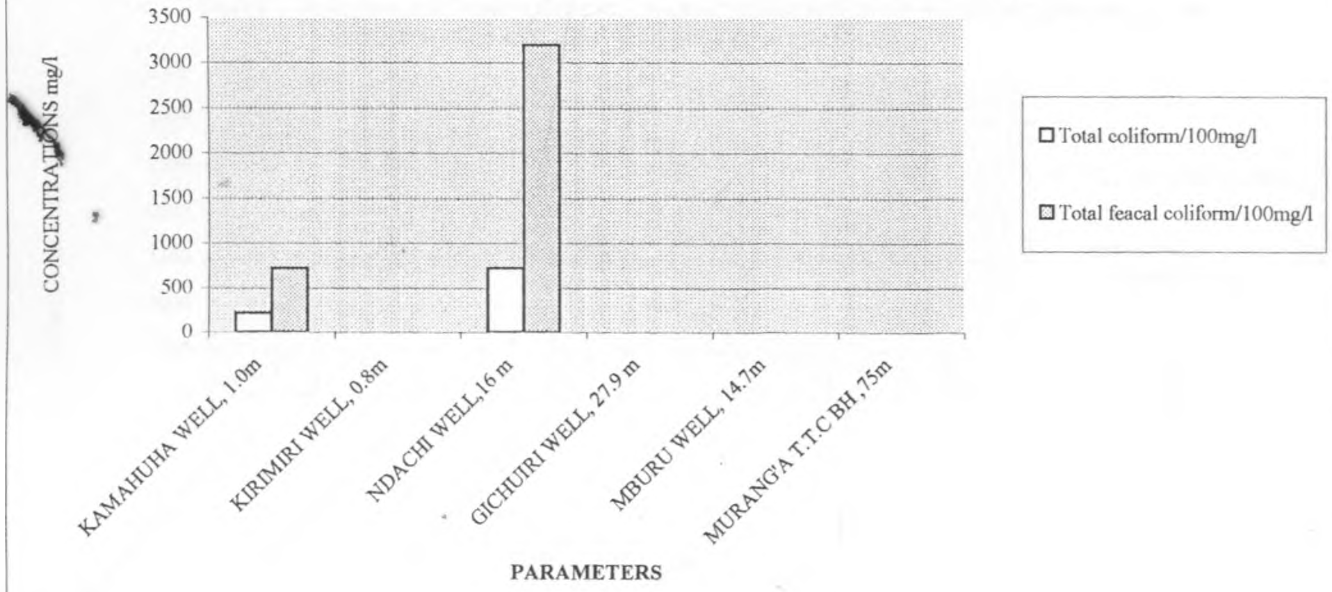
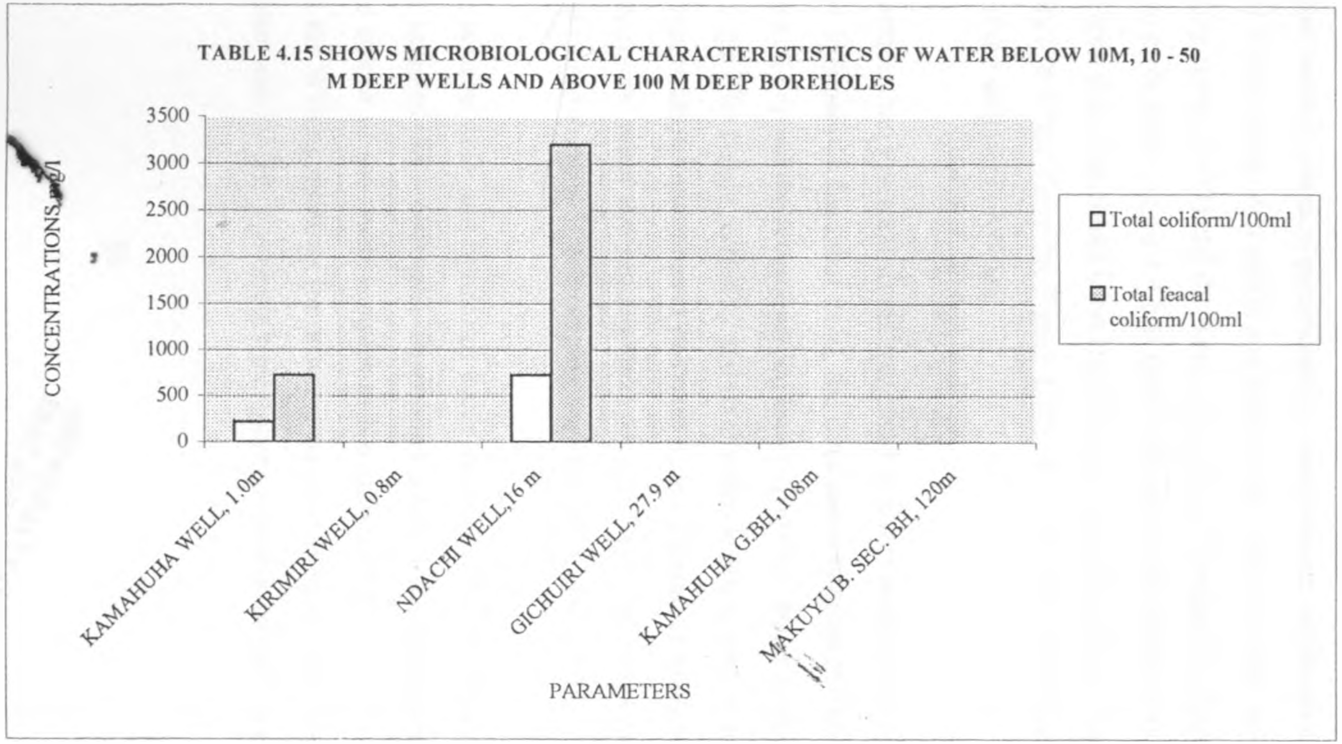


