UNIVERSITY OF NAIROBI

COLLEGE OF BIOLOGICAL AND PHYSICAL SCIENCES

FACULTY OF SCIENCE

DEPARTMENT OF GEOLOGY

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN GEOLOGY

TITLE:
WATER POLLUTION AND WASTE DISPOSAL PROBLEMS IN THE THIKA AREA, KENYA

BY

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REGISTRATION NO. I56/7446/89

NAIROBI, 1994

DECLARATION

I Yusuf Abdi Salah, hereby declare that this is my own work and has not been presented for a degree at any other university. All sources of information have been specifically acknowledged by means of references.

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THIS THESIS HAS BEEN SUBMITTED FOR EXAMINATION WITH OUR KNOWLEDGE AS UNIVERSITY SUPERVISORS.

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November 1994

ABSTRACT

Thirty three surface water samples, thirty one groundwater samples and nine samples of sewage and industrial effluents were collected and analysed for various parameters mainly for Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrate, phosphorus and metals. Data on solid waste disposal methods and their geoenvironmental consequences as well as the chemical / biological characteristics of aquifers in the study area were collected. Factor analyses and Pearsons product moment correlation coefficient were used to analyse the analytical data.

Open dumping systems is mostly used for the disposal of solid waste. The aquifers in the area of study consist of confined and unconfined aquifers.

The physical and chemical properties of the water of Thika, Komu and Athi rivers are modified by industrial and sewage effluents. The average concentrations of BOD and COD in the samples obtained from Komu and Athi rivers were found to be higher than the concentration of BOD (2ppm) and COD (20ppm) for unpolluted surface waters (Chapman, 1992).

THe concentration of elements in the surface water samples except Cd, Al and NO_3^- in certain samples fell below the WHO (1982) limit. The concentration of all elements in the groundwater samples except Ca and Al fell below the maximum permissible limits recommended by WHO (1982).
Shallow wells are more contaminated than the deep ones.

ACKNOWLEDGEMENTS

I am greatly indebted to Dr. T. C. Davies, my immediate supervisor, for his guidance and support in the execution of this research work. I am also indebted to my second supervisor, Prof. S. J. Gaciri for his encouragement.

I am grateful to the Germany Academic Exchange Service (DAAD) for the award of a scholarship which saw me through the entire programme.

My thanks also go to Mr. Mboya, my Sedimentary Petrology lecturer for his advise on the use of statistical programmes for data analysis, and to Dr. Jumba of the Chemistry Department for providing some references for the analytical work.

I thank Mr. Waiharu for his assistance in the analysis of my samples, Mrs. Kahuthia for her patience in typing the thesis and P. Mutonyi for drawing some of the figures in this work.

I wish to thank my colleague, Mr J.K. Nzomo for his invaluable assistance in the use of computer-graphics software for setting and drawing both graphs and tables.

I also thank my colleagues Abdi Omar, Farhia, M. A. Jimale and A. Mayow for their support throughout the course of my research.

Finally, my thanks go to my parents, brothers and sisters for their moral support during my entire study in Kenya and my wife Malyun for her understanding during the difficult months that this work lasted.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Purpose and Scope

Concern about environmental levels of many pollutants worldwide has led to a considerable increase in efforts at monitoring water concentrations. Much of this work however, has been carried out in the industrialised countries. The rate of industrial growth in some areas of the developing countries is often greater than the global average. It is therefore interesting to look at pollution problems in such areas, especially pollutants such as heavy metals which may have their origin in industrial effluents.

Some water quality data exist for a number of rivers and boreholes in Kenya, but these are largely confined to major cations, such as sodium, potassium and calcium, and anions such as chloride, sulphate and carbonates. Data relevant to the pollution of the water points, such as indices of gross organic pollution like BOD- biochemical oxygen demand or levels of toxic micro-pollutants like heavy metals are seldom collected.

The reason for this lack of pollution data is that industrial activities and the consequential urbanisation have been and still are at a low level in most African countries. Many of the rivers and groundwaters in some of the African countries have therefore remained largely unpolluted, or the pollution stress is low and can easily be accommodated by natural self-purification.

However, as a result of industrial growth, the situation has been changing rapidly in Kenya since independence and especially during 1970's. Increased industrial activities have led to urbanisation and pollution stress on the environment both from industrial and domestic sources.

Thika is one of the areas in Kenya where the pollution problem is of particular concern. Since the 1970's, Thika town has been the site of considerable industrial development and the industries are still growing because of the good climate, good links with Nairobi, the country's capital city, adequate water supply and availability of land for industrial growth.

Apart from Thika municipality, the townships or estates in the study area have no piped water supply. In most of these estates, the inhabitants obtain drinking water from rivers, small springs and wells dug into the surficial aquifers. Toilets built on cesspools with no insulated walls serve for the accommodation of faecal matter in these shallow aquifers in some places like Kalimoni Estate.

The widespread use of chemical fertilisers raises various health problems, not least that of preventing such chemicals from contaminating the populations' water supplies. The study of the conditions under which chemical fertilisers can find their way into surface and groundwaters is of great practical interest, since in such a situation the health of the users of the contaminated water is at stake.

The pollution of the natural environment changes the natural trace element composition of surface and groundwaters. The trace elements derived from the pollutants move into groundwater, directly from waste disposal reservoirs and sewage systems from which leaching occurs. They also can be washed downwards by the rain-water infiltrating the soil zone from solid-waste materials deposited on the surface of the earth.

Some trace elements are essential for life, others are toxic or cause disease when present in excess. Knowledge of the background levels of trace elements in environmental samples and the changes occurring is essential to the environmental geology and to many other fields of science. The data collected on trace element occurrence in both surface and groundwaters may also facilitate the identification of pollutant sources connected with urban/industrial or agricultural activities and can be used in tracing pollution movement into the groundwater.

Dedication of a substantial proportion of the total research effort on the surface and groundwater quality of the Thika area was justified by this area's critical importance, high population and the almost complete lack of published work on the area's water quality. A detailed survey of the trace elements in surface and groundwaters and the pollutant sources has been carried out with the purpose of obtaining a picture of the present state of water pollution in the area studied.

The specific objectives of this research work were as follows:

1. To make a detailed study of the stratigraphy of the study area in order to establish the aquifers as well as the suitability of proposed site for waste disposal.
2. To assess the quality of groundwaters and surface waters in the study area by determining the level of toxic elements such as Pb, Cd, Ni, Co, Zn, Cu, Fe, Mn as well as NO_3^- and P. The concentrations of these species are compared with maximum

levels permissible based on recommendations by for example, the WHO or National Environmental Protection Agency (NEPA) of the USA.

3. To evaluate the existing methods of waste disposal in the area in order to bring out their merits and demerits.

4. To study the impact of the methods of waste disposal and ground and surface water management on the population, based on 1,2,3 above.

5. To make recommendations based on this study, a) on ways by which the surface and groundwater quality in the study area can be improved and prevented from pollution, and b) on the adoption of a more effective and environment-conscious approach to the problem of solid waste disposal.

1.2 Location

The area studied is situated in the Central Province of the Republic of Kenya, about 40 km north -east of Nairobi; it is approximately 532 km^2 in extent, and is bounded by longitude 37^0,00 E and 37^0,15 E and latitude 1^0,00S and 1^0,10.05′(Fig 1.1).

The area is covered by 1:50,000 topographic Sheet number 149/1, published by the British Ministry of Overseas Development in 1975.

1.3 Previous Related Work

Gregory (1894) referring to his journey of 1893 to the Rift Valley, described passing through Machakos and across the Kapiti plains to Fort Smith and gave a full account of the nature of the Iveti hills, which he regarded as forming part of

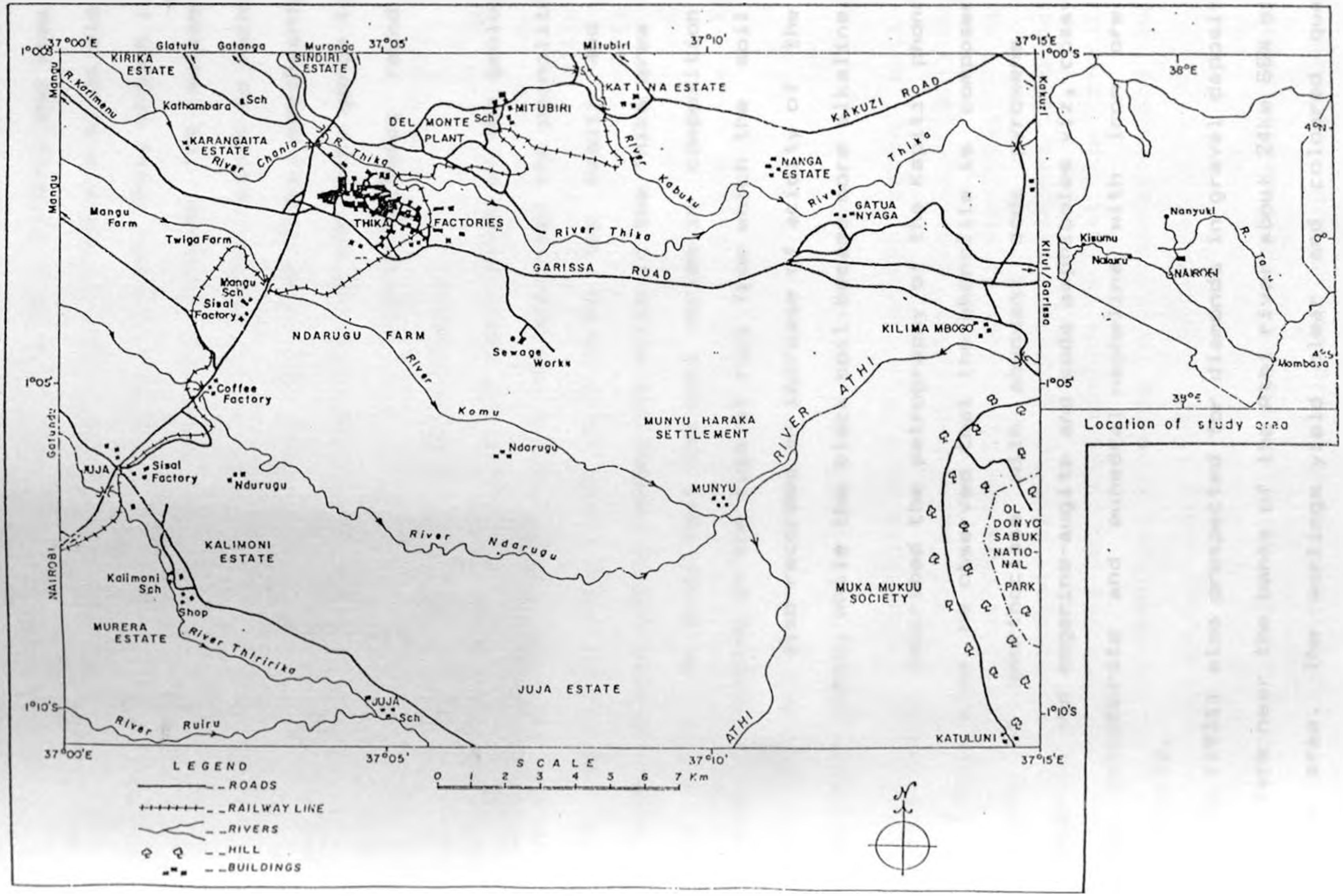


FIG. 1.1 – STUDY AREA

a primitive axis of Africa. In a more detailed account of his journey Gregory (1896) described the lava plain west of Machakos and the ridges of gneiss forming Lukenya and Koma Rock that stand above it. He had been led to believe by an old map that this plain was recent alluvium and not lava, though it is possible that the map intended to indicate the sedimentary basin between Lukenya and Mua hills. On his return to Machakos, Gregory followed the course of the river Thika, southwards to Voroni (Mabaloni), and then westwards up the Thika gorge to the lava plain, before turning south towards Machakos round the southern end of Ghangari (Oldoinyo Sabuk).

Later Gregory (1921) gave a brief description of the geology of the Fort Hall and Thika regions. He described the phonolite in the region of Athi river which forms the Kapiti and Athi plains. Gracie (1930) tested the soils in the Thika area upto Mua hills. He found that the soil varies in composition and colour depending on the type of rock from which the soil was derived. He also recorded an increase of acidity of the red soil with depth, while the black soil became more alkaline.

Smith (1931) described the petrography of the Kapiti phonolite in Thika area. He observed that the phonolite is composed of prisms of anorthoclase with abundant soda pyroxene viz, aegerine and aegerine-augite and soda amphiboles viz, cossyrite and kataphorite and euhedral nepheline with iron ore and analcite.

Smith (1931) also prospected for diamonds in gravel deposits on his farm near the banks of the Athi river about 24km SSW of the Juja area. The workings yield clear and coloured quartz, feldspar, agate chalcedony and fragments of Tertiary lava but no diamonds.

Sikes (1934) presented a paper dealing with the groundwater condition of Nairobi area, including part of the Thika area. He indicated that the large supply of water is extracted from the deeper aquifers which are composed of phonolite and basalt. The water quality here is quite satisfactory. Sikes (1939) also presented a report and a geological map of the country surrounding Nairobi. His mapping includes the Kapiti phonolite of the Thika area. His petrographic description of this phonolite agrees with that of Smith (1931).

Shackleton (1945) presented a geological report of Nyeri area. He concluded in his report that the rocks in the area consist of Pleistocene and Tertiary volcanics. The former are comprised of the Laikipian basalts and Mt. Kenya volcanics, while the later comprises the lower Laikipian basalts, Nyeri tuffs and Sattima and Simbara Series. Shackleton (1945) found no indication of the Simbara Series overlying the Kapiti phonolite.

Schoeman (1948) described the petrography of the Kapiti phonolite of the Thika area. His findings agreed well with those of Smith (1931) and Sikes (1939). Schoeman (1948) studied the granites that form the Lion rocks of the Thika - Garissa road and indicated that the granite resembles granitoid - gneiss in outcrop but is dissimilar in that the granite is unfoliated in hand specimens and is in uncomformable contact with the surrounding rocks.

Baker (1954) and Joubert (1957) studied the basement system and its structure. They found that granitization sequences took place between the unaltered metamorphic rocks and the granitoid gneisses which is the end product of the sequences. They expressed the view that the foliation of the basement system is parallel to the original bedding planes of the sedimentary rocks from which the system was derived.

Fairburn (1963) carried out geological mapping of the North Machakos - Thika area and concluded that the area consists of flat volcanic plains in the west and generally hilly country to the east. He also concluded that the rocks in this area consist of horizontal Tertiary lavas, pyroclastics and sediments to the west and folded basement system gneisses and schist to the east. The basement rocks are metamorphic and in some places have been granitised to a considerable degree into granitoid gneiss. Soil types in the area are dependent on drainage; black - cotton soils develop in the poorly drained regions while sandy soils and murram form in the well drained regions.

Gevaerts (1970) produced a hydrogeological report of the Nairobi area which also covers part of the Thika area. He concluded in his report that the area can be divided into groundwater areas and zones on the basis of the different modes of occurrences of the main groundwater supplies. The groundwater occurs in both confined and unconfined aquifers which are mainly recharged by atmospheric precipitation and the rivers. The recharge of the free groundwater appears to be adequate but the confined aquifers have suffered loss of storage at localities of continuous large abstraction. Gevaerts (1970) also demonstrated that the water is of good quality except for its fluoride content which is excess of the safe limits (1.5 ppm) as recommended by WHO. Water in deep aquifers contain high concentration of chlorides and sulphates which are derived from lacustrine sediments intercalated with the lavas.

The Ministry of Water Development, Pollution Control Division and the Thika Municipality Council do monitor some of the water quality parameters in several rivers in most of the area studied. Results though not published are kept as records.

1.4 Communication

The study area is easily accessible and served by a well developed and extensive communication system (roads, railways etc.) designed to provide maximum support for agricultural and industrial activities. Tarmac roads through Nairobi-Thika, Thika-Garissa and Thika-Murang'a cross the study area, while railway communication is provided by Nairobi-Nanyuki railway at Thika. In addition to the tarmac and railway communication, there are rough motor-tracks passable by robust vehicles only, several motorable routes practicable to small four-wheel-drive vehicles and numerous footpaths. Most of these tracks are maintained in fairly good condition, though during heavy rains they are sometimes impassable.

1.5 Hydrological Conditions

1.5.1 Climate and Vegetation

The climate in the area is similar to that of Nairobi. Mean annual air temperature is 19.5°C and mean annual relative humidity is 70 - 90% . Mean annual precipitation is 1000 mm, with mean annual surface water evaporation at 1100 mm (Ministry of Water Development, 1988). Almost all the rainfall is concentrated in two rainy seasons which last from about March to May and mid- October to December respectively.

The greater part of the area is covered by large- and small-scale farms. Pineapples, coffee and sugar-cane are the widely grown crops. The coffee plantations are mainly found in the western part of the area, while pineapple is well-developed in the eastern part. Maize, beans, millet and sisal are also common. Most of the plantations are irrigated by the waters of Thika, Chania, Ndarugu and Thiririka rivers.

The ground near the rivers and a considerable part of Oldoinyo Sabuk (Fig. 1.1) is covered by forest consisting of tall trees and thick bushes. At the Thika waste disposal site and around the sewage plant, the land is swampy and little cultivated.

1.5.2 Hydrography

The surface drainage system of the area consists of the Athi, Thika, Chania, Ndarugu, Thiririka and Komu rivers, all of which receive their inflow from streams rising further west on the high ground at the edge of the Rift Valley. Ndarugu and Komu rivers join with Athi river near Munyu township. Samuru tributary together with Kabuku contribute their waters to Thika river at Nanga Estate. Chania receives inflow from Gitathuru tributary near the Thika water supply dam. Ruiru river connects with Thiririka river near Juja township.

Thika river flows through the densely populated industrialised Thika town, receiving effluents from many industries. Komu river flows 500 m away from the Thika waste disposal site and about 200 m away from the sewage treatment plant. It receives effluents from the sewage plant. All rivers flow toward the east.

There are a number of river gauging stations on the Thika, Athi and Ndarugu rivers. These stations record the daily flow volume of these rivers. Data on the average monthly discharge of these rivers for ten years collected from the Ministry of Water Development are presented in Appendix (I, II, III).

1.6 **Geomorphology**

The area studied consists of a flat volcanic plain at an altitude of about 1524 m above sea level and hills with altitude of about 450m above the volcanic plains. Oldoinyo Sabuk which is the highest hill in the area reaches an altitude of 2100m a.s.l. and about 623 m above the general level of the surrounding plain. The volcanic rocks rest on a sub-Miocene peneplain which emerges from beneath the lavas, 16km east of Thika at about 1400m a.s.l.(Dixey, 1948). The level of the sub-Miocene peneplain at any point is represented by the altitude of the base of the lowest volcanic rocks. The altitude of the peneplain rises to a little over 1524m to the west of Thika (Schoeman, 1948). At the present time the volcanic rocks are being eroded by a series of easterly flowing rivers, which have developed gorge-like valleys with numerous water-falls (Fairburn, 1963).

1.7 **Human Activities**

There are two towns and about eight coffee estates in the study area. Thika municipality has a population of about 100,000 inhabitants, according to the latest population census carried out in 1989. The population growth rate has recently been projected by the Ministry of Finance as lying between 7.15% and 8% (Mwangi, 1990).

Thika municipality has a sewage treatment plant; the estates and villages do not have sewage system but use septic tanks for primary treatment of their waste. This leads to seepage of domestic waste into the subsoil in some cases.

The area has many industries and large farms. The industrial sector consists of 23 major industries and several small coffee factories. The agricultural sector consists of more than eight large coffee and pineapple estates.

Industrial sector constitutes the main employment sector and income earner for most of the population. Future population growth will mainly be due to growth in the industrial sector. The agricultural sector also plays an important role on the population's activities. Large part of the population engages in agricultural activities, either in the cultivation of the crops (coffee, pineapple, sugar-cane etc.), or cattle raising (dairy farming).