Table 4.6.6 Shows Microbiological characteristics of water from below 10 m, 10 - 50 m deep wells and above 100 m deep boreholes.

WATER SOURCES	Total coliform/100mg/l	Total feacal coliform/100mg/l
KAMAHUHA WELL, 1.0m	220	725
KIRIMIRI WELL, 0.8m	0	0
NDACHI WELL,16 m	725	3200
GICHUIRI WELL, 27.9 m	0	0
KAMAHUHA G.BH, 108m	0	0
MAKUYU B. SEC. BH, 120m	0	0



From the tabulated data, there was high precision because the difference from one value and another for the same parameter for the same sample is very small. This suggests high degree of reproducibility and hence high reliability of the methods used. The standard deviation is a function of the sharpness of the frequency curve, the smaller the value of standard deviation the better the precision.

4.3 Discussion

4.3.1 Physical properties

The results of the 12 boreholes and nine wells water samples in Tables 4.1.1 – 4.1.4 and Figures 4.1 – 4.4) shows that most of physical parameters i.e. temperature, conductivity, colour, turbidity, dissolved solids, suspended solids and total solids were low, well below the WHO guidelines for drinking water (1993) and the Kenya Bureau of Standard for drinking water (1985). Wamtega borehole from Figure 4.4 had high total dissolved solids (4000 mg/l). It was located in the same area with Kamahuha Girls High School, which has high total solids (4290 υS/cm), and turbidity (38 FTU). From the Figure 4.10 – 4.11, the physical properties do not varies with the depth of the wells or boreholes.

The shallow wells water samples had low total solids compared to rivers water samples, which has high total solids. Whereas on the other hand, the river water samples in Table 4.1.5, the physical properties were all beyond the recommended limits. The river water samples colour and turbidity were high. The colour, turbidity and total solids levels in river water were above the World Health Organization Guidelines (1993) and Kenya Bureau of Standards (1985). The turbidity of the rivers' water was ranging from 41 – 85 FTU. The temperature of the water was same in most of the sources. It was ranging between 22 ^{0}C and 23 ^{0}C.

The total solids were high in deep wells and boreholes water samples (182 – 4290 mg/l) than in the shallow wells water samples (38 – 698mg/l). Suspended solids in surface water ranged from 21 – 81.8 mg/l. The colour of the water samples in Kamahuha girls high school were high (20 – 70 ^{0}H) beyond the WHO guidelines for drinking water (1993). For the Kamahuha girls' high school, the colour was 20 ^{0}H. The rivers water samples colour ranged between 30 ^{0}H and 70 ^{0}H.

This indicates that the river water would require treatment before use, especially for domestic use

4.3.2 Chemical properties

The results of the 12 boreholes, nine wells and three rivers water samples in Tables 4.2.1 – 4.2.5 shows that most of these parameters are low, well below the WHO guidelines for drinking water (1993) and the Kenya Bureau of Standard for drinking water (1985). From the results, the concentration of nitrates was high in river water samples than boreholes and wells water samples. The concentration of nitrates is high in shallow wells (0 – 50 metres) than in deep wells and boreholes (50 metres and above) e.g. Kirimiri shops' well which is 0.8 m deep has a concentration of 1.46 mg/l and Kamahuha shops' well which is one metre deep has concentration of 1.34 mg/l.

Figures 4.5 – 4.8 also show comparison between the boreholes, wells and rivers water samples chemical properties. From the Figure 4.8, the concentration of nitrates and sulphate was high in surface water than in groundwater. This can be attributed to agricultural activities upstream of the rivers. In the study area people were growing French beans through irrigation along the rivers riparian area.

The concentration of fluoride was within World Health Organisation Guidelines (1993) and Kenya Bureau of Standards (1985) except for Makuyu secondary school borehole water sample, which is high at 2.5 mg/l. The recommended level for fluoride in drinking water is 1.5 mg/l (WHO, 1993). There is thus need to address the issue of high fluoride content. Blending with water lower fluoride concentration could correct the problem.

The concentration of iron and manganese were 1.145 mg/l and 1.019 mg/l, respectively, in Kamahuha girls' high school borehole water sample. These were higher than the World Health Organisation Guidelines (1993), which is 1.0 mg/l for iron and 0.5 mg/l for manganese. The borehole was abandoned late last year 2002 due to blockage of the pipes by precipitates of iron Fe^{3+} and frequent breakdown of pump.

The school had constructed a treatment plant to address the problem of iron and manganese. The plant consisted of tank packed with course aggregate. The aggregates used were prepared from Nairobi blue stone hardcore. Water was pumped into the tank after pumping from the borehole. Water traversed through the aggregates and was collected by a pipe placed at the bottom of the tank. Water was then conveyed under gravity to a storage tank on the lower side of the school. It was then pumped to an elevated tank for distribution. After sometimes, the pipes were found to be coated by iron Fe^{3+} deposits and after three months iron Fe^{3+} deposits clogged the filter. Thus, the plant was abandoned. Effective methods of iron and manganese removal from groundwater include iron exchange and chlorination. They could be investigated for the removal of these two ions from the water.

The heavy metals analysed were titanium, copper, zinc, strontium, yttrium and zirconium results were low, well below the WHO guidelines for drinking water (1993) and the Kenya Bureau of Standards for drinking water (1985) for both groundwater and surface water. The heavy metal concentrations values from 0 – 0.0588 mg/l for titanium, 0.0011 – 0.0142 mg/l for copper, 0.0027 – 0.1692 mg/l for zinc, 0.0011 – 0.0016 mg/l for strontium, 0.0012 – 0.0043 mg/l for yttrium and 0.0013 – 0.0043 mg/l for zirconium.

In the test for pesticides, all the pesticides sought were not detected. These include: - Diazinon, malathion, carbofuran, p'p' DDT, p'p' DDE, eldrin, aldrin, heptachlor and atrazine, Chlorpyrifos, methyl parathion, dimethoate, ethyl parathion and fenalimol. Pesticides were rarely used in the study area due to the high costs of the chemicals. This was one of the contributing factors to the absence of pesticides. It was only in the Kakuzi estate where pesticides were used extensively but their boreholes were located in the uncultivated area.

From the Figures 4.5 – 4.8 and Figure 4.12 – 4.13, the chemical properties do not varies with the depth of the wells or boreholes. The chemicals depend on the human activities within the area and the geological conditions of the area. For example, Kamahuha girls' school borehole has concentration of iron because of its location. It is situated in an area with salt bearing rock. In addition, Kamahuha shop's well has concentration of phosphates (1.21 mg/l). This can be attributed to livestock wastes, as there is a path nearby leading their grazing field, agricultural activities and detergents used in washing clothes.