The use of chemical products for agricultural purpose has been adopted in many parts of the area. The area has also some informal (Jua Kali) industries.

CHAPTER TWO

2.1 GEOLOGICAL SETTING

The main rock types exposed in area of study and its surroundings (from the oldest to the youngest) are (refer to Fig. 2.1 in the Appendices):

a) basement system
b) Metamorphosed intrusive (meta-dolerite)
c) Tertiary volcanics and sediments
d) Pleistocene sediments
e) and alluvial deposits .

Fairburn (1963) has classified the Tertiary volcanics and sediments as follows (from the oldest to the youngest):

(I) Kapiti phonolite
(II) Simbara Series which consist of basalts and agglomerate, and;
(III) Athi tuffs and lake beds which consist of:
b) Lower Thika building stone
c) Coarse agglomerate
d) Lake beds
e) Upper Thika building stone
f) Welded tuffs
g) Trachytic tuffs with thin basalt

2.1.1 Basement system

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

The lengthy period of time between the end of Precambrian and the Tertiary was probably one of repeated rejuvenation and erosion but the oldest clearly recognisable erosion bevel is only end - Cretaceous in age. A younger peneplain matured in sub-Miocene times after renewed uplift.

2.1.2 Metamorphosed Intrusive Rocks (Meta-dolerites)

The meta-dolerite forms the impressive hill of Oldoinyo Sabuk which rises to a height of 2100m a.s.l. and about 623 m above the general level of the surrounding plain. In outcrop, the meta-dolerites is massive with no visible foliation. A foliation can however be observed in some hand specimens caused by coarse banding of light and dark minerals.

Fairburn (1963) expressed that originally the rock consisted of large porphyritic pyroxene in a groundmass of coarsely crystalline plagioclase. Remnants of the original structure are now represented by large altered crystals of hornblende or hornblende enclosing pyroxene and occasional feldspars in a fine - grained groundmass of metamorphic origin. The primary pyroxene , probably augite, has been largely replaced by a pale green faintly pleochroic hornblende. The untwinned plagioclase has a composition in the region of andesine. Epidote is also abundant. Accessory minerals, mainly pyrite and calcite are not uncommon.

2.1.3 Tertiary Volcanics and Sediments

2.1.3.1 Kapiti Phonolite

The Kapiti phonolite appears to be resting on the sub-Miocene peneplain. The thickness of the phonolite varies. Borehole evidence shows that under the Thika plain, the phonolite is sometimes absent or up to over 95m . This is caused by relief in the basement system over which the lava flowed, accumulating in hollows and leaving the higher points to be covered by later pyroclastics (Fairburn, 1963). West of Kakuzi the pyroclastics rest directly on the basement with no underlying phonolite. The Kapiti phonolite also occurs under the pyroclastics in the Thika and Athi valleys.

The phonolite is a hard, black and fine - grained rock with prominent phenocrysts of orthoclase and nepheline. Microscopically , the groundmass consists of prisms of anorthoclase with abundance of soda pyroxene, aegerine and aegerine - augite, soda amphibole, cossyrite and kataphorite. Euhedral nepheline is also present with iron ore and analcite.

2.1.3.2 Simbara Series

Overlying the Kapiti phonolite in the Thika valley is a variable sequence of basaltic agglomerate of the Simbara series described by Shackleton (1945) in the Chania valley at Nyeri. These rocks are best displayed in the Thika valley, but also occur in the Komu and Ndarugu valleys and in the Kabuku tributary. There is no indication of basaltic agglomerates in the Athi valley, overlying the Kapiti phonolite. The surface of the basaltic agglomerates is extremely uneven, a feature well demonstrated in the Ndarugu valley. It is a fine-grained dark grey rock with small phenocrysts and clusters of calcic plagioclase feldspars and small insets of iddingsite and iron oxide, probably representing altered olivine phenocrysts. Tabular prisms of labradorite can also be seen in the fine-grained groundmass consisting of small feldspar prisms, granular magnetite and pyroxene, and small specks of iddingsite (Fairburn, 1963).

2.1.3.3 Athi Tuffs and Lake Beds in the Thika Area

The Athi tuffs and lake beds consist of pyroclastics, welded tuffs and Thika building stone interbedded with sediments. The pyroclastics and tuffs form a well marked horizon in the valley south of Thika. They are the most abundant of the volcanic rocks in the Thika area. Overlying the welded tuffs and forming the surface of the plains west of Oldoinyo Sabuk are grey trachytic tuffs with thin basaltic lava flows and are here considered as the upper tuffs of the Thika area.

The pyroclastics are probably of trachytic nature, commonly containing crystals of orthoclase and anorthoclase, and rarely crystals of aegerine in a groundmass made up largely of glass shards (Fairburn, 1963). The pyroclastics in the Thika area are well displayed in all the valleys and tend to give a uniform sequence over a wide area. The lowest pyroclastic horizon in the Thika area is a coarse soft plate agglomerate. This horizon is unbedded and about 15m thick, consisting mainly of coarse pumice and glass in a fine groundmass of glass.

Obsidian and lava fragments are rarely present (Fairburn, 1963).

The youngest pyroclastic bed in the Thika area is grey pumicious tuff underlying the thin Laikipian-type basalts which are exposed between the Ndarugu and Komu rivers.

Thika building stone is composed of a series of massively bedded fine - grained tuff or claystones. They occur in the Thika, Komu and Ndarugu valleys. Generally they are pale bluish in colour and resemble mudstones or fine-grained limestone more than volcanic rocks. In the Thika valley, two building stone horizons are present, a lower building stone up to 9 m thick and upper building about 5m thick. The extent of the lower building stone is considerable, occupying an area of about 129 km^2 in the Thika region. But the upper building stone is not thick, forming discontinuous exposure in the Thika and Komu valleys. The distinctive feature of the building stones is their fine grained character and their uniform pale colouring, which varies in tints of blue, purple, green and brown. This rock consists mainly of glass fragments with occasional crystals of orthoclase.

The most typical sediment deposits in the Thika area are soft clays, but sandstone and grits are also present along with calcareous bands and bands of chalcedonic silica. Near Juja township, the sediments are about 15m thick with a great variation of finely banded clays to coarse conglomerate (Fairburn, 1963). Fossils are not present in the sediments, which in the case of the coarser deposits, were definitely derived from the volcanic rocks (Fairburn, 1963). In the Komu and Ndarugu valleys, the sediments show much less variation and mainly consist of coarse grits with small fragments of obsidian. The coarse conglomerate is made up of small sub-angular grains of orthoclase, quartz, microcline and hornblende, cemented together by clay and secondary silica.

2.1.4 Basalts in the Upper Tuffs of the Thika Area

The youngest volcanic rocks in the Thika area are olivine basalts which form two fairly conspicuous ridges between the Komu and Ndarugu rivers. The basalts are probably of the same age as the thin basalts mapped in Githuyu by Thompson(1964) in the southern part of the Kijabe area (Fairburn, 1963). The rock is fine - grained, apparently non-porphyritic and platy with numerous amygdales of calcite. Iddingsite is fairly abundant giving the rock a speckled appearance. The basalt contains olivine, pyroxene, augite, magnetite, calcite, feldspar and analcite.

2.1.5 Pleistocene Sediments

These sediments are mainly composed of coarse poorly cemented sandstones. They cannot be definitely dated, but as they lie on the highest pyroclastics in the area, they are considered to be late Tertiary or Pleistocene in age (Fairburn, 1963).

2.1.6 Recent Deposits

Recent deposits include soils and alluvial sand deposits. The soils are normally residual weathering deposits whose composition is controlled more by the physical conditions of formation than by the type of the rock from which they were derived. The alluvial sands include river deposits and outwash fans from the hills. In general the well-drained soils are sandy and badly drained, black cotton soils which are mostly confined to the area under investigation. They are probably derived from the volcanics displayed under the plains of the area. On the eastern edge of the area probably on the Kapiti phonolite near Oldoinyo Sabuk, chocolate brown soil has developed which contains materials derived from the basement system. Gracie (1930) stated that the black soils show more alkaline tendency than the red soils.

Another important feature of the soils on the plains near Juja township is the development of mound topography. On the top of the mounds, the underlying rock surface, usually composed of cemented brecciated material is exposed or covered by only a few centimetres of soil. The mounds and depressions owe their shape to the action of drainage along the channels which may have originated from the development of fissure polygon networks caused by soil desiccation and shrinkage; this leads to increased erosional activity along the fissures or to subsidence along polygonal joint systems in the underlying rock (Fairburn, 1963).

2.1.7 Structure

The general strike direction in the basement, as in much of Kenya is between north and north-west (Fairburn, 1963).

Dips are dominantly to the west generally at moderate angles of 20° to 40°. Lineations are approximately parallel to the normal regional trend, plunging to the north or north-west and rarely to the south-east at low angles. Foliations are mostly pronounced in the schistose rocks and to a lesser extent in the other rocks. The foliation is paralleled by the boundaries between distinct rock types.

Cylindroidal folding with a predominance of westerly dips, which could indicate folds overturned to the east or folds with

more prominent westerly limbs was observed in the basement system (Fairburn, 1963).
Overturned folding is also prevalent in the basement. This was demonstrated by minor folds that have concordant axes (Fairburn, 1963).

The volcanic rocks are consistently horizontal or near horizontal. Mapping has revealed, however, that there is in fact a gentle dip to the east, the volcanic beds rising towards the Rift Valley. Two small faults throwing east were recorded in the volcanics, one in the Thika valley and the other in the Thiririka valley.

2.1.8 **Mineral Deposits**

No valuable mineral deposits have been observed in either the basement system or the volcanics. Earlier mineral researchers claimed that there are some traces of diamond, graphite, coal, manganese, garnet, kaolin, talc, gold and corundum in the basement system.

The only deposit of economic value in the area are the pyroclastic beds which yield high quality building stone. Many of the more important beds, such as those in the Thika and Komu rivers, and near Munyu township have been extensively quarried for a number of years. Presently , there is a need for the quarries to be worked on an organised basis to reduce inefficiency and wastage.

2.1.9 **Historical Geology of the Area**

In the Precambrian , the deposition of sediments of the basement occurred. Basic magma intruded into the rocks of the basement system; hence intense compression with rising

temperatures resulted in the transformation of the sediments into highly folded metamorphic series.
During compression and folding of the basement system rocks, much of the sedimentary series was affected to a lesser or greater degree by granitization. Over much of the system considerable alkali metasomatism took place giving rise to microcline - rich rocks.

After the formation of the sub-Miocene peneplain, disturbances along the Rift Valley resulted in outcropping of the Kapiti phonolite and the deposition of a considerable thickness of pyroclastics. In this period, lake beds were also deposited, interbedded with the pyroclastics. It is believed that the volcanics and the lake beds are Tertiary in age. In the Pleistocene, younger sediments were then deposited.

Recent deposits owing their origin to weathering and erosion, include soils, laterite and alluvial deposits.

2.2 HYDROGEOLOGICAL CONDITIONS

The area studied is characterized by a sequence of volcanic rocks (tuffs, basalts and phonolites) interbedded with sediments consisting of clay, sand and grits. The upper parts of these volcanic sequences is covered by soil in some places, and weathered volcanic material in some other places. The areas where groundwater occurs are in either confined or unconfined aquifers which are made of consolidated or unconsolidated materials. These sequences of volcanics and sediments are confined at the base by Precambrian basement systems.

2.2.1 Confined Aquifers

The confined aquifers encountered in the study area are mainly composed of the pyroclastics, tuffs and the sediments of Athi series, the Kapiti phonolite and the basalts of Simbara Series. These types of rocks are also encountered in the adjacent areas of Nairobi, Nyeri and Limuru.

Water supply studies conducted in the Nairobi area dealt with water bearing properties of these rocks. The basement system has been studied to some extent. It is not extensively fractured and jointed, and do not contain or transport groundwater.

The aquifers associated with the Kapiti phonolite are confined and occur on top or below the uppermost flow. In a study of the Nairobi area, Gevaerts (1970) stated that the phonolite is extensively fractured and jointed, and does contain and transport groundwater. He also noted that the piezometric surface of the these aquifers (at Thika) stands slightly below that of the aquifers of the Athi series at a depth of about 60m. Going northwards the piezometric surface approaches ground level. The Kapiti phonolite is overlain in the western side of the area studied by 152m and in the east by about 60m of Athi series. For obtaining an adequate supply it will be necessary in most cases to penetrate the Kapiti phonolite. A supply ranging from 0.128 l/sec to 0.25 l/sec is likely to be obtained from a depth of not more than 213m in the western side and 121m in the east. The water is highly alkaline and unsuitable for irrigation purposes (Gevaerts, 1970).

Other confined aquifers are in the Athi series. These aquifers are unpersistent and may be struck at any depth. As the yield and piezometric surface of the individual aquifers are not known, it is convenient to group them together. Gevaerts (1970) has divided the aquifers in the Athi series into two categories:

a) aquifers in the Upper Athi series, and

b) aquifers in the Middle Athi series

The Lower Athi series is composed of argillaceous material which is about 61m throughout. No water was encountered in this argillaceous lower Athi series.

The Upper Athi series consists mainly of sand, tuffs and welded tuffs with clays being subordinate. Welded tuff is conspicuous in and along the streams around Thika. It represents a thin, indurated and coarse lithic tuff with abundant thin and sub-horizontal lenses of obsidian.

Gevaerts (1970) stated that the base of the Upper Athi series has been reached in boreholes where a maximum thickness of 183m has been recorded. Locally the Upper Athi series includes basalts which occur 6km south of Thika.

In the aquifers of the Upper Athi series, water may either be struck at the top or at the base. The aquifers at the top are shallow and have small yield. It appears that the shallow aquifers are not connected with the deeper ones (Gevaerts, 1970). The aquifers at the base provide high supply. Boreholes drilled in the top are likely to give a yield of over 0.19 l/sec, those drilled in the base yield over 0.25 l/sec. The water quality of these aquifers is good. Its fluoride content is about 2 ppm.

The Middle Athi series consists of basalt flows, basaltic sand and agglomerates. It is usually impossible to differentiate the lavas from the derived sediments by examination of the drilling samples. The lavas show abundant insets of felspars (plagioclase) and the sands often have a clayey matrix. In his report, Gevaerts (1970) stated that the maximum thickness of this series is about 152.4 m at the north. The yield of the boreholes is erratic. In fact unsuccessful boreholes occur close to good producers, but as a rule, those sunk in the valleys strike adequate supplies. In general, one may say that a supply ranging from 757 - 7570 l/h may be expected in boreholes that are 150m deep.

2.2.2 **Unconfined Aquifers**

Unconfined aquifers contribute substantially to the supply where the surface is underlain by a thick pervious material. In a restricted area east of the Athi river, adequate supplies from unconfined aquifers are obtained along dry sandy stream courses where shallow boreholes not deeper than about 30m tap the subsurface flow.

In some other areas which are underlain by thick lateritic loam of a high permeability, free groundwater may be suspected where the loam rests on fresh lava that outcrops in the nearby stream. The free groundwater contained in the loam drains into the valleys , but where no shallow lavas occur both rain and run - off tend to percolate downward and subsequently into the permeable sand between the lavas.
The quality of the water in the unconfined aquifers is excellent (Gevaerts, 1970).

2.2.3 Recharge of the Aquifers

At the outset it may be stressed that although there are numerous localities where recharge of groundwater may possibly occur, nowhere is the rate of replenishment yet known (Gevaerts, 1970). In general, it may be said that confined aquifers are replenished near the surface at their upper end by free groundwater. However, in the area under review, there are confined aquifers particularly those in the upper Athi series that do not outcrop at their upper end, but remain deeply buried below the surface. Taking into account the westerly rise of the pressure surfaces, it is generally assumed that the aquifers are being supplied in the west by water stored in fractured zones. There are two modes of replenishment in the area (Gevaerts, 1970):

(a) direct replenishment at the surface
(b) indirect replenishment by water stored in fractured zones.

As the rainfall is high, a large quantity of water may be assumed to penetrate directly into the top weathered material and the dry sand stream. Also a large quantity of water may be assumed to percolate the joints of the Kapiti phonolite into the underlying aquifers during each rainy season on the wide treeless plain south of Athi river Township (Gevaerts, 1970). The mean annual rainfall of the area is 508 mm whereas the total run - off as measured in the Stony Athi river just above its confluence with the Athi river, amounts in normal years of rainfall to not more than 3 per cent. The remaining 97 per cent represents evapotranspiration, evaporation and recharge to groundwater. Unfortunately, no figures can be given yet for groundwater recharge alone. However, a large proportion of the rainfall is bound to reach the stream channels. As these flow under the Kapiti phonolite for long stretches, the water might well disappear into the joints and recharge deeper aquifers. Other aquifers that are bound to be replenished by stream-water are all those that outcrop in the streams. Reference is made to the Thika and Athi rivers where they flow on Kapiti phonolite and basalts. The water passes into the deeper aquifers through the joints and fractures of the phonolite and basalts.

No evidence of faulting has been observed in the study area except those in Thika and Thiririka valleys mentioned by Fairburn (1963). The fact that free CO_2 occurs in the aquifers suggests that the confined aquifers in the western side of the area is being replenished from groundwater in the faults and fractures in the Thika and Thiririka valleys. In his report Gevaerts (1970) argues that evidence of replenishment and depletion was observed from water level measurements in some boreholes. In the Kapiti phonolite aquifers, boreholes which were artesian, today are no longer artesian. In the middle Athi series, boreholes situated in the valleys have usually a substantial yield than elsewhere, which suggests that recharge takes place from local run - off. Some boreholes in the upper Athi series indicate that the rest-level of these boreholes have fallen well below their initial level. The steady fall of the rest level in some of these boreholes is attributed to loss of storage in the area.

2.2.4 **Water Quality**

The groundwater is of good quality except for its fluoride level which is in excess of the desirable limit of 1.5 ppm in some boreholes (Gevaerts, 1970). Water struck from deep aquifer near the base of the upper Athi series represents high degree of hardness and free CO_2. A high chloride and sulphate content is encountered in waters from Kapiti phonolite. As the Cl and SO_4 content in the phonolite itself is not more than about 0.01 and 0.03 per cent respectively, it is obvious that the salts have been derived from the lacustrine deposits intercalated with the lavas. Little is yet known about the salt content of these strata. The hole which reached the basement, struck unpotable water with a carbonate hardness of respectively 346 and 357 ppm and a Cl and SO_4 content of respectively 1220 and 720 ppm. Though the permanent hardness is rather typical of the basement water, the chloride and sulphate should largely have been from the sediments (Gevaerts, 1970).

CHAPTER THREE

3.0 METHODOLOGY

The methodology employed involved the field sampling of surface and ground waters, and effluents from waste disposal sites in the area; field measurements of several parameters were performed on the spot (water temperature, pH, electrical conductivity, etc.) and later laboratory analyses for various major, minor and trace elements were carried out mainly by atomic absorption spectrometry (AAS). The use of questionnaires in the field provided additional information on socio-economic and other aspects of waste disposal problems in the area.

3.1 FIELDWORK

3.1.1 Examination of Waste Disposal Methods in the Study Area

Several visits were made to many sites in the study area. The sites which were visited include; the Kang'oki waste disposal site which is about 6 km SE of Thika township. On this occasion, the type or composition of waste and the existing method of disposing of the waste were examined. A visit was also paid to the abandoned waste disposal site which is situated near the main market in the Thika town.

Samples were taken from all the ponds of the sewage treatment plant. Questionnaires were developed for use during the sewage plant visit (Appendix 4). The format of the questionnaires was as follows:

The type of operation of the sewage plant, problems associated with the sewage; treatment methods to remove nutrients like phosphorus; amount of waste that enters the sewage. The interviews were conducted with the plant manager or the plant foreman.

A councilor of Thika Municipality was also interviewed on the method of waste disposal in the study area, the amount of waste production, and the type of waste material. The percentage of street sweepings was estimated by Municipal Council to be 40% combustible.

Some collection and storage places where waste materials were placed until disposed of were inspected. The quantity and types of waste materials were estimated.