4.3.3 Microbiological properties

The results of the 12 boreholes water samples in Tables 4.3.1 and 4.3.2 shows zero presence of total coliform/100mg/l and feacal coliform/100mg/l. This was as required by the WHO guidelines for drinking water (1993) and the Kenya Bureau of Standard for drinking water (1985). Whereas on the other hand, the river water samples in Table 4.1.3, the total coliform and feacal coliform were detected. The total feacal coliform/100ml values ranged from 30 – 250 and for total coliform/100ml values ranged from 100 – 210 for river water samples. This indicates that the river water would require treatment before use, especially for domestic use.

Figure 4.9 also shows comparison between the wells of varying depths and rivers' water samples. In addition, Figure 4.14 – 4.15, the microbiological characteristics do not vary with depth of the groundwater source but depend on the human activities around the groundwater source. The total coliforms were detected in wells, which are found near pit latrines like Ndachi wells and Muruithia's well. Ndachi well water sample had a value of total feacal coliform/100ml as 3200. It was located 5 metres from the pit latrine. The Kamahuha shops' well is 0.8 metres and it is located in area adjacent to a path that is occasionally used by livestock. There is also a small bush where children sometimes defaecates. These could be factors contributing to presence of feacal coliforms. The well was not protected and water users fetched the water from the well using buckets and tins. These containers can also pollute the water if they are contaminated.

For the other wells in which total coliforms and feacal coliforms were detected e.g. Esbon well and Gikungu well, this can result due to contamination of wells by water fetching buckets. The shallow wells water samples were the one, which had feacal coliforms. Thus, groundwater from deep wells and boreholes is better for domestic use than shallow wells based on microbiological pollution. This was because it was not polluted by animal wastes.

In addition, the method of water extraction used could also affect the water characteristics. For the boreholes, water was pumped and for the shallow well, water was fetched using buckets. These buckets if not properly cleaned could contribute to water contamination. Some of the water users in Kamahuha shops well and Kirimiri shops well were using plastic containers to fetch water. This could also result to water contamination

CHAPTER 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the presented study findings of the status of both surface water and groundwater from the 12 boreholes, nine wells and three rivers, the following conclusions were made: -

- Surface water from the three rivers: Sabasaba, Ndera and Thaara were mainly polluted physical and microbiological properties and thus require a full treatment.
- Groundwater quality in the Makuyu Division shows that the physical parameters colour, turbidity and total solids were all below the maximum allowable limits.
- Groundwater quality in the Makuyu Division shows that the chemical parameters were below the maximum allowable limits except for fluoride in Makuyu Secondary School borehole and iron and Manganese in Kamahuha girls' high school borehole.
- Groundwater quality in the Makuyu Division shows that the biological parameters were below the maximum allowable limits except for wells, which were near pit latrine like Ndachi well and Muruithia well and the unprotected ones like Kamahuha shops' well. In addition, in the shallow wells feacal coliform were detected like Esbon well and Gikungu well.
- The heavy metals pollution for the groundwater was below the World Health Organisation Guidelines (WHO, 1993) and Kenya Bureau of Standards specification for drinking water (1985).
- In addition, the pesticides e.g. organochlorides and organophosphates were not detected in all the water sources.

5.2 RECOMMENDATIONS

Based on the above findings of the status of the surface and groundwater in Makuyu Division of Maragua District, the following recommendations were made: -