Visits were also paid to the quarries to see the amount of waste produced by quarrying activities. Final effluents derived from several industries which are situated along the Thika river were sampled. Wastes from food processing industries were also inspected. The methods of waste disposal in the areas where sewage work plant was not designed were also observed.

3.1.2 Borehole Log Data Collection

Records of borehole data were collected from the Ministry of Water Development. The information available in the records include: The borehole number, the location of the borehole, the water rest level, the depth of the borehole. Also available is the sequences of rock types in the boreholes. The aquifers in the study area were studied by employing the borehole log data.

3.1.3 Determination of Temperature, pH and Electrical Conductivity

Temperatures can change very quickly and pH may change significantly in a matter of minutes; for this reason determinations of pH, temperature and electrical conductivity were carried out at the time of sample collection.

3.1.3.1 Temperature

Temperature measurements are necessary for water quality studies and many other fields of science. It is important for its effect on other proceses like speeding up of chemical reactions, reduction in solubility of gases and amplification of the taste and odour (Tebbut, 1983). The temperature of a water course can be markedly affected by discharge of heated effluents from industries. Water courses unpolluted by heated effluents are usually a little lower temperature than the mean air temperature, but very warm weather can cause a stream to be a little higher in temperature than the ambient air temperature (Klein, 1962). Therefore temperature measurements is very important for pollution studies.

Temperature measurements were done with a mercury-filled centigrade thermometer. The thermometer has been provided with a wood case to prevent breakage. The thermometer was immersed in the water, waiting for a few minutes to obtain a constant reading.

3.1.3.2 Hydrogen ion concentration

The hydrogen ion concentration (pH) values were determined at the time of sample collection with a battery powered portable pH metre equipped with a glass electrode. Two buffer solutions (pH 4 and pH 7) were used to initially standardise the instrument by following the manufacturer's instruction. Before and after each measurement the electrodes were rinsed with distilled water. The results obtained by the pH meter were then compared with those obtained using a pH indicator paper.

3.1.3.3 Electrical Conductivity

The conductivity values of the water were measured in the field employing a portable conductivity meter standardised to 25°C. Before and after each measurement the conductivity cell was cleaned with distilled water.

3.1.4 Sampling Technique

Sampling surveys were carried out on two occasions, namely, from 21st October, 1990 to 27th October, 1990, river water together with effluents from the sewage system were collected. From 13th February, 1991 to 26th February , 1991, surface and groundwater samples as well as sewage and industrial effluents were taken.

The groundwater was sampled only on the second occasion, since the movement of underground water is slow enough for changes in quality with time to be much less significant than that of surface water (Hem, 1959). A complete analysis of each daily or monthly sampling was not feasible because of the cost.

31 boreholes including springs and 6 rivers with their tributaries were sampled to obtain at least the minimum information needed to define the conditions in the area

studied. The rivers which were studied were: Chania, Thika, Komu, Ndarugu and Thiririka. The Thika and Chania rivers are considered as one transect in that they are named differently at different sections within the area studied. At the downstream section, the river receives effluent from more than 25 industries situated near or on the bank of the river. Eight sampling stations were set up along the transect. About 1 km downstream from the Thika water supply, the Gitathuru tributary joins the transect. Two stations were set up along this tributary. Between the stations G1 and G2, there is a small sewage basin which sometimes overflows into this tributary (refer to Fig. 3.1a in the Appendices).

Komu river flows near the sewage treatment plant. The sewage plant discharges its effluent into a small channel which joins the Komu river. Six stations were set up along this river. Ndarugu river passes through a relatively small agricultural area. Four stations were set up along it. Athi river was the largest river in the study area . It receives water from the Komu and Ndarugu rivers. Five stations were set up along it. Three stations were set up along Thiririka river. In addition, Stations Y1 and Y2 were established, where Y1 was in a small stream passing through an agricultural area near Kilimambogo and station Y2, located at a dam near a sugar plantation within the same area.

For surface water, sampling was done upstream to represent the quality of the river water before pollution takes place due to industrial effluents or sewage, and downstream after pollution. Immediately below the confluence of two streams a distinct colour separation was observed at several points; sampling such locations where mixing of the two rivers is incomplete were avoided as much as possible because the extent to which a small sample may be considered to be representative of a large volume material depends on several factors, such as the homogeneity of the material being sampled (Hem, 1959). All the sampling stations are shown in Figures 3.1a and 3.1b (see the Appendix).

The water and effluent samples were collected in polythene bottles, cleaned by washing several times with dilute solution of nitric acid followed by deionized distilled water. The bottles were closed before being taken to the field as a safeguard against contamination.

For rivers and shallow hand-dug wells, the samples were taken at a point half-way between the surface and the bottom, carefully avoiding stirring up the sediment at the bottom. Samples from deep wells were collected only after the well were pumped a number of times to ensure that the samples represent the groundwater which feeds the well.

Before filling, the sample bottle was rinsed out four times with the water to be collected and was tightly closed, leaving only a small air bubble below the stopper.

Since the desire was only the soluble portion in the water, the sample was filtered through Whatman filter paper No. 42. A sample volume of one and half litres was collected in separate bottles for all the chemical analyses required . 500ml of water were collected for cation analysis, 500ml for Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) analyses and 250ml for phosphorus and nitrate analyses.
For each parameter, the samples were preserved in different ways because analysis of each parameter calls for a different

method of preservation of the samples (West and Nurnbreg, 1989) For cation determination, the sample was preserved with nitric acid at a pH 2.0 to reduce the chemical and biological processes occurring when the sample is taken and to stop or at least to slow down the adsorption of ions onto the walls of the container.

For the other parameters, such as BOD, COD, nitrate and phosphorus, since a satisfactory chemical preservative was not available, the best that have been done was to refrigerate the samples at 4^{O}C and to analyse them as promptly as possible.

A record was made of each sample collected and each bottle was identified preferably by labelling. The record includes the date, the temperature, weather condition, depth, colour and velocity of the stream.

3.2 ANALYTICAL PROCEDURES

Analyses were carried out with minimum delay on arrival at the laboratory and in any case not later than twenty four hours, for Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrate and phosphorus. The metals were analysed three weeks later since they had been preserved with HNO_3.

Analyses for Ca, Mg, Mn, Fe, Na, K, P and NO_3^- were performed at the laboratory of Chemistry Department (University of Nairobi). Measurement of trace elements was conducted at Madini House Laboratory (Ministry of Environment and Natural Resources). BOD and COD analyses were carried out at Kenya Water Research Laboratory of the Ministry of Water Development. Water analysis was performed using a variety of instrumental procedures because the measurement of elemental concentration levels in water requires equipment and methodologies that have capabilities for detecting the trace, minor and major elements concentration with high precision, accuracy and speed (West and Nurnberg, 1989).

Atomic Absorption Spectrophotometer (AAS) was the method of choice for most of the metal analysis. Among spectrophotometric methods of elemental analysis, AAS is particularly suited for the analysis of water. It may handle liquid samples directly with little or no chemical pre-treatments so that contamination is minimised. AAS is suitable for the determination of both major and minor trace elements using the same basic equipment with the alteration of only instrumental procedural settings. Because of its versatility and simplicity of operation, AAS has become the most extensively used method for the determination of metals in water. Ca, Mg, Fe, Mn and Al were performed on Perkin Elmer (2380) AAS model following methods described by the U.S. Environmental Protection Agency (1974). These elements and some other trace elements like Zn and Cu were measured by direct aspiration of the sample into the AAS . Major elements and several trace elements like Zn, Cu and Mn can be directly measured without pre-concentration (Fishman and Midget , 1968).

Pb, Ni, Co, and Cd were analysed on a spectra AA-10 varian AAS model using the organic solvent extraction technique described by Fishman and Midget (1966). These elements normally occur at very low concentrations in natural waters, and direct measurement by atomic absorption is not possible. The extraction procedure offers a rapid, simple, accurate and sensitive means for the determination of these elements. The detection limits are at least one order of magnitude lower than with other chemical procedures and there is less chance for contamination (Fishman and Midget, 1968). Solvent extraction techniques rank among the most important technique for pre-concentration and/or separation. Trace metals in the waters were chemically converted to complexes with ammonium pyrrolidine dithiocarbamate (APDC) and extracted with methyl isobutyl ketone (MIBK) (Minear and Keith, 1984). Many chelating agents have been used to preconcentrate trace elements in natural waters. Ammonium pyrrolidine dithiocarbamate (APDC) as the chelating agent and methyl isobutyl ketone (MIBK) as the solvent have been the most frequently used reagents (Minear and Keith, 1984).

Sodium and potassium were carried out by flame photometer because of their relatively low excitation potential and the simplicity of the flame photometer technique. The flame photometer technique is simple and rapid (Minear and Keith, 1984).

Concentration of soluble phosphorus and nitrate were determined by means of UV spectrophotometer, adopting the molybdenum blue spectrophotometric method described by the International Organisation for Standardisation (ISO, 1984) for phosphorus analysis and Orange I method described by Heans (1975) for nitrate determination. The molybdenum blue method is very sensitive and produce precise results at least down to 0.01 mgP/l (Minear and Keith ,1984). The Orange I method is simple and free from interference, provided that procedures carried out before colour developments are carefully standardised (Heanes, 1975).

Biochemical Oxygen Demand and Chemical Oxygen Demand were determined following the methods described in the 13th Edition of Standard methods for the examination of water and wastewater (American Public Health Association, 1975). The standard test conditions for Biochemical Oxygen Demand (BOD) included dark incubation at 20^{o} C for five days. The BOD test is an empirical bioassay-type procedure which measures the dissolved oxygen consumed by microbial life while assimilating and oxidising the organic matter present in the waste water.

The COD test involves the determination of the quantity of oxygen required to oxidise organic and oxidizable inorganic substances in an aqueous sample. The organic and inorganic oxidizable substances are oxidised by potassium dichromate. The excess dichromate is titrated with standard ferrous ammonium sulphate using orthophenanthroline ferrous complex (ferroin) as indicator. The test utilizes a rigorous chemical oxidation rather than a biological process, and the result has no definable relationship to the Biochemical Oxygen Demand (BOD) (U.S. Environmental Protection Agency, 1974).

BOD and COD for groundwater samples could not be determined simply because they reached the laboratory after too long a time. Hydrogen ion concentration (pH), electrical conductivity and temperature were measured at the time of sample collection employing a portable pH meter, electro-conductivity and thermometer, respectively.

All the glassware and laboratory equipment coming in contact with the samples, stock solution, working standard solutions and reagents have met a rigid standard of cleanliness. They were cleaned with hot soapy water, then rinsed thoroughly with distilled water, 20% nitric acid solution, distilled water and finally deionized distilled water in that order, prior to use.

Weighing and transferring of the samples had been performed in an evaporation chamber to control airborne contamination. All the reagents used were prepared from high purity analytical reagent grade chemicals of known stoichiometry. Doubly deionized distilled water which had been regularly tested to confirm the absence of heavy metals was used for the preparation of all reagents, calibration standards and as dilution water.

Stock solutions containing at least 1000 ppm of the element of interest in an appropriate acid was prepared to prevent hydrolysis. A blank and calibration standard solutions in graduated amounts of the analyte were prepared by diluting the appropriate stock metal solution to cover the desired concentration range and to measure their absorbance at an appropriate wavelength. Calibration standard solutions were prepared fresh at each time of analysis and discarded after use. The instrument parameters were optimised for each element following the manufacturer's operating instructions.

The following table shows the instrumental parameters for cation analysis and their limit of detection.

Table (3.1): Instrumental parameters and limits of detection of the analysed elements.

Cation	Wavelength	Flame	Limit of detection
Ca^{++}	422.5 nm	Air/Acetylene	0.003 mg/l
Mg^{++}	285 nm	Air/Acetylene	0.005 mg/l
Mn	279 nm	Air/Acetylene	0.01 mg/l
Fe	248.1 nm	Air/Acetylene	0.02 mg/l

Al	309.2 nm	Nitrous Oxide/ Acetylene	0.1 mg/l
Zn	213.9nm	Air/Acetylene	0.025mg/l
Cu	324.7nm	Air/Acetylene	0.05 mg/l
Pb	217 nm	Air/Acetylene	0.11 mg/l
Ni	232 nm	Air/Acetylene	0.066mg/l
Co	240.7nm	Air/Acetylene	0.066mg/l
Cd	228.3nm	Air/Acetylene	0.011mg/l

For AAS measurements, a warm - up time of at least 10 minutes is allowed after the choice of the relevant hollow cathode lamp. During this period, the instrument is aligned, the monochromater positioned at the current wavelength and the hollow cathode lamp current adjusted according to the manufacturer's recommendation. Subsequently, the flame is lighted, the flow of fuel regulated and the burner and nebulizer flow rate adjusted for the maximum percentage absorption and stability. The blank and the series of standard solution were then run. Beginning with the blank and working toward the highest standard, the samples were aspirated and the readings recorded. The operation was repeated three or four times with both the calibration standards and the samples to secure reliable average readings for each sample.

Samples which have shown concentrations beyond the calibration range were diluted to adjust their concentration to the centre of the range determined by calibration. The concentration of the elements were determined from the calibration graphs constructed by plotting the concentrations of the standards against the absorbance. All the data were expressed in ppm.

2.2.1 Preparation of Stock and Standard Solutions

stock solutions were prepared by dissolving in an appropriate acid a specific amount of the salt of the element to be analysed and the solution made up to 1000ppm. To prepare the standard solutions, portions of the stock solutions were appropriately diluted to desired concentrations. However in the preparation of Ca and Mg standard solutions, lanthanum solution was added to both the standard solutions and the samples. This was done to overcome any possible interference by phosphate ions which form stable and refractory compounds. All reagents were of analytical grade.

3.2.2 Extraction Technique for the Determination of Lead, Nickel, Cobalt and Cadmium

The pH for optimum extraction of the elements is very important and must be given great consideration. The pH of Pb is critical (pH 2.8), Ni, Co and Cd can be extracted at pH 5.
Lead was determined from 100ml of the sample to recover 2.8ml of ketone layer (a volume sufficient for only one reading).
Ni, Co and Cd were determined from the same sample, but increasing the volume of the sample (300ml) and reagents proportionately to obtain a volume of ketone layer (3 x 2.8ml) sufficient for the three readings.

Procedure:

100ml of the sample, 100ml of blank and 100ml of standards were added to the following reagents in this order: 3 drops of .1% of bromophenol blue indicator, drops of 10% of NaOH until blue colour appears, drops of 2.5% of HCl until the pH of the solution reaches 2.3, 2.5ml of 100% ammonium pyrrolidine dithiocarbamate (APDC) and finally 5ml of methyl isobutyl ketone (MIBK). The solution was shaken for 60 minutes, then given few more minutes for the ketone layer to separate. Deionized distilled water was then added upto the mark of the flask. The samples were then aspirated into the flame.

Determination of Nickel, Cobalt and Cadmium.

The same procedure mentioned above was employed. The sample volume and the reagents were increased proportionately as follows:

a) sample volume: 300ml
b) 0.1% biophenol blue indicator: 9 drops
c) 2.5% hydrochloric acid: 6ml
d) 100% APDC: 7.5ml.
e) MIBK: 15ml.

3.2.3 Determination of Nitrate in Water by an Adoption of Orange I Method

The method involves quantitative reduction of nitrate to nitrite by zinc powder followed by colorimetric determination of azodye (Orange I) produced by the diatozitation and coupling of nitrite, 1-napthol and sulphuric acid (Heans, 1975).

Procedure

10ml of the sample was added to the following reagents: calcium acetate solution, manganese sulphate solution, zinc powder, diazotisation reagents, in that order. The standard solutions and the blank were treated the same way as the sample. The preparation of the samples and the procedures used were described by Heans (1975). A nitrate standard solution for calibration in the range of 0.05-1.00 ppm was prepared for analysis.

3.2.4 Determination of Phosphorus by Molybdenum Blue Spectrophotometric Method

The method involves the decomposition of the sample by treatment with hydrochloric acid, nitric acid and perchloric acid. Molybdate is added to convert the phosphate into molybophosphate complex and reduction to molybdenum blue is effected by means of ascorbic acid. The spectrophotometric measurement of the absorbance of the molybdenum blue complex is made at a wavelength of approximately 725nm. The preparation of all the reagents and the procedures used were described by the International Organisation for Standardisation (ISO, 1984). Standard solutions in the range of 0 to 0.1 ppm of phosphorus were prepared for the analysis.

3.3 DATA ANALYSIS

Data analyses were carried out by means of IBM (P/S2) computer. The analytical procedures used for this study are:

(a) Factor analysis

The multi-variance technique of factor analysis (cf. Davis, 1973) which includes a varimax rotation scheme was used for this study. Factor analysis is a numerical technique for defining groups of related samples (Q-mode) or variable (R-mode) based on high similarity coefficient.

Variable association (R-mode) was used in this study. In R-mode factor analysis, a data matrix is obtained which consists of a number of variables. Similarity coefficients were computed between each pair of variables. With the Factor Analysis program, a maximum of five rotation runs with different number of factors are possible.

(b) **Pearson's product moment correlation coefficient**

This statistic was also used for the data analysis. Many geological variables do not follow a normal distribution (Davis, 1973); therefore two additional steps were necessary to transform the data into a format suitable for these analyses. First, it was determined that each parameter in the elemental data had either a log-normal or pseudo-normal distribution, whereas the procedures used for the data analysis require that all data be normally distributed. Therefore a log-transform was used to convert these data into proper format. This was done to avoid the problem of artificially high negative or positive coefficients.

All the methods used for the data analysis were aimed at identifying the relationship between pairs of elements as well as between the elements and other variables -physical, chemical and biological.

CHAPTER FOUR

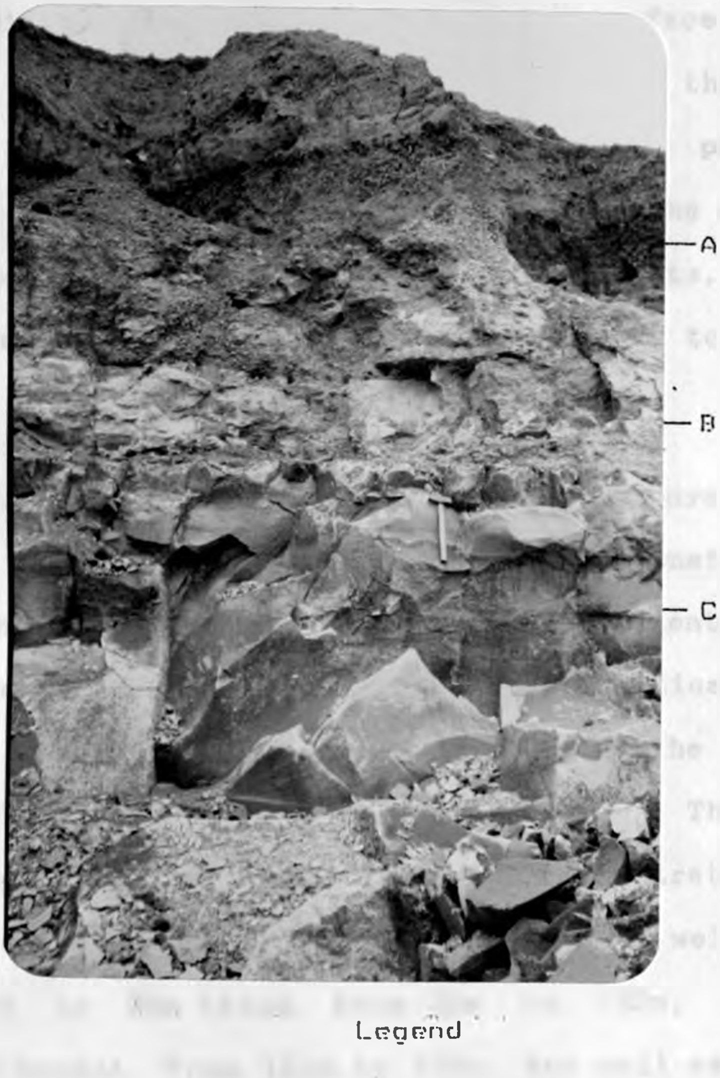
4.0 RESULTS

4.1 Results of the Fieldwork

4.1.1 Stratigraphic Sections from the Borehole Data

Most of the boreholes in the study area are shallow hand-dug wells. The record of their stratigraphic sections have not been documented. Most of the data were obtained from boreholes which were not sampled in the field because they were not functioning. Those wells include , the wells at Blue Posts Hotel, Katina Estate, Kenya Taitex Mill, and Leyland. Others are out of the study area, like the well at Anglo-French Sisal, Kisima Estate and moreover they are not indicated on the map. The data obtained from the boreholes log data are limited only to the rock sequence, water levels and yields.
In addition to the borehole records, representative stratigraphic sections were used to show the rock sequences of the study area.

The stratigraphic section at the Quarry near Komu river represents the stratigraphic sequence of the area around the sewage treatment plant (Fig. 4.1). The section shows that the ground surface is underlain by soil composed of altered black and brown horizons, 1 m thick. The soil is underlain by gravelly lateritic layer 0.5 m thick. Below this gravelly layer is a yellow weathered porphyritic tuff 1.5 m thick. Below the tuff is 1 m of slightly weathered tuff with dark phenocrysts. This is underlain by a light blue compacted and porphyritic phonolite with some phenocrysts of nepheline. Other stratigraphic sections observed in the quarry near the Thika



Legend

A = gravelly lateritic soil

B = weathered tuff

C = phonolite

Fig. 4.1: Stratigraphic section at the quarry near Komu river.

river represent the same sequences of rock as that near the sewage works, except that the upper soil is removed in the sequence near the Thika river. Small springs were seen emerging from the contact of the upper weathered tuff and the compacted rocks.

The well at Mangu Farm was drilled to a depth of 166 m. The stratigraphic sequence at this well (Fig. 4.2a) indicates that the well penetrated 5 m of soil below the land surface. From 5m the well passes into grit and basaltic sand of 95 m thick. From 100 m to 157 m below the ground surface the well penetrates basalts. Below 157 m to 166 m is clayey deposit. The water in this well is supplied by an aquifer composed of grits, basaltic sand and sand, and its static water level goes down to a depth of 43 m.

The stratigraphic section of the borehole in the Kenya Chemical Industry (Fig. 4.2b) indicates that the well penetrates an aggregate thickness of 199 m with only 47m of sediments and the other 152 m composed of volcanic rocks . This indicates that the thickness of the sediments interbedded with the lava is relatively smaller than the thickness of the lava. The well is supplied by a confined lava aquifer. The well penetrated 7m of red clay soil below the land surface. From 7m, the well passes into tuff which is 36m thick. From 36m to 122m, the well penetrates dark basalt. From 122m to 159m, the well passes into grey sand clay with gravelly bed. From 159m to 199m is grey lava. The static water level of the well is 161m below the ground surface.

The data from the well at Blue Posts Hotel (Fig. 4.2c) indicate also that the thickness of the sediment is smaller than that of

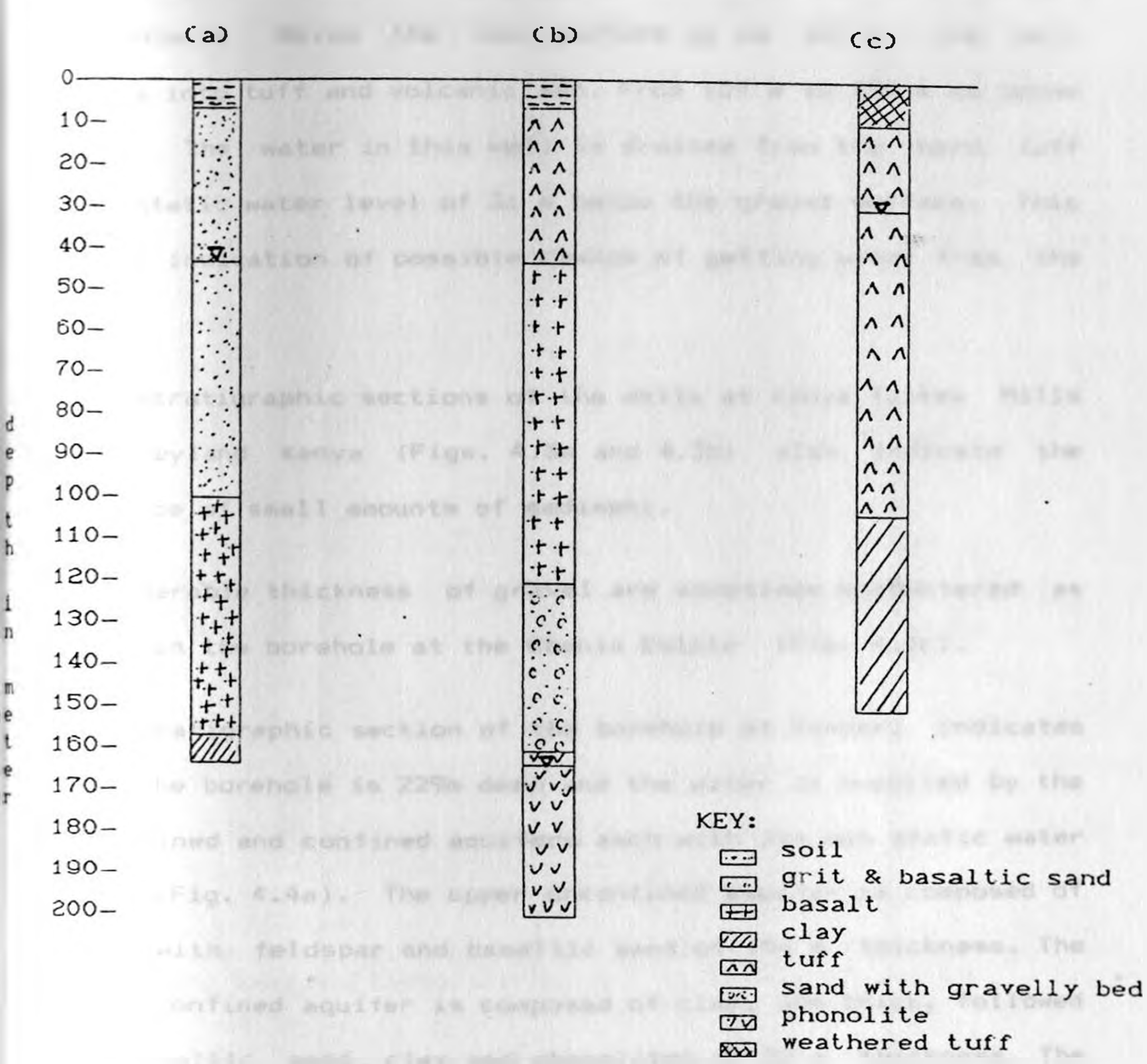


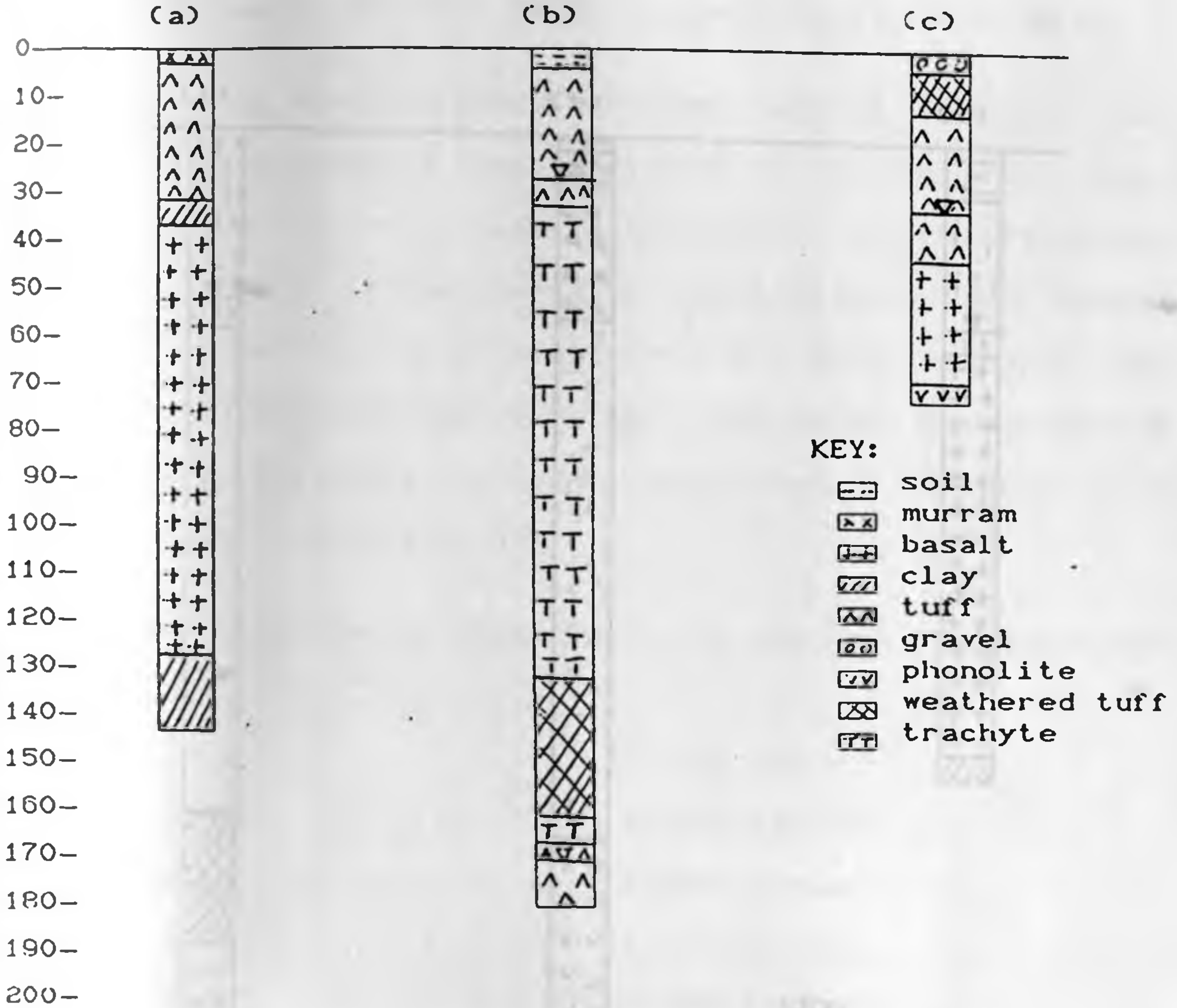
Fig. 4-2: Stratigraphic sections of the boreholes in Mang'u (a), Kenya Chemicals Ltd(b).and Blue Post Hotel(c).-

the lava. This well is 150 m deep, but only 44 m of clay was encountered. Below the land surface up to 107 m, the well passes into tuff and volcanic ash. From 107 m to 150 m is brown clay. The water in this well is drained from the hard tuff with static water level of 31 m below the ground surface. This is an indication of possible chance of getting water from the tuff.

The stratigraphic sections of the wells at Kenya Taitex Mills and Leyland Kenya (Figs. 4.3a and 4.3b) also indicate the presence of small amounts of sediment.

considerable thickness of gravel are sometimes encountered as shown in the borehole at the Chania Estate (Fig. 4.3c).

The stratigraphic section of the borehole at Kanyeri indicates that the borehole is 229m deep and the water is supplied by the unconfined and confined aquifers each with its own static water level (Fig. 4.4a). The upper unconfined aquifer is composed of sand with feldspar and basaltic sand of 104 m thickness. The lower confined aquifer is composed of clay, 30m thick, followed by basaltic sand, clay and phonolites of 52 m thickness. The static water level of the unconfined aquifer is 37 m below the land surface and piezometric surface of the confined aquifer reaches a depth of 213 m below the ground surface. The well at the Anglo French Sisal which is 214 m deep is supplied by the Kapiti phonolite (Fig.4.4b). Its static water level reaches a depth of 215 m below the surface. The well at Kisima Estate (Fig. 4.4c) is 137 m and is supplied by confined aquifer comprised of basaltic sand and basalt. The aquifer is overlain by tuff, pumice and fine - grained sand. The Piezometric surface of this well is 41.1 m below the ground surface.



g. 4-3: Stratigraphic sections of the boreholes in Kenya itex Mills(a), Leyland Kenya Ltd(b) and in Chania estate(c).

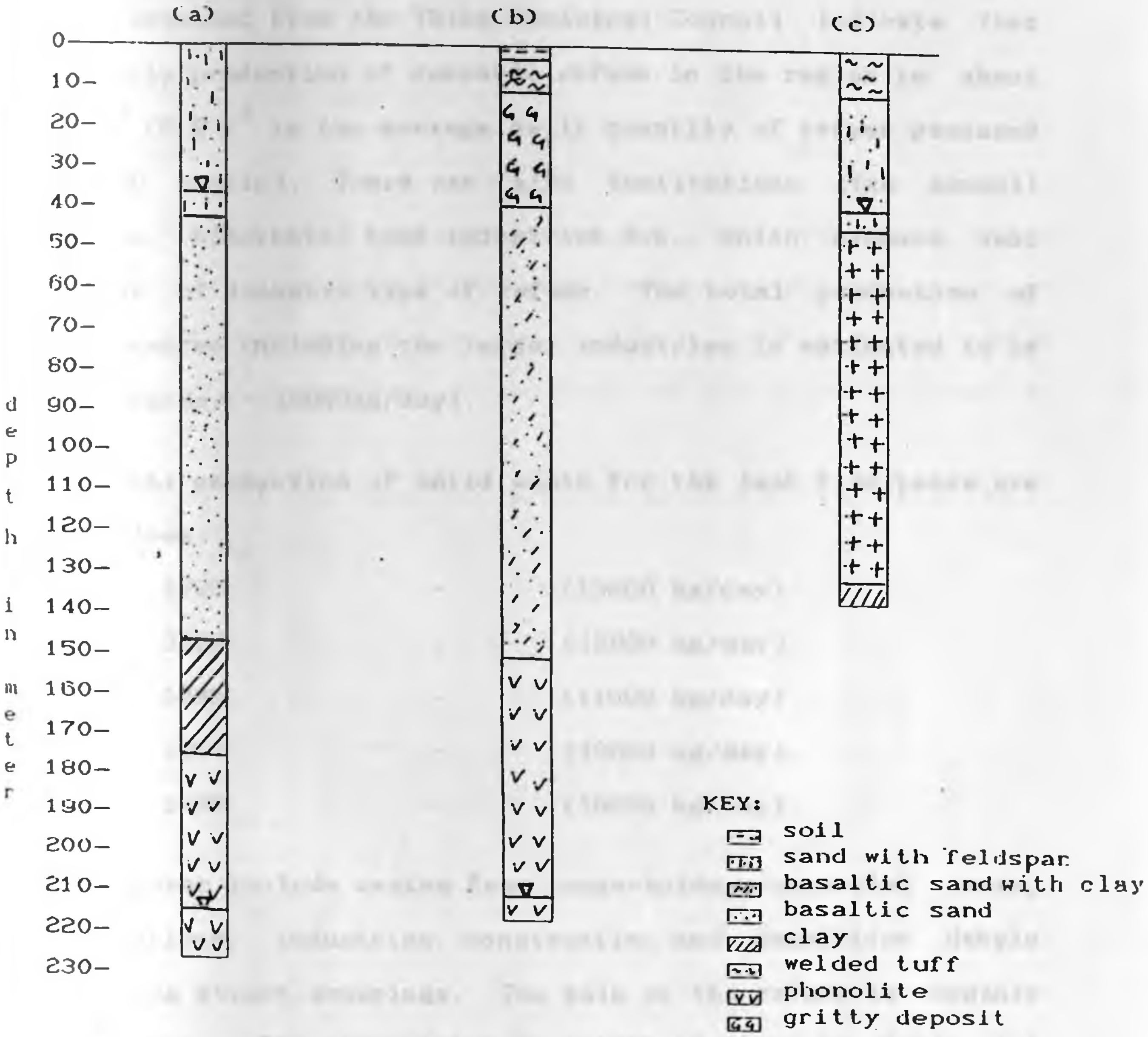


Fig. 4-4: Stratigraphic sections of the boreholes in Kanyeri(a), Anglo-French sisal(b) and Kisima estate(c).

4.1.2 Existing Method of Waste Disposal in the Thika Area

Data obtained from the Thika Municipal Council indicate that the daily production of domestic refuse in the region is about 133 m^3 (0.8 m^3 is the average daily quantity of refuse produced by 600 people). There are also institutions like council markets, hospitals, food industries etc., which produce vast amounts of domestic type of refuse. The total production of solid wastes including the larger industries is estimated to be (10000kg/day - 15000kg/day).

The total production of solid waste for the last five years are as follows:

1990 - (15000 kg/day)
1989 - (12000 kg/day)
1988 - (11000 kg/day)
1987 - (10000 kg/day)
1986 - (10000 kg/day)

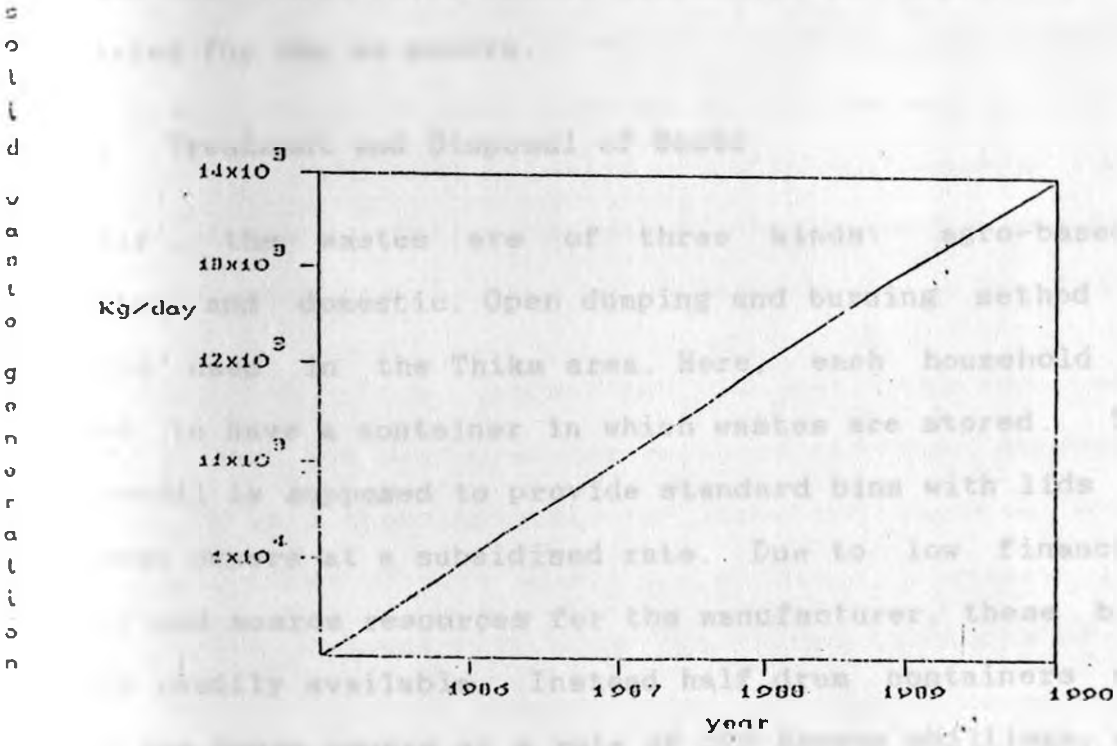
The figures include wastes from house-holds, commercial areas, institutions, industries, construction and demolition debris including street sweepings. The bulk of the refuse is organic in nature. The composition by weight is shown in Table 4.1 below:

Items	Composition%
Vegetable\putrescible	2
glass	2
paper	3
metal	2
plastics	25
leather	60

wood, bones	1
textiles	3
miscellaneous inerts	1
(stone, brick particles)	1
Total	100%

The amount of waste registered in the past five years shows that there has been an increase in the generation rate of waste. This has been due to the continuos increasing of number of population; increased consumption and the improved level of service.