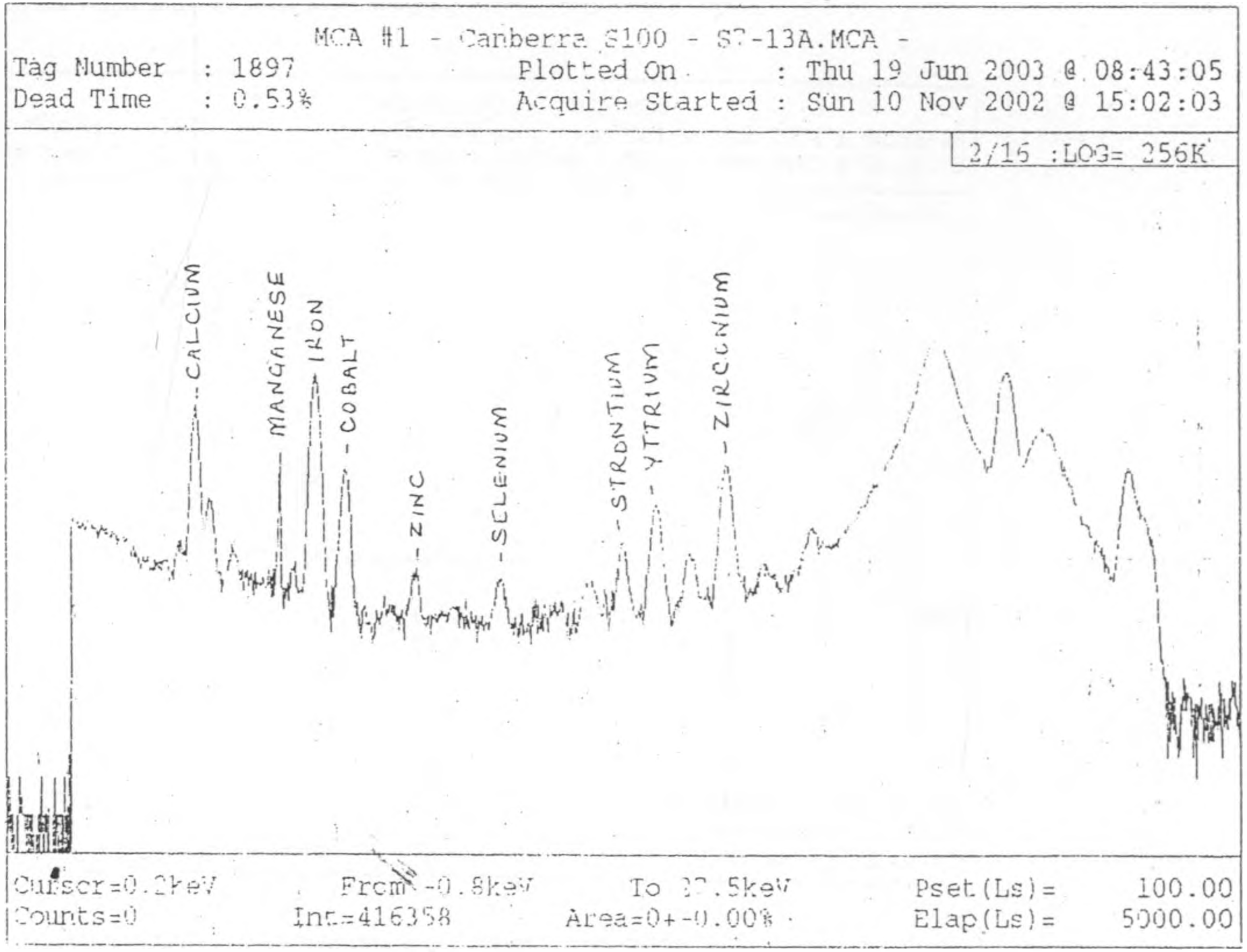
- The present quality for groundwater in the area is fairly good but measures should be instituted to conserve the quality.
- The community should be sensitized on the status of groundwater and be encouraged to use the groundwater for domestic purposes.
- To prevent groundwater pollution in communal groundwater sources, awareness should be created on hygienic matters. Clean water alone will not significantly alter health status if not accompanied by an intensive educational programme.
- Pit latrines should not be built near the water sources but should be 15m away as recommended to prevent pollution. This can be proved by the fact that Ndachi well water sample had high concentration of feacal coliforms unlike the other shallow wells.
- The study has found groundwater source for Makuyu Division as unpolluted source in comparison with surface water source from the three rivers Nonetheless, there is need to ascertain the well yields especially during the dry season, in order to ascertain the reliability of the source.

APPENDIX

A1. Spectrum of the standard.

A2. Spectrum of the water sample filter after analysis.

Fig. A1 A spectrum of the standard used in the x-ray fluorescence for analyses of water samples filters.