Projection of the total solid waste generation for the Thika town is shown below;



Compared to the available literature values, the generation rate figures for the area studied are higher than the figures obtained from other low income countries (0.4 to 0.6 kg/person/day) and middle income countries (0.5 to 0.9kg/person/day) (Cointreau, 1982).

Quarrying activities produce wastes composed of building stone, and crushed material. The soil or superficial material were removed. The water from surrounding lands is not protected against draining into the quarry.

In the coffee estates, nitrogenous fertilisers are usually applied to the soil to improve its fertility. Some areas, like Komu and near Thika river cattle excrements are deposited and accumulated for use as manure.

4.1.2.1 **Treatment and Disposal of Waste**

Basically , the wastes are of three kinds: agro-based , industrial and domestic. Open dumping and burning method is generally used in the Thika area. Here, each household is supposed to have a container in which wastes are stored. The town council is supposed to provide standard bins with lids to the house owners at a subsidised rate. Due to low financial capacity and scarce resources for the manufacturer, these bins are not readily available. Instead half drum containers are sold to the house owners at a rate of 320 Kenyan shillings, and dustbins at a rate of 420 shillings. Even these drums and garbage - bins are not readily available and consequently, many domestic and commercial establishments lack the bins. This has led to indiscriminate dumping of waste alongside streets, curbs etc. In the estates, some people use small pits to accumulate the waste, and others collect and burn the waste in small heaps.

Wastes from large scale industries, hospitals and schools are collected by city council and finally disposed at the present Kang'oki waste disposal site which is a crude open dumping site (Fig. 4.5) currently located at about 7km south-east of Thika town . Up to 1979, the council used to dispose solid wastes at old quarries situated at Moi gardens, opposite G.K. prison in the Thika municipality. By 1980, disposal operations had already started at the site where Leather Industries of Kenya Ltd. is situated. By 1980/1981 refuse were disposed in old quarries adjacent to Thika river. The current owners of these quarries complain about occupation of their sites. Due to poor access roads and very steep gradients, there were frequent vehicle break-downs. In 1982, disposal of refuse was started at the current Kang'oki site situated along Munyu township road. Due to inadequacy of the councils operations hapharzard disposal of waste has resulted in uneconomic use of the land.

The waste output from industries is very high and most of it is organic and biodegradable hence it produces obnoxious smell and forms a breeding place for flies and rodents which may act as vectors of both edemic and epidemic diseases like cholera. Waste disposal pits show in vertical thickness of 1-1.5m of soil and in other places, lateritic formations outcrop. The soil is reddish-brown in colour and has relatively low permeability. Topographically the land generally slopes gently towards SE towards Komu river which is about 500m from the waste disposal site; thus the waste finds its way into this river together with the runoff during the rainy seasons. Moreover, leachate from the waste dumps may reach the

Fig. 4.5: Waste disposal site in the Thika area. The waste is composed of leather, plastics, papers and miscellaneous inerts.

hydrogeologic system through percolation, thus polluting ground water.

Most of the large industries discharge liquid effluents into Thika river without any pretreatment. Pineapple and coffee processing industries are found near or at river-banks and their raw waste is discharged into the river, which encourages breeding of flies, mosquitoes etc. Pulp from processed coffee beans and pineapple peelings are dumped in the vicinity of the factory (Fig. 4.6), which would also encourage prowing by rodents and breeding of flies.

4.1.2.2. **Sewage Work Treatment Plant**

There is a major sewage treatment plant located about 9km from Thika - Garissa road along Munyu road. A total of 2943268m^3 of raw sewage was recorded entering the works in 1990. The sewage has the grey colour of ordinary domestic sewage. The water content of the sewage is more than 99.9%. The total dry solid matter (organic or inorganic) is only 0.1 per cent. The large solid materials are removed and the other degradable materials are grounded by machine before they enter the primary ponds. The sewage sludge from drying beds is directly sold as fertiliser to the residents. The sewage plant consists of nine primary treatment ponds, six secondary ponds, three tertiary ponds and two maturation ponds which are arranged in series and parallel (Fig 4.7) . The sewage has an excessive growths of sewage fungus and algae. Aerobic, anaerobic, and facultative bacteria are present in the primary and secondary ponds. The bacteria break down the organic matter in the sewage. The method of sewage treatment in this area is very cheap due to lack of chemicals necessary to use for the treatment. The waste

Fig. 4.6 : Coffee pulp accumulated near factory. The raw effluents derived from the factory goes into the Thika river.

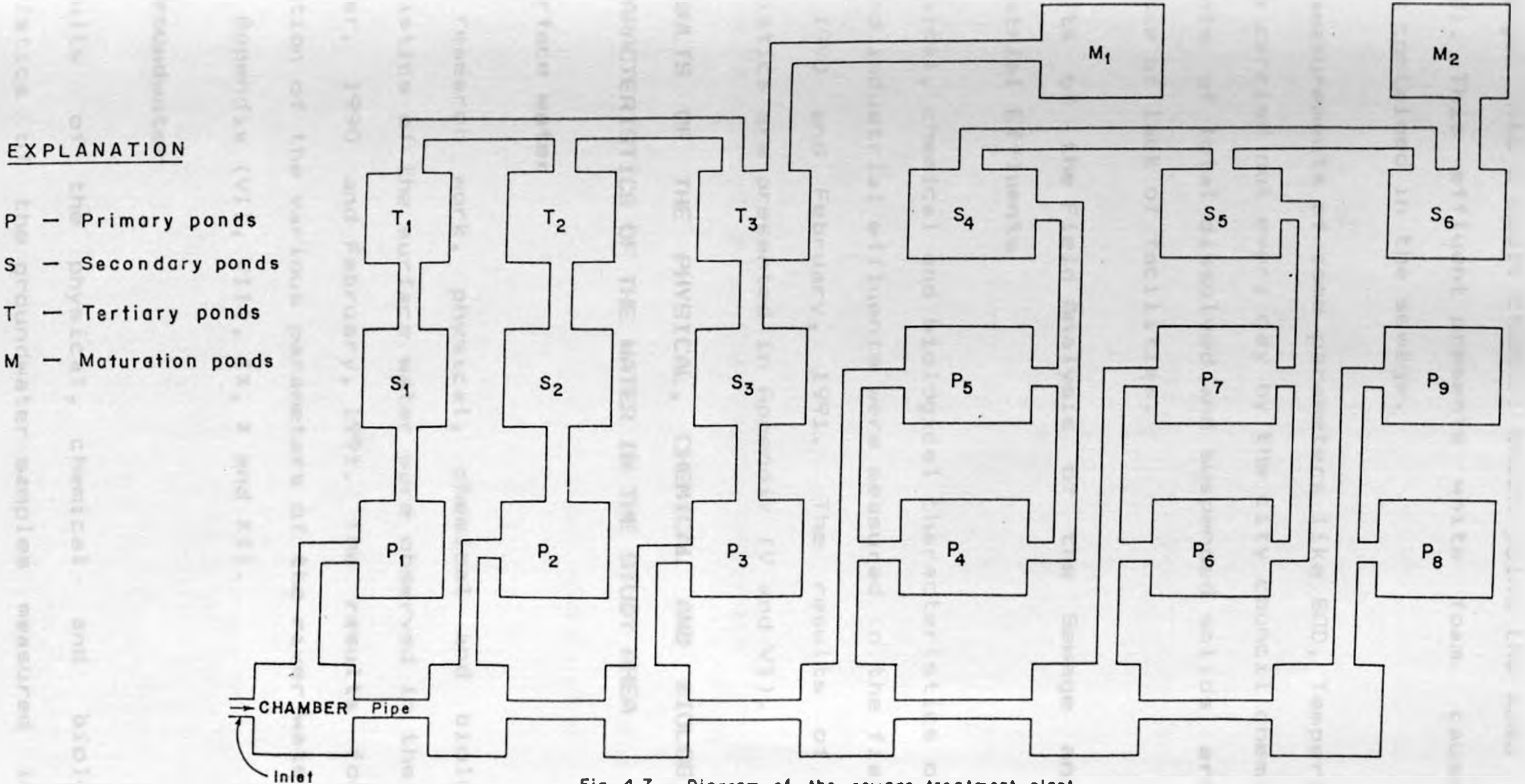


Fig. 4.7 — Diagram of the sewage treatment plant .

water is not recycled due to lack of finance. Nutrients like phosphorous are not removed. The final effluent from the sewage is discharged into a small channel which joins the Komu river (Fig. 4.8). This effluent presents white foam caused by detergents contained in the sewage.

Only few measurements of some parameters like BOD, Temperature and PH are carried out every day by the city council chemists; measurements of total dissolved and suspended solids are not done because of lack of facilities.

4.2 Results of the Field Analysis of the Sewage and Industrial Effluents

Some physical, chemical and biological characteristics of the sewage and industrial effluents were measured in the field in October, 1990 and February, 1991. The results of these characteristics are presented in Appendix (V and VI).

4.3 RESULTS OF THE PHYSICAL, CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF THE WATER IN THE STUDY AREA

4.3.1 Surface water

In this research work, physical, chemical and biological characteristics of the surface water were observed in the field in October, 1990 and February, 1991. The results for the determination of the various parameters of the river waters are given in Appendix (VII, VIII, IX, X and XI).

4.3.2 Groundwater

The results of the physical, chemical and biological characteristics of the groundwater samples measured in the field are presented in Appendix XII.

ig. 4.8: Final effluents from the sewage works in the Thika area is discharged into a small channel which joins komu river.

4.4 RESULTS OF THE LABORATORY ANALYSIS

4.4.1 Sewage and Industrial Effluents

Sewage and industrial effluents were sampled in October, 1990 and February, 1991 for analyses of BOD, COD, major and trace elements, and nutrients like nitrate and phosphorus. The results of the major element, BOD and COD determinations for the samples collected in October, 1990 are shown in Table 4.1a. The range and average values of these parameters are shown in Table 4.1b . For trace elements, the samples were directly aspirated into the AAS. Due to the low concentration encountered, the trace element content in the samples were at or below the detection limits and the results are not therefore presented in tabular form. The results of the laboratory analysis of the samples collected in February, 1991 are shown in Table 4.2a. Their range and average values are presented in Table 4.2b. Trace elements of these samples collected in February, 1991 were detected with the help of the Organic Extraction Technique, and they are given in those Tables (4.2a and 4.2b).

4.4.2 Surface water

The results of the analyses of the major element, BOD and COD of the surface water samples collected in October, 1990 and February, 1991 are presented in Tables 4.3a and 4.4a respectively. Their range and average values are shown in Tables 4.3b and 4.4b. The local variations of those major elements: Ca, Mg, Na, K, Mn and Fe in the Thika, Komu and Athi rivers are graphically shown in Figures 4.9 - 4.11 . But the local variations of Ndarugu and Thiririka rivers are not shown in the Figures because the sample stations of those rivers are able 4.1(a): Concentrations in ppm of major elements ,BOD and OD in sewage and industrial effluents (October,1990).

sample no.	element						BOD	COD
	Ca	Mg	Na	K	Mn	Fe		
SW1	30	7.5	100.0	30.0	.1	.09	28	145
SW2	30	7.0	95.2	30.0	1.0	.10	58	175
SW3	29	6.2	95.2	30.0	1.0	.10	90	298
SW4	25	5.0	82.5	27.0	1.2	.09	95	245
SW5	25	5.4	45.0	17.0	1.1	.20	100	240
SW6	24	5.2	45.0	17.0	1.1	.10	540	780
EF1	200	35.0	401.0	265.0	16.0	.20	450	630
EF2	105	15.0	285.0	200.0	4.9	5.5	197	370
EF3	100	4.5	79.0	40.0	.09	.10	180	235

able 4.1(b):Range and mean concentration of major elements, BOD nd COD (in ppm) for the sewage samples(October, 1990).

	Ca	Mg	Na	K	Mn	Fe	BOD	COD
range	24-30	5-7.5	45-100	17-30	.1-1.1	.09-.2	28-540	145-780
average	27.2	6.05	77.2	25.2	.92	.11	151.1	313.8

legend for sample abbreviation

SW_1	outlet
SW_2	maturation
SW_3	tertiary
SW_4	secondry
SW_5	primary
SW_6	inlet
EF_1	waste disposal site
EF_2	kenya paper mill
EF_3	leather industry

Table 4.2(a):Concentrations in ppm of the major and trace elements, nitrate, phosphorus, BOD and COD in the sewage effluents(February,1991

	sample								
element	SW1	SW2	SW3	SW4	SW5	SW6	EF1	EF2	EF3
Ca	.35	36	34.5	29	24	25	208	104	97
Mg	8.5	8.8	6.4	5.9	5.5	5.7	34	13	4.3
Na	120	119	102	87.5	49	50	400	280	80
K	34.5	35	30	28	15	17	270	210	42
Mn	1.6	1.6	1.5	1.2	1.2	1.2	15	5.1	.1
Fe	.1	.1	.2	.2	.1	.5	.1	6.2	.08
Al	.1	.1	.1	.1	.2	.2	.5	.2	.2
Zn	<.05	<.05	<.05	<.05	.05	.05	2.5	.05	.05
Cu	<.025	<.025	<.025	<.025	<.025	<.025	1.1	<.025	.05
Pb	.002	.002	.0	.0	.0	.0	.12	.08	.007
Ni	.002	.002	.001	.0	.0	.0	2.5	.05	.07
Co	.0	.0	.0	.0	.0	.002	.075	.012	.005
Cd	.002	.001	.001	.001	.001	.001	.25	.062	.008
P	10.5	10	11.6	16.5	16.6	17	11.2	9.0	1.9
NO_3^-	90.5	98	98.2	102	100	115	70.5	16.5	25.5
BOD	16	16	40	40	70	340	390	195	175
COD	135	125	145	145	250	690	695	390	235

Table 4.2(b) : Range and mean concentrations of major and trace elements, NO_3^-, P, BOD and COD in the sewage effluents(February,1991).

element	range (ppm)	average(ppm)
Ca	24-36	30.6
Mg	5.5-8.8	6.8
Na	49-120	87.9
K	15-35	26.6
Mn	1.2-1.6	1.4
Fe	.1-.5	.2
Al	.1-.2	.13
Zn	0-.05	.02
Cu	0	0
Pb	0-.002	.0006
Ni	0-.002	.0008
Co	0-.002	.0003
Cd	.001-.002	.001
P	10-17	13.7
NO_3^-	90.5-115	182.1
BOD	16-340	87
COD	135-690	228.1

Table 4.3(a): Concentrations of the major elements, BOD and COD in ppm of the surface water samples (October,1990).

sample station	parameters							
	Ca	Mg	Na	K	Mn	Fe	BOD	COD
G_1	8.5	2.4	12	5.4	.04	.6	3.0	10.0
G_2	9.0	1.8	12.5	5.2	.04	.5	1.35	4.2
K_C	9.5	2.0	18.0	5.0	.5	3.4	2.0	5.2
S	4.2	.8	8.0	5.1	.01	.2	2.0	7.0
K	9.5	.8	15.0	5.0	.01	.1	.5	4.0
T_8	8.5	2.4	10.5	5.0	.01	.32	1.2	4.0
T_7	8.3	2.2	8.5	5.1	.02	.4	1.5	5.0
T_6	8.0	2.0	8.0	4.0	.01	.14	1.5	4.5
T_5	14.0	3.2	20.0	4.2	.8	1.0	1.3	5.0
T_4	14.5	3.0	18.2	4.5	.4	.9	2.0	4.0
T_3	12.0	2.4	15.0	4.4	.09	.8	2.0	5.0
T_2	18.0	3.5	20.0	8.0	.7	.9	1.4	3.5
T_1	14.0	4.0	20.0	8.1	.8	.9	2.14	6.0
KM	9.0	.8	20.0	16.0	.05	.6	18.0	22
KM_1	30.0	5.0	60.5	24.0	1.0	1.8	12.0	75.0
KM_2	30.0	5.5	60.0	24.2	1.2	1.5	21.0	70.0
KM_3	29.5	5.5	60.0	25.0	1.0	1.2	22.0	69.0
KM_4	30.0	5.3	60.2	26.0	12.0	1.2	21.0	70.0
KM_0	23.0	3.0	30.0	20.0	.1	.5	1.6	15.0
ND_1	6.2	1.5	10.0	4.2	.0	.5	.6	3.0
ND_2	6.5	1.5	10.0	4.2	.0	.6	2.0	5.0
ND_3	6.3	1.2	8.5	4.0	.0	.2	1.0	4.1
ND_4	6.0	1.2	8.2	4.0	.0	.2	.8	3.8
A_1	14.2	2.5	18.0	18.0	.5	.8	11.0	22.0
A_2	16.0	2.8	28.0	24.0	.2	.6	10.0	24.0
A_3	16.0	2.8	26.0	23.0	.2	.5	10.0	24.0

(Table continued on next page)

Table 4.3(a) continued.

A_4	14.5	2.6	25.0	23.2	.1	.5	9.8	25.0
A_5	15.0	2.5	26.0	18.0	.1	.4	2.0	23.0
TR_1	10.0	2.0	14.0	12.0	.1	.3	1.2	14.0
TR_2	6.5	1.5	10.5	4.5	.05	1.2	1.1	15.0
TR_3	6.0	1.5	10.0	4.6	.05	.11	1.0	12.0
Y_1	5.5	1.0	9.0	5.0	.04	.2	2.5	6.0
Y_2	6.0	1.2	7.5	10.5	.06	.2	2.0	1.9

Table 4.3(b): Range and average concentrations of the major elements, BOD and COD in ppm in the studied rivers(October, 1990).

el-em-ent	THIKA		KOMU		NDARUGU		ATHI		THIRIRIKA	
	range	av.	range	av.	range	av.	range	av.	range	av
Ca	8-18	12.2	23-30	25.3	6-6.5	6.3	14.2-16	15.1	6-10	7.5
Mg	2-4	2.8	.8-5.5	4.2	1.2-1.5	1.4	2.5-2.8	2.6	1.5-2	1.7
Na	8-20	15.0	20-60.5	48.5	8.2-10	9.2	18-28	24.6	10-14	11.5
K	4-8.1	5.4	16-26	22.5	4-4.2	4.1	18-24	21.2	4.5-12	7.0
Mn	.01-.8	.35	.05-1.2	.76	0	0	.1-.5	.22	.05-.1	.07
Fe	.14-.9	.55	.5-1.8	1.13	.2-.6	.38	.4-.8	.56	.11-.3	.18
BOD	1.2-2.14	1.63	18-22	20.8	.6-2.0	1.1	1.6-11	7.4	1-1.2	1.1
COD	3.5-6.0	4.63	15-75	53.5	3-5	3.9	22-25	23.6	12-15	13.7

Table 4.4(a): Concentrations of the major elements, BOD and COD in ppm of the surface water samples(February,1991).

sample station	parameters							
	Ca	Mg	Na	K	Mn	Fe	BOD	COD
G_1	10.0	3.0	14.0	7.0	.05	1.0	2.0	8.0
G_2	9.6	2.5	15.0	5.8	.06	.9	2.0	9.0
K_C	11.0	2.8	21.0	8.5	.06	4.1	3.0	8.0
S	5.1	.95	21.0	6.0	.01	.6	2.5	7.0
K	10.4	.98	10.0	6.6	.03	.1	.5	3.0
T_8	10.0	2.8	12.0	5.9	.02	.60	1.38	3.88
T_7	9.5	2.9	9.0	5.2	.01	.5	2.0	5.0
T_6	9.3	2.4	8.8	5.0	.02	.20	1.4	4.0
T_5	16.0	4.0	22.0	5.2	1.1	1.2	2.5	4.0
T_4	17.0	3.5	22.8	5.5	1.0	1.0	2.7	6.0
T_3	16.0	3.0	20.5	5.4	.05	1.0	2.3	4.0
T_2	20.0	4.0	22.0	8.1	.1	1.2	2.25	4.0
T_1	15.0	4.6	25.0	12.0	1.8	1.4	3.0	8.0
KM	20.0	1.0	30.0	18.0	.05	.5	20.0	4.0
KM_1	32.0	6.0	80.0	28.1	1.3	2.3	25.0	60.0
KM_2	33.0	5.8	79.5	28.5	1.4	2.2	23.0	70.0
KM_3	33.0	5.9	81.0	30.0	1.4	2.2	23.0	70.0
KM_4	34.0	6.1	82.0	28.0	1.20	2.0	22.0	70.0
KM_O	26.0	3.9	38.0	27.0	1.0	1.7	2.0	20.0
ND_1	10.0	2.2	17.0	8.5	.0	.4	1.5	3.5
ND_2	9.0	2.2	18.0	8.0	.0	.8	2.0	6.0
ND_3	8.2	2.1	17.9	7.8	.0	.5	1.2	4.0

(Table continued on next page)

Table 4-4(a) continued.

ND_4	7.5	2.0	17.8	7.0	.0	.4	1.21	4.2
A_1	16.0	3.8	19.0	24.0	1.3	1.0	12.0	27.0
A_2	18.0	3.8	30.5	26.0	1.3	1.1	10.0	27.0
A_3	18.0	3.7	30.0	26.0	1.3	.9	10.0	25.0
A_4	17.0	3.6	30.0	24.0	1.0	1.0	11.0	26.0
A_5	17.0	3.6	28.0	20.0	1.0	.9	2.7	25.0
TR_1	8.5	2.5	14.0	11.0	.1	.3	1.0	10.0
TR_2	7.0	1.5	11.0	5.0	.1	0.25	0.5	10.0
TR_3	7.1	1.0	11.2	5.0	.09	.25	.5	7.0
Y_1	6.0	2.0	18.0	6.0	.05	.24	2.5	6.0
Y_2	6.0	1.5	7.8	11.0	.07	.2	1.0	10.0

Table 4.4(b): Range and averge concentrations of the major elements, BOD, COD in ppm in the studied rivers (February,1991).

element	THIKA		KOMU		NDARUGU		ATHI		THIRIRIKA	
	range	av.	range	av.	range	av.	range	av.	range	av.
Ca	9.3-20.0	14.1	20-34	29.7	7.5-10	8.7	16-18	17.2	7-8.5	7.5
Mg	2.4-4.6	3.4	1-6	4.8	2.0-2.2	2.1	3.6-3.8	3.7	1-2.5	1.7
Na	8.8-25	17.8	30-82	65.1	17-18	17.7	19-30.5	27.5	11-14	12.1
K	5-12	6.5	18-30	26.6	7-8.5	7.8	20-26	24.0	5-11	7.0
Mn	.01-1.8	.51	.05-1.4	1.06	0	0	1-1.3	1.18	.09-.1	.097
Fe	.2-1.4	.89	.5-2.3	1.82	.4-.8	.53	.9-1.1	.98	.25-.3	.27
BOD	1.38-3.0	2.20	20-25	22.6	1.2-1.5	1.48	2-12	7.95	.5-1	0.7
COD	3.88-8.0	4.80	20-70	55.0	3.5-6.0	4.43	25-27	26.0	7-10	9.00

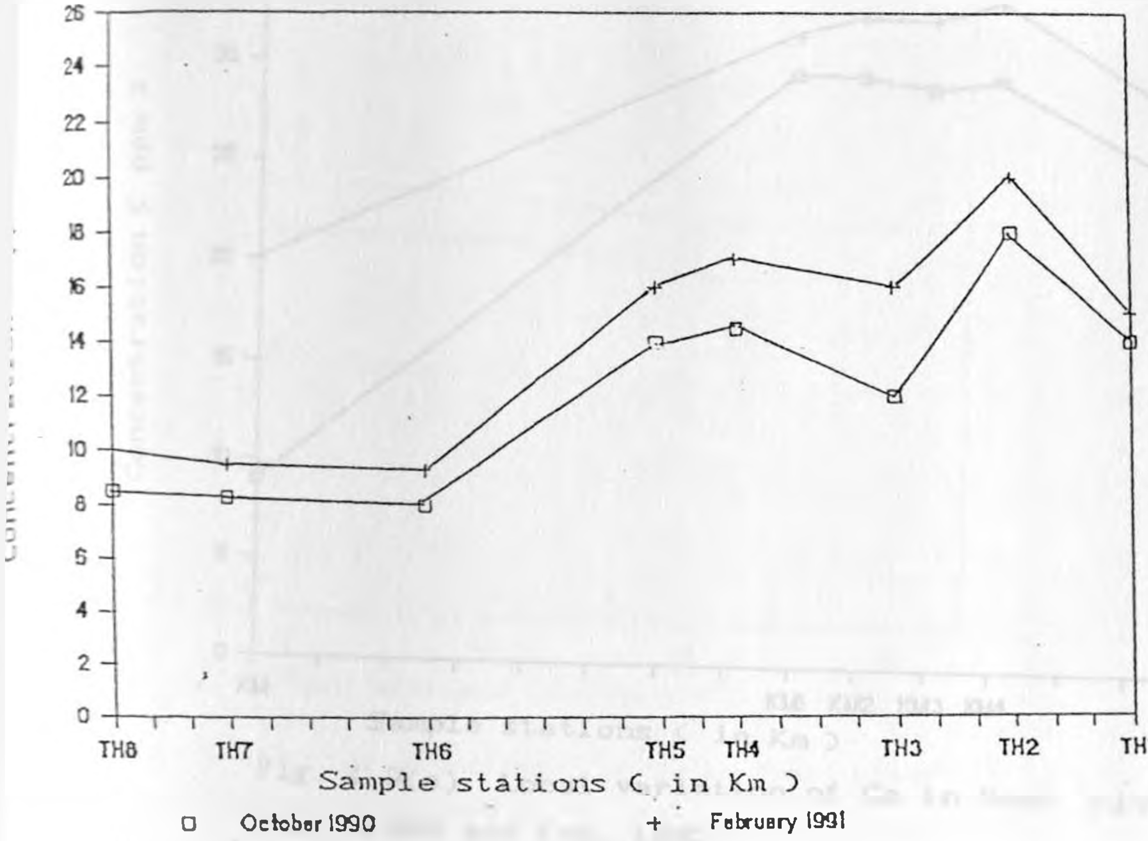


Fig. 4.9(a): Local variation of Ca in Thika river (Oct: 1990 and Feb. 1991)

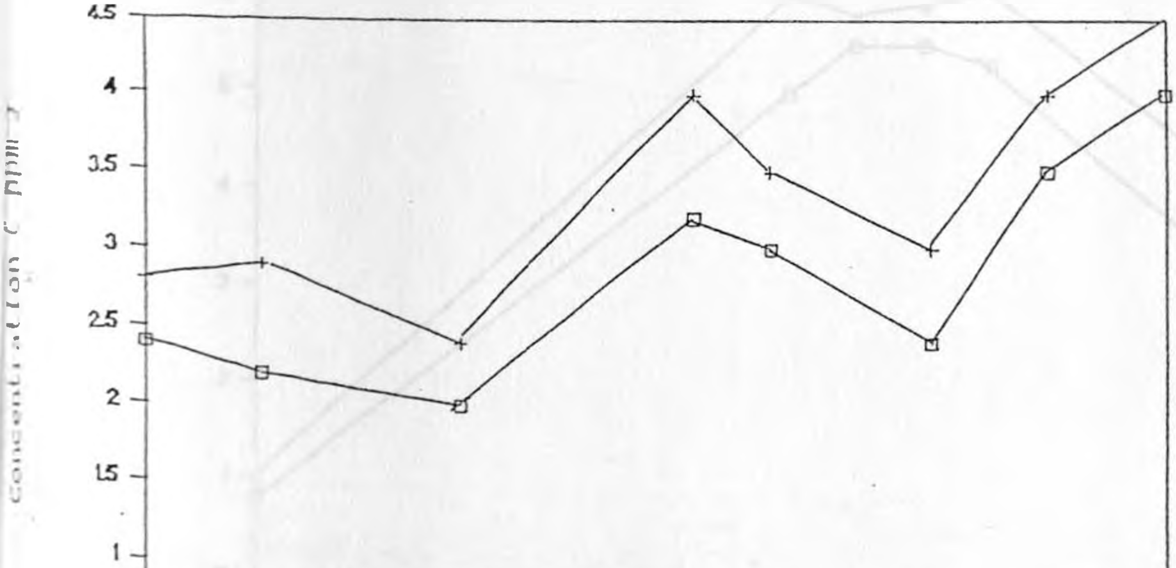


Fig 4.9(b): Local variation of Mg in Thika river (Oct. 1990 and Feb. 1991)

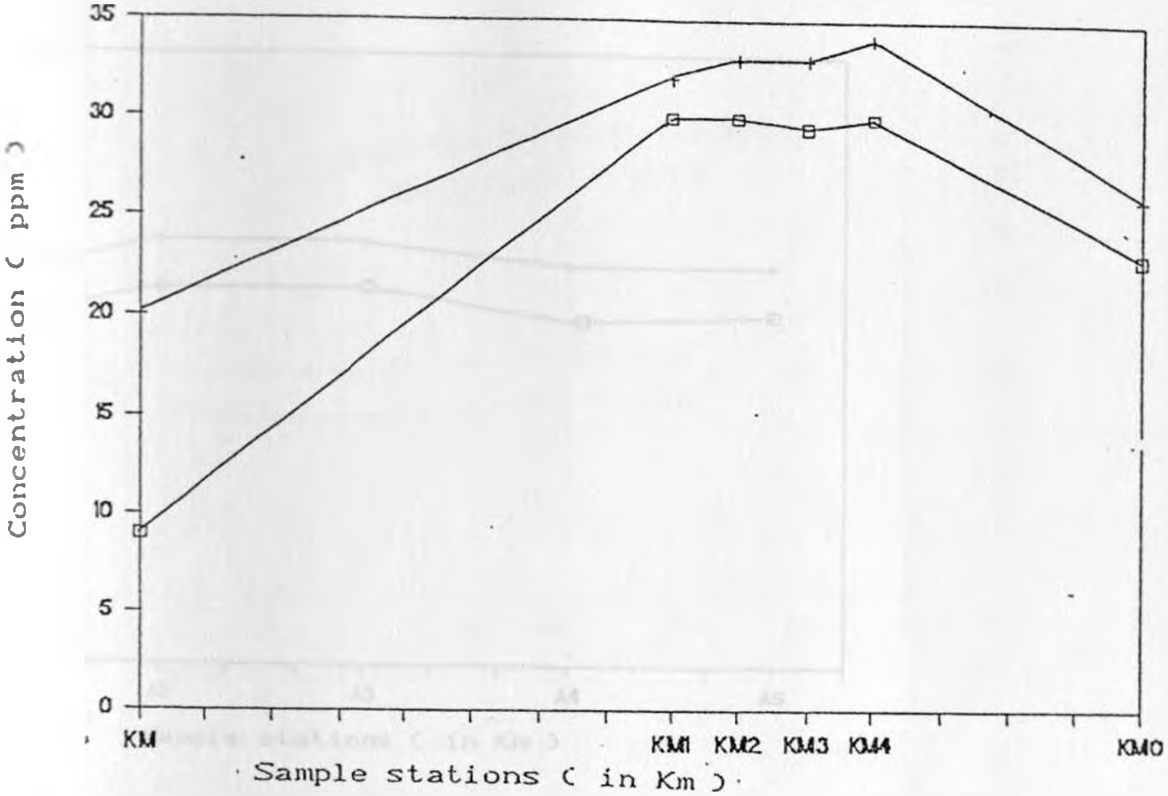


Fig. 4.9(c): Local variation of Ca in Komu river (Oct. 1990 and Feb. 1991)

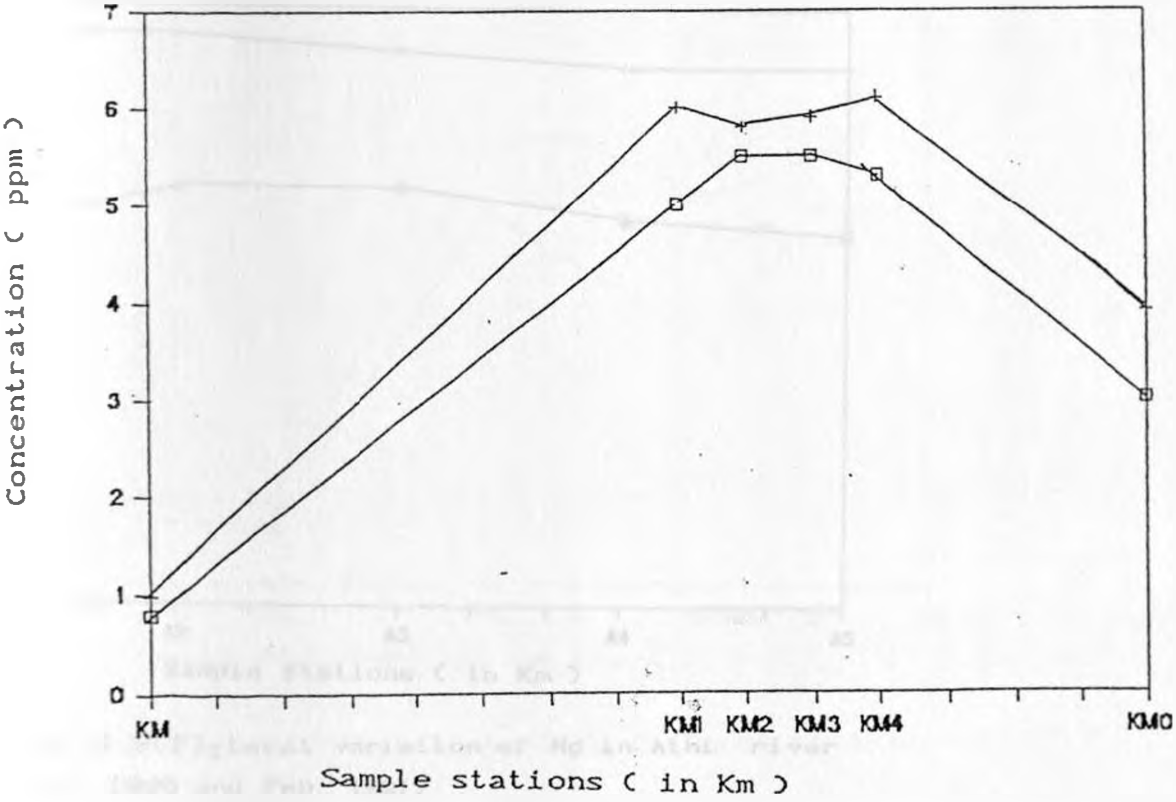


Fig. 4.9(d): Local variation of Mg in Komu river (Oct. 1990 and Feb. 1991)

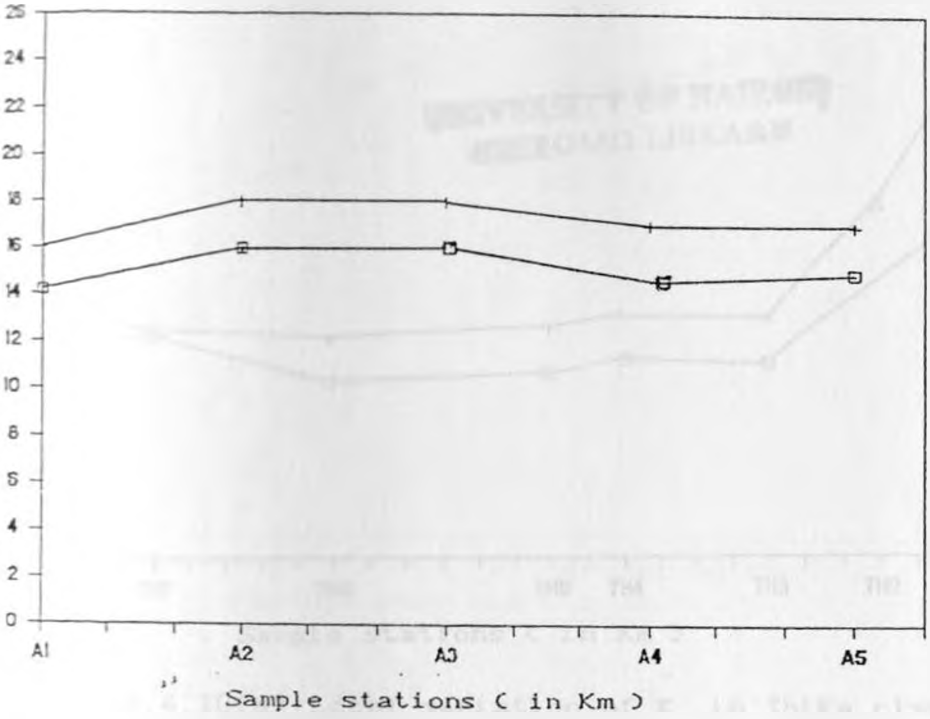


Fig. 4.9(e): Local variation of Ca in Athi river (Oct. 1990 and Feb. 1991)

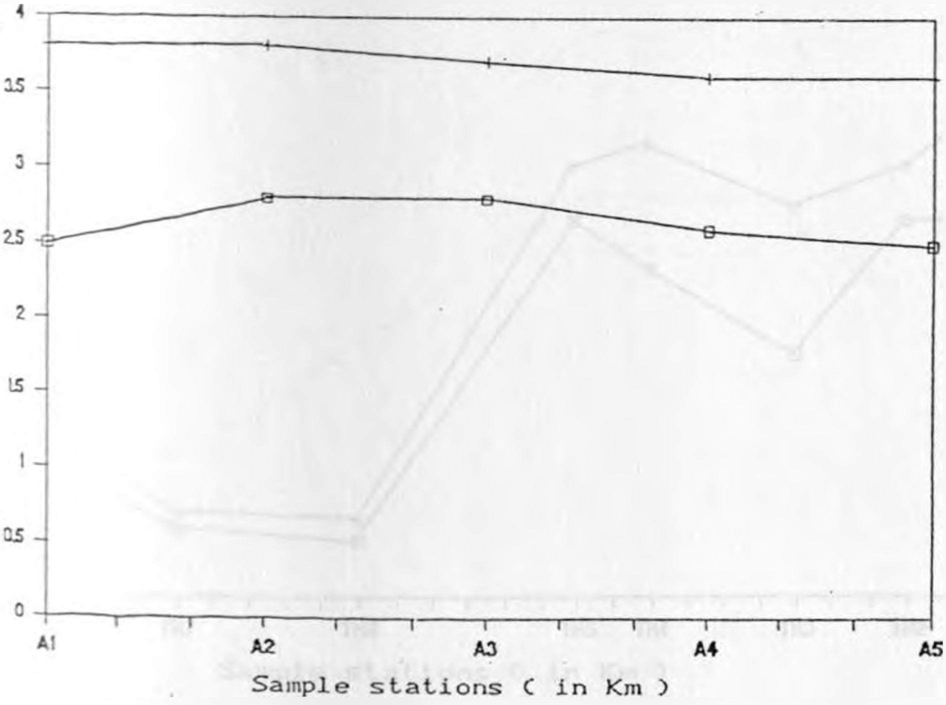


Fig. 4.9(f): Local variation of Mg in Athi river (Oct. 1990 and Feb. 1991)