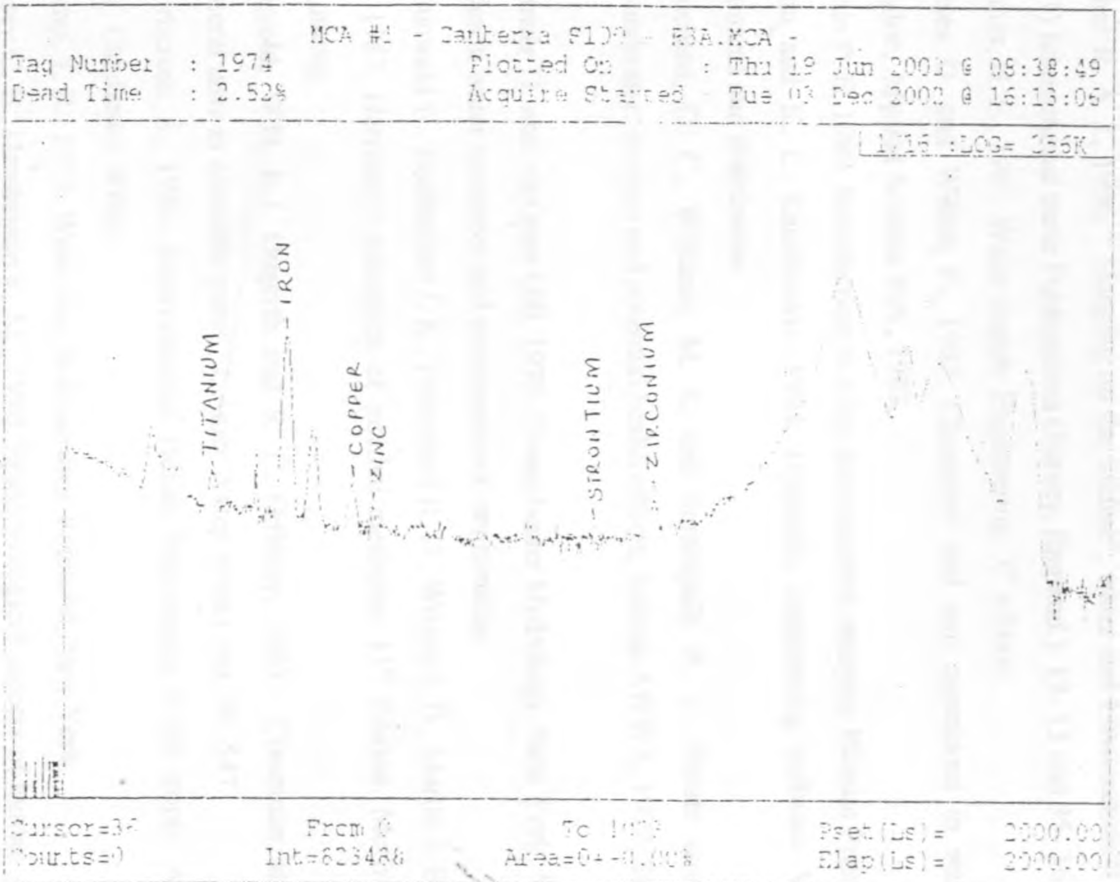


```
                MCA #1 - Canberra S100 - ST-13A.MCA -
Tag Number   : 1897              Plotted On        : Thu 19 Jun 2003 @ 08:43:05
Dead Time    : 0.53%             Acquire Started  : Sun 10 Nov 2002 @ 15:02:03
                                                              2/16 :LOG= 256K

Cursor=0.2keV        From -0.8keV       To [illegible].5keV       Pset(Ls)=     100.00
Counts=0          Int=416358      Area=0+-0.00%       Elap(Ls)=    5000.00
```

]

Fig. A2 A spectrum of one of the water samples filter after analyses in the X-ray florescence.



```
                    MCA #1 - Canberra S100 - R3A.MCA -
Tag Number   : 1974                  Plotted On        : Thu 19 Jun 2003 @ 08:38:49
Dead Time    : 2.52%                 Acquire Started     Tue 03 Dec 2002 @ 16:13:06
                                                               1/16 :LOG= 256K
Cursor=36            From 0             To 1023              Pset(Ls)=     2000.00
Counts=0             Int=623488         Area=0+-0.00%        Elap(Ls)=     2000.00
```

The spectrum was then analysed using quantitative X-ray analysis program (QXAS) and corresponding concentrations calculated with the help of a pro- 350 microcomputer. The same procedure was used for all the spectrum.

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