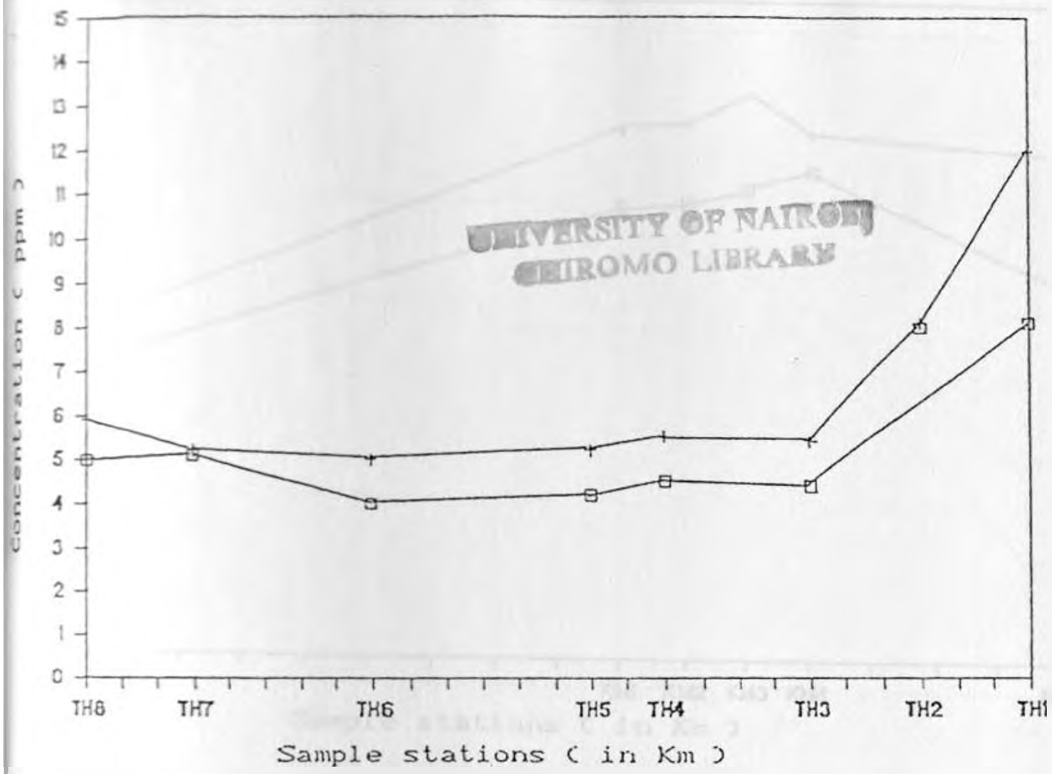


Fig.4.10(a):Local variation of K in Thika river (Oct. 1990 and Feb. 1991)

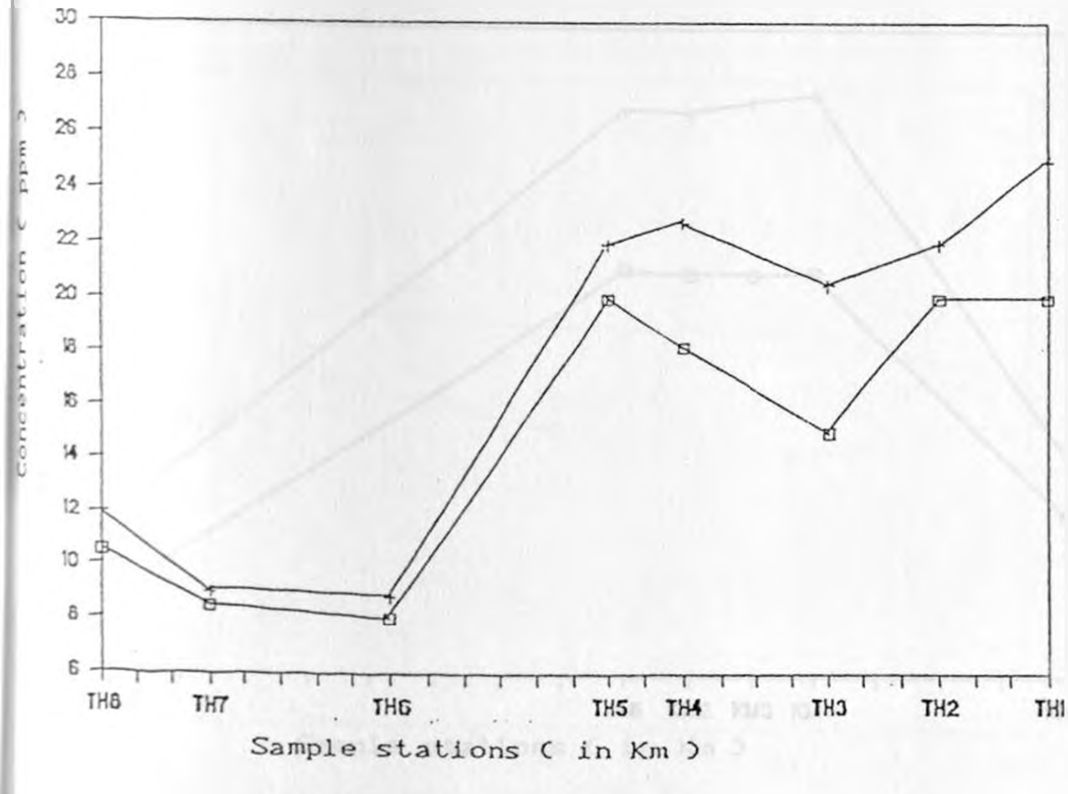


Fig.4.10(b): Local variation of Na in Thika river (Oct. 1990 and Feb. 1991)

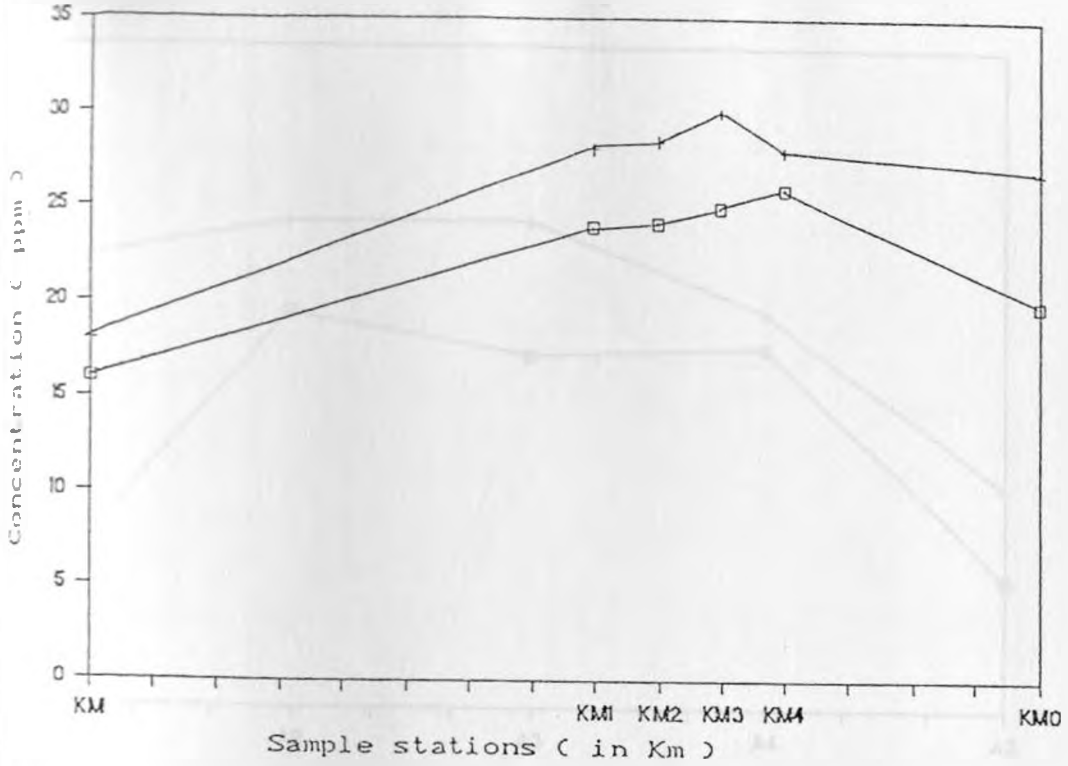


Fig.4.10(c): Local variation of K in Komu river (Oct. 1990 and Feb. 1991)

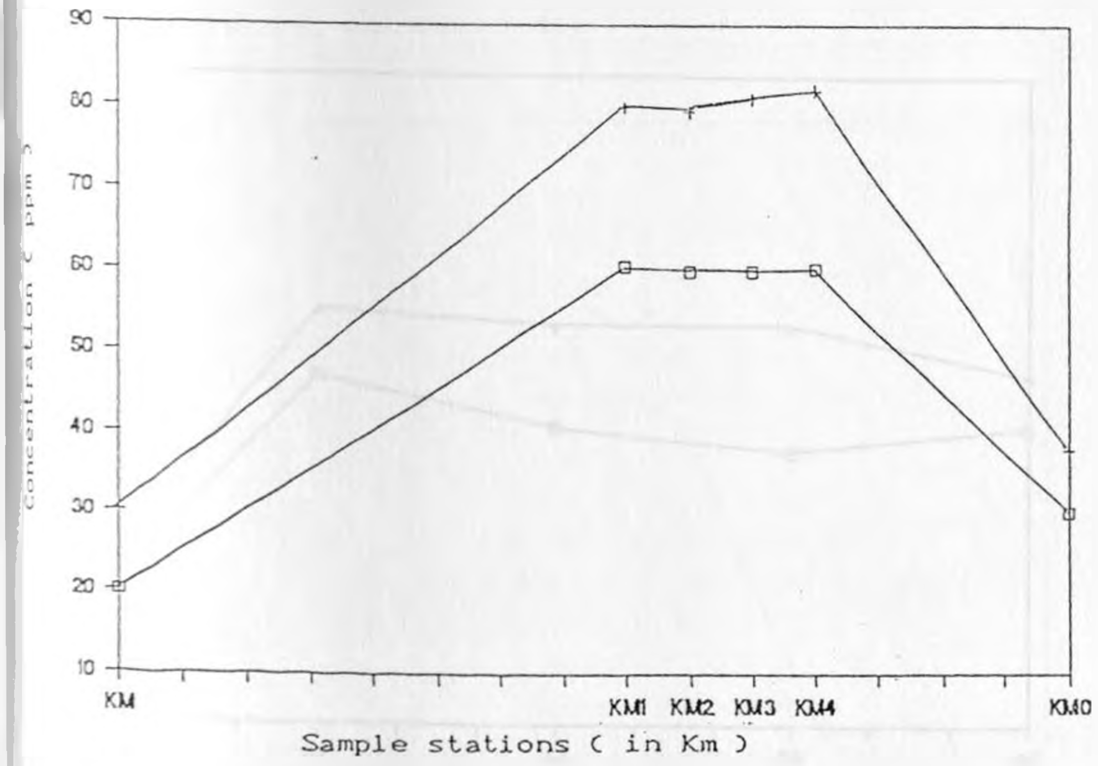


Fig.4.10(d) Local variation of Na in Komu river (Oct. 1990 and Feb. 1991)

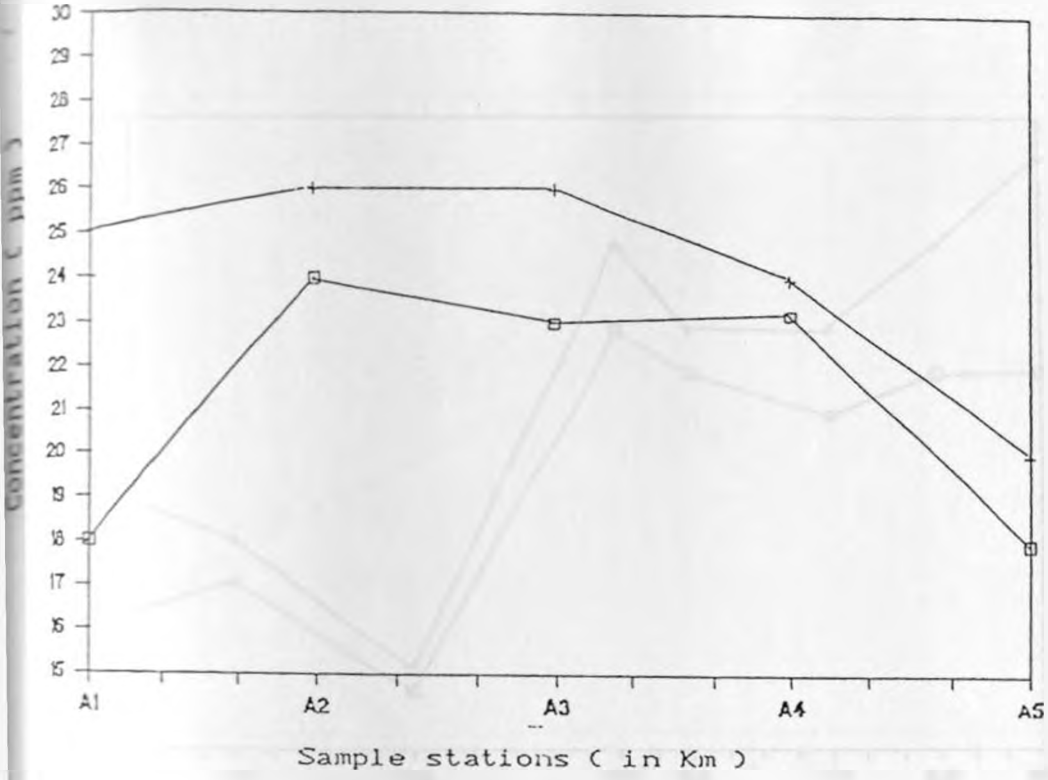


Fig. 4.10(e): Local variation of K in Athi river (Oct. 1990 and Feb. 1991)

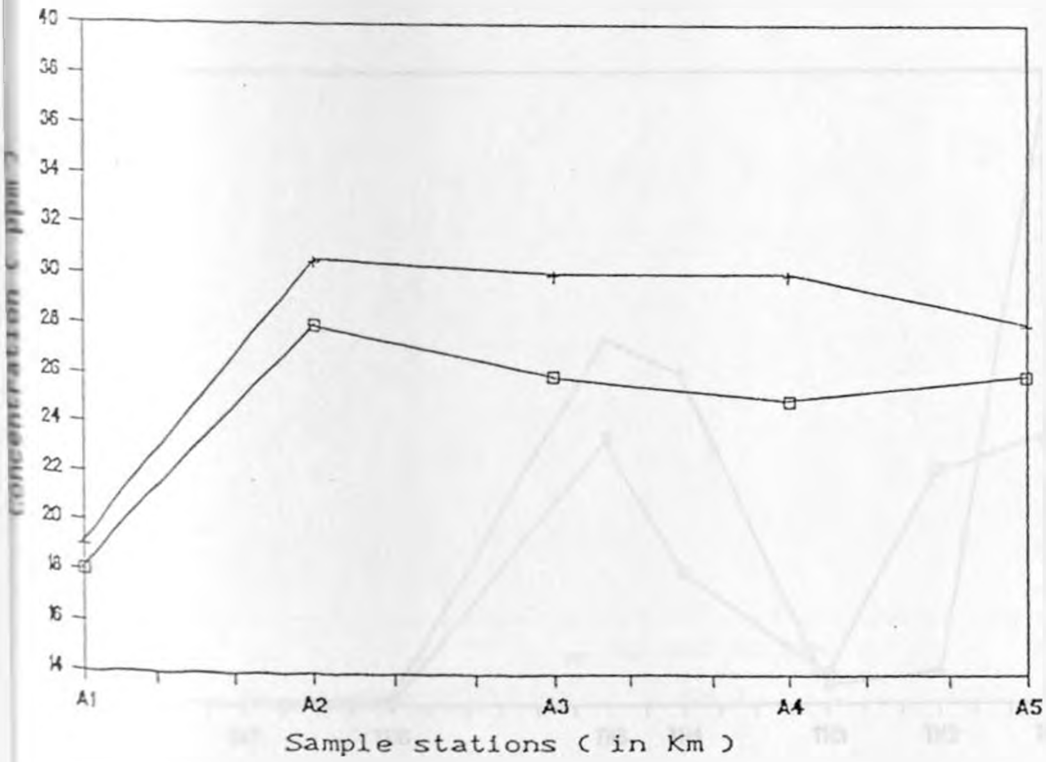


Fig. 4.10(f): Local variation of Na in Athi river (Oct. 1990 and Feb. 1991)

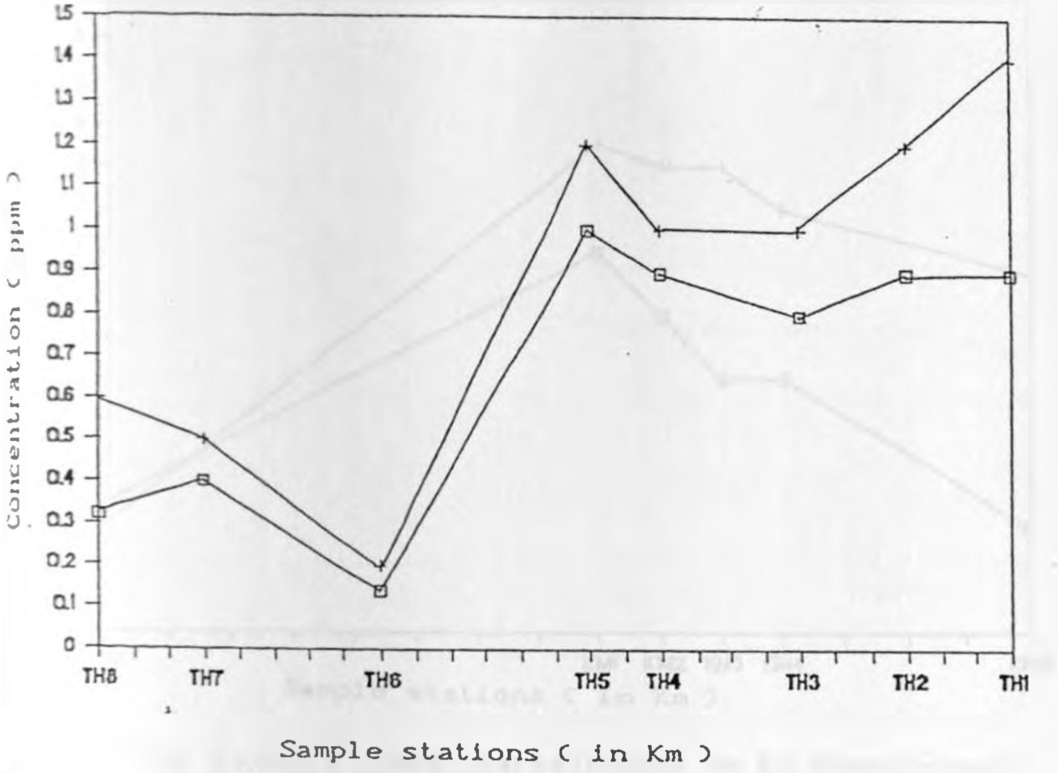


Fig. 4.11(a):Local variation of Fe in Thika river (Oct. 1990 and Feb. 1991)

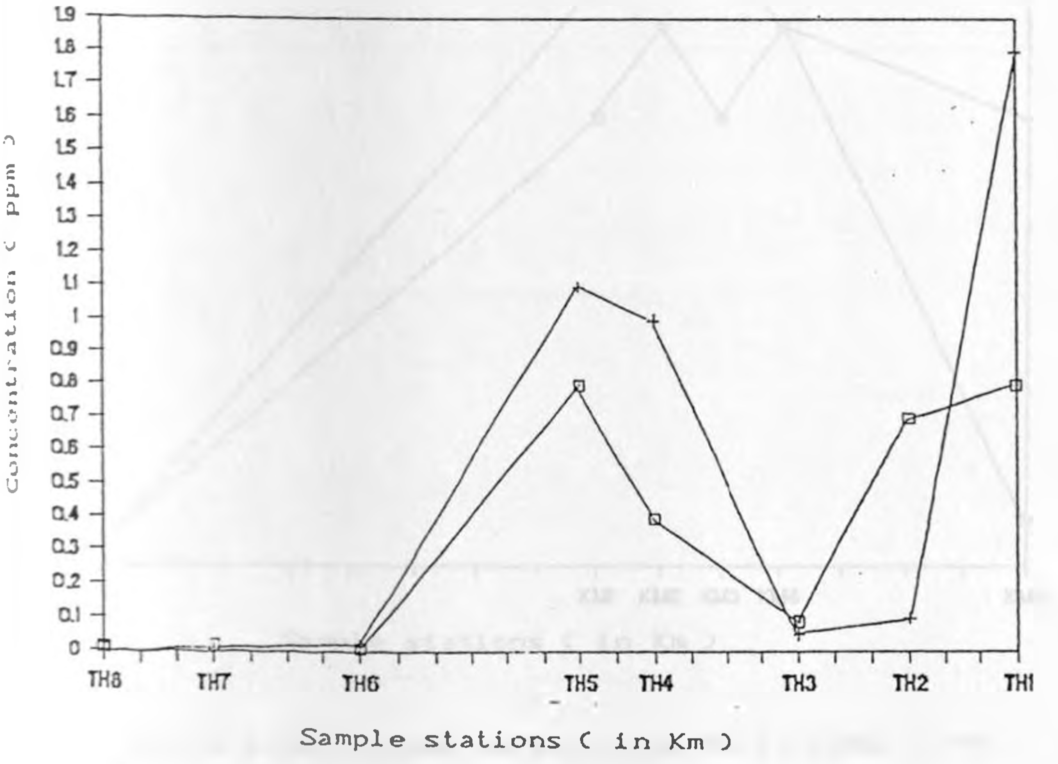


Fig.4.11(b): Local variation of Mn in Thika river (Oct. 1990 and Feb. 1991)

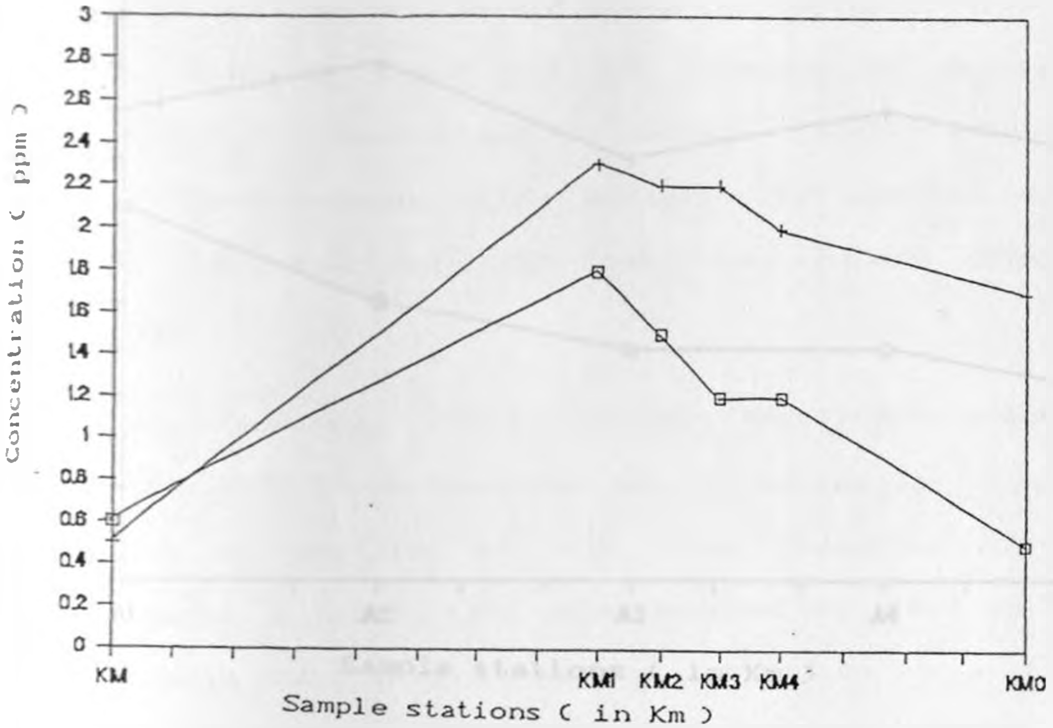


Fig.4.11(c) Local variation of Fe in Komu river (Oct. 1990 and Feb. 1991)

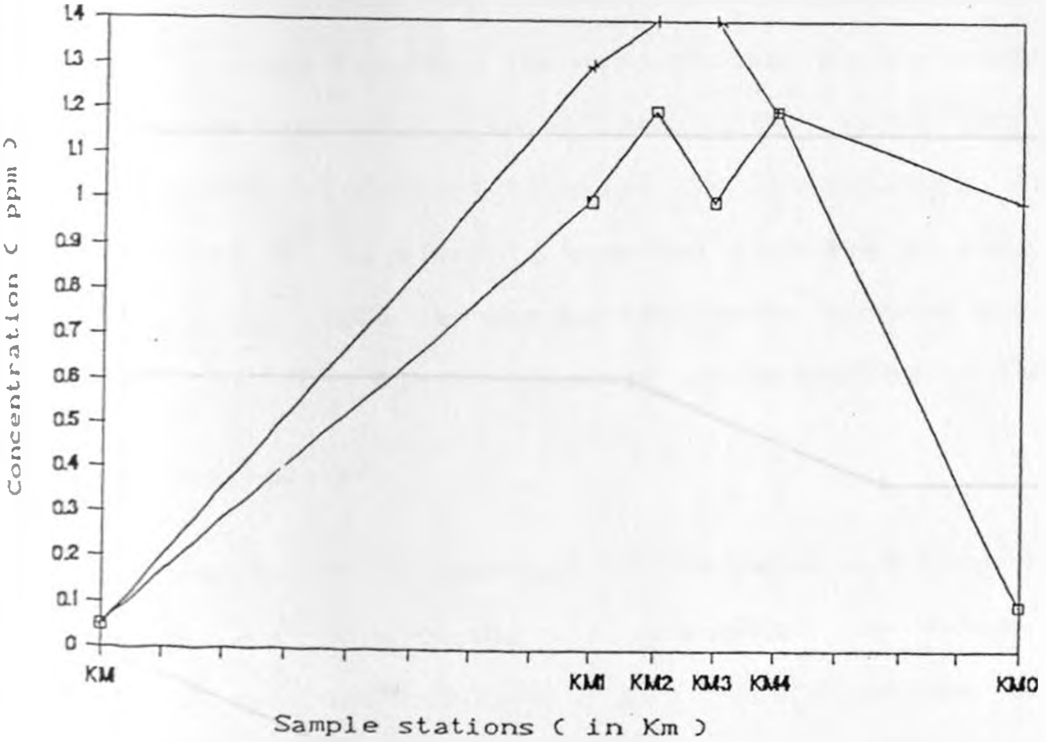


Fig.4.11(d): Local variation of Mn in Komu river (Oct. 1990 and Feb. 1991)

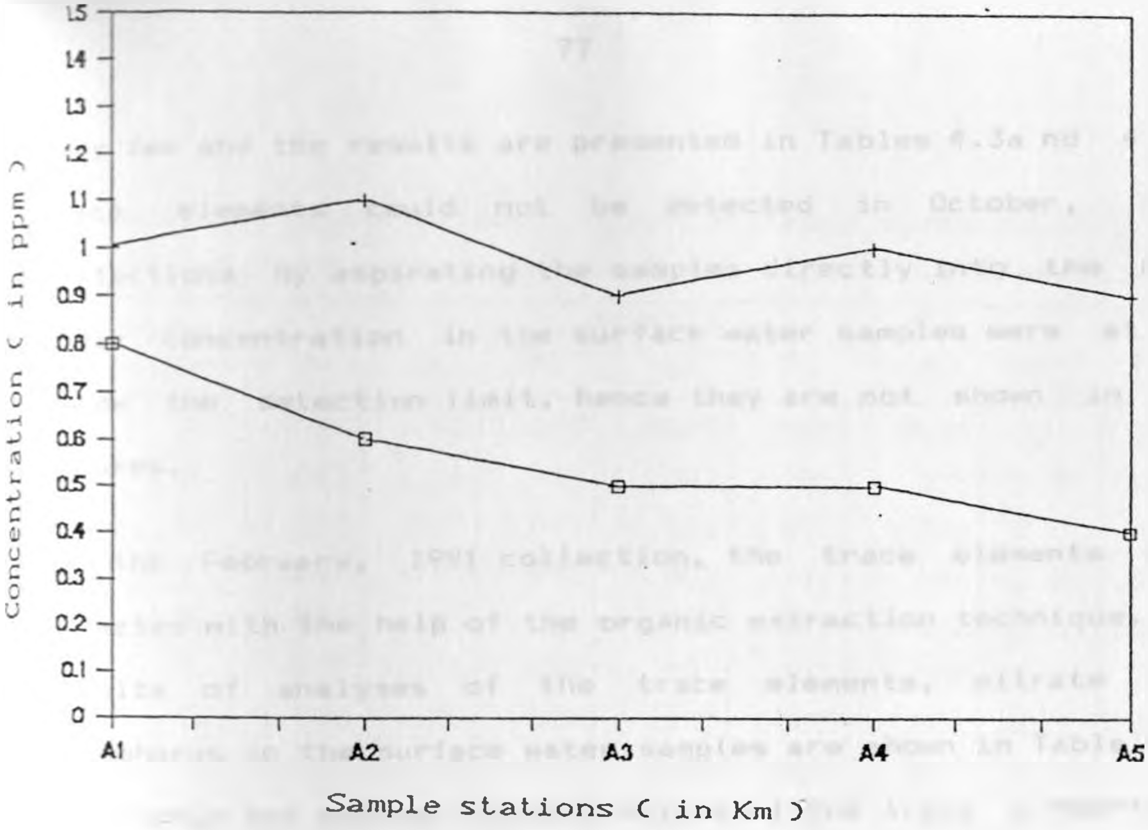


Fig.4.11(e):: Local variation of Fe in Athi river (Oct. 1990 and Feb. 1991)

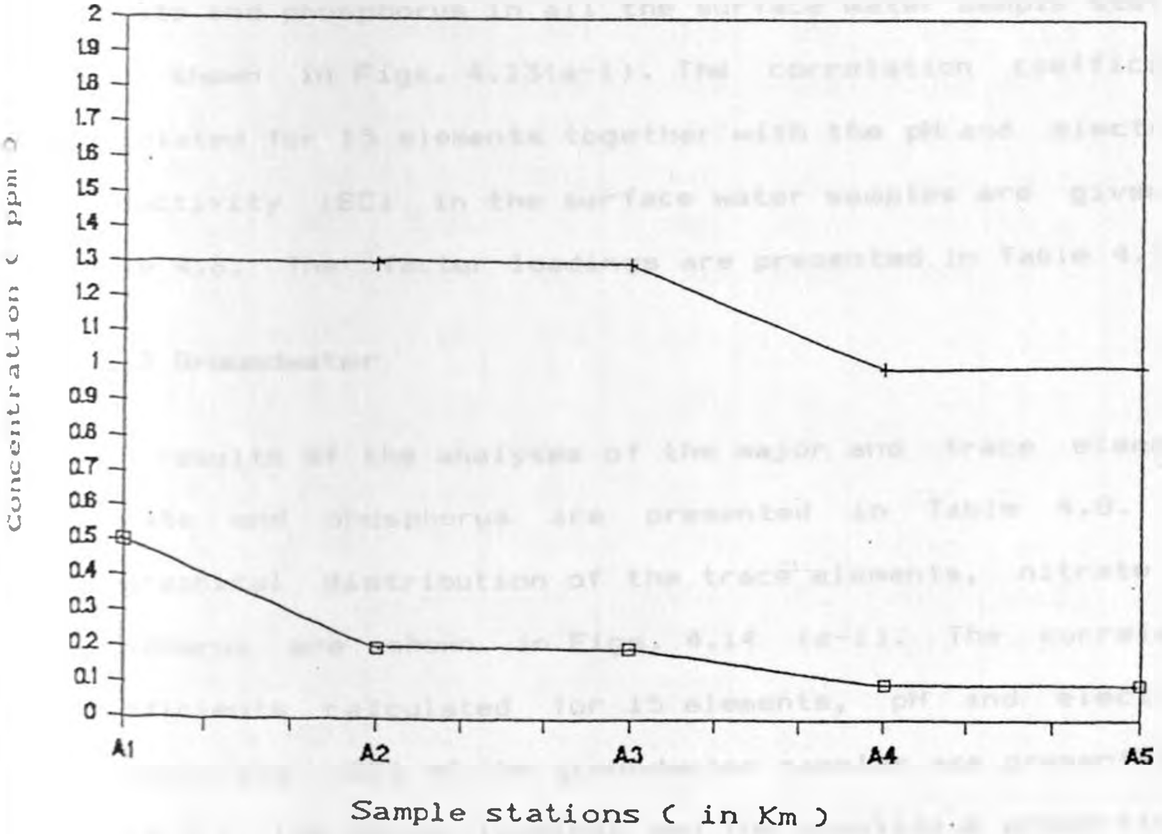


Fig.4.11(f):: Local variation of Mn in Athi river

very few and the results are presented in Tables 4.3a nd 4.4a. Trace elements could not be detected in October, 1990 collections by aspirating the samples directly into the AAS. Their concentration in the surface water samples were at or below the detection limit, hence they are not shown in the Figures.

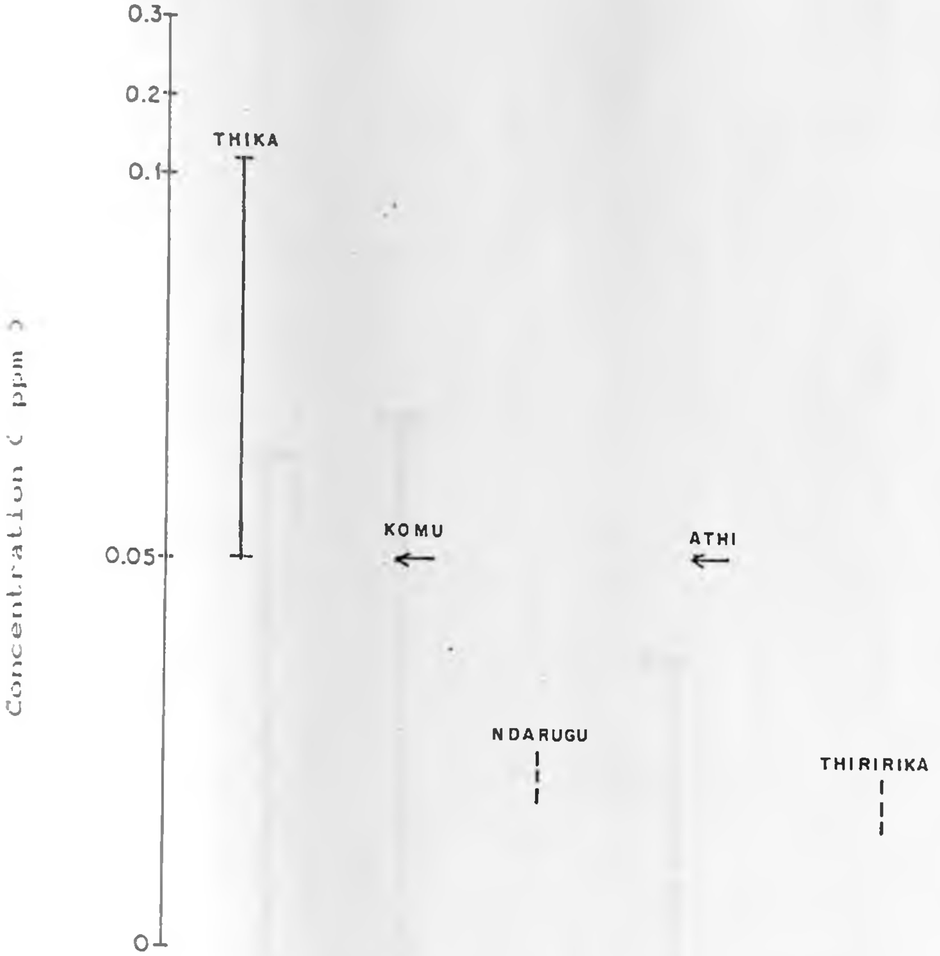
In the February, 1991 collection, the trace elements were detected with the help of the organic extraction technique. The results of analyses of the trace elements, nitrate and phosphorus in the surface water samples are shown in Table 4.5. The range and average concentrations of the trace elements , their background levels in the surface waters and the recommended limits by WHO (1982) are given in Figs. 4.12(a-i). Nitrate and phosphorus contents in the studied river are also shown in those Figures. The distribution of the trace elements, nitrate and phosphorus in all the surface water sample stations are shown in Figs. 4.13(a-i). The correlation coefficients calculated for 15 elements together with the pH and electrical conductivity (EC) in the surface water samples are given in Table 4.6. The factor loadings are presented in Table 4.7.

4.4.3 Groundwater

The results of the analyses of the major and trace elements, nitrate and phosphorus are presented in Table 4.8. The geographical distribution of the trace elements, nitrate and phosphorus are shown in Figs. 4.14 (a-i). The correlation coefficients calculated for 15 elements, pH and electrical conductivity (EC) of the groundwater samples are presented in Table 4.9. The factor loadings and the cumulative proportion of the total variance are given in Table 4.10.

Table 4.5 : Concentrations in ppm of trace elements, NO_3^- and P in the surface water samples of the study area (February, 1991).

sample stations	element								
	Zn	Cu	Pb	Ni	Co	Cd	NO_3^-	P	AL
G1	<.025	<.05	.003	.0065	.002	.0025	10	.01	.2
G2	<.025	<.05	.001	.007	.002	.002	8.5	.006	.06
Kc	<.025	<.05	.001	.001	.001	.001	2.0	.006	2.2
S	<.025	<.05	.001	.002	.001	.001	3.0	.001	.1
K	<.025	<.05	.001	.002	.001	.001	3.0	.0014	.4
T_8	<.025	<.05	.002	.002	.001	.002	4.5	.01	1.2
T_7	<.025	<.05	.002	.003	.001	.001	6.5	.018	.2
T_6	<.025	<.05	.002	.003	.001	.001	2.0	.001	1.5
T_5	.1	.09	.009	.006	.003	.005	4.5	.09	.2
T_4	.11	.09	.009	.008	.004	.006	4.5	.08	.3
T_3	.05	.05	.005	.004	.002	.004	4.5	.06	.2
T_2	.05	.05	.004	.01	.008	.008	6.2	.1	.1
T_1	.125	.05	.005	.01	.008	.008	6.0	.12	—
KM	.05	<.05	—	.002	.005	.004	3.0	.005	.4
KM_1	.05	<.05	.003	.015	.006	.005	50	.35	.6
KM_2	.05	<.05	.003	.015	.006	.005	50	.35	.6
KM_3	.05	<.05	.002	.015	.005	.004	47.5	.34	.6
KM_4	.05	<.05	.002	.013	.003	.004	45	.35	.5
KM_0	<.025	<.05	.001	.001	.002	.003	4.5	.1	.1
ND_1	<.025	<.05	—	.001	.002	.001	5.6	.005	.1
ND_2	<.025	<.05	.006	.001	.002	.002	4.0	.005	.1
ND_3	<.025	<.05	.002	.001	—	—	1.5	.002	.1
ND_4	<.025	<.05	—	.001	—	—	1.2	.001	.4
A_1	<.025	<.05	.0015	.005	.004	.004	4.5	.12	.1
A_2	.05	.05	.002	.007	.005	.003	20.5	.15	.1
A_3	.05	.05	.002	.003	.003	.002	12	.1	.1
A_4	<.025	<.05	.002	.002	.002	.001	4.0	.1	.2
A_5	<.025	<.05	.001	.002	.002	.001	4.0	.1	.1
TR_1	<.025	<.05	.002	.002	.001	.002	4.0	.001	.1
TR_2	<.025	<.05	—	.001	.001	—	3.0	.001	.2
TR_3	<.025	<.05	—	.001	.001	—	3.0	.001	.2
Y_1	<.025	<.05	.002	.002	.002	.003	5.0	.01	.1
Y_2	.05	.05	.002	.004	.004	.002	5.4	.01	.1



LEGEND

I Range

← Values measured in certain sample stations

¦ Undetected

The maximum permissible limit of Zn is 5ppm as recommended by WHO(1982)

Fig. 4.12(a): Range and values of Zn in the rivers of the area studied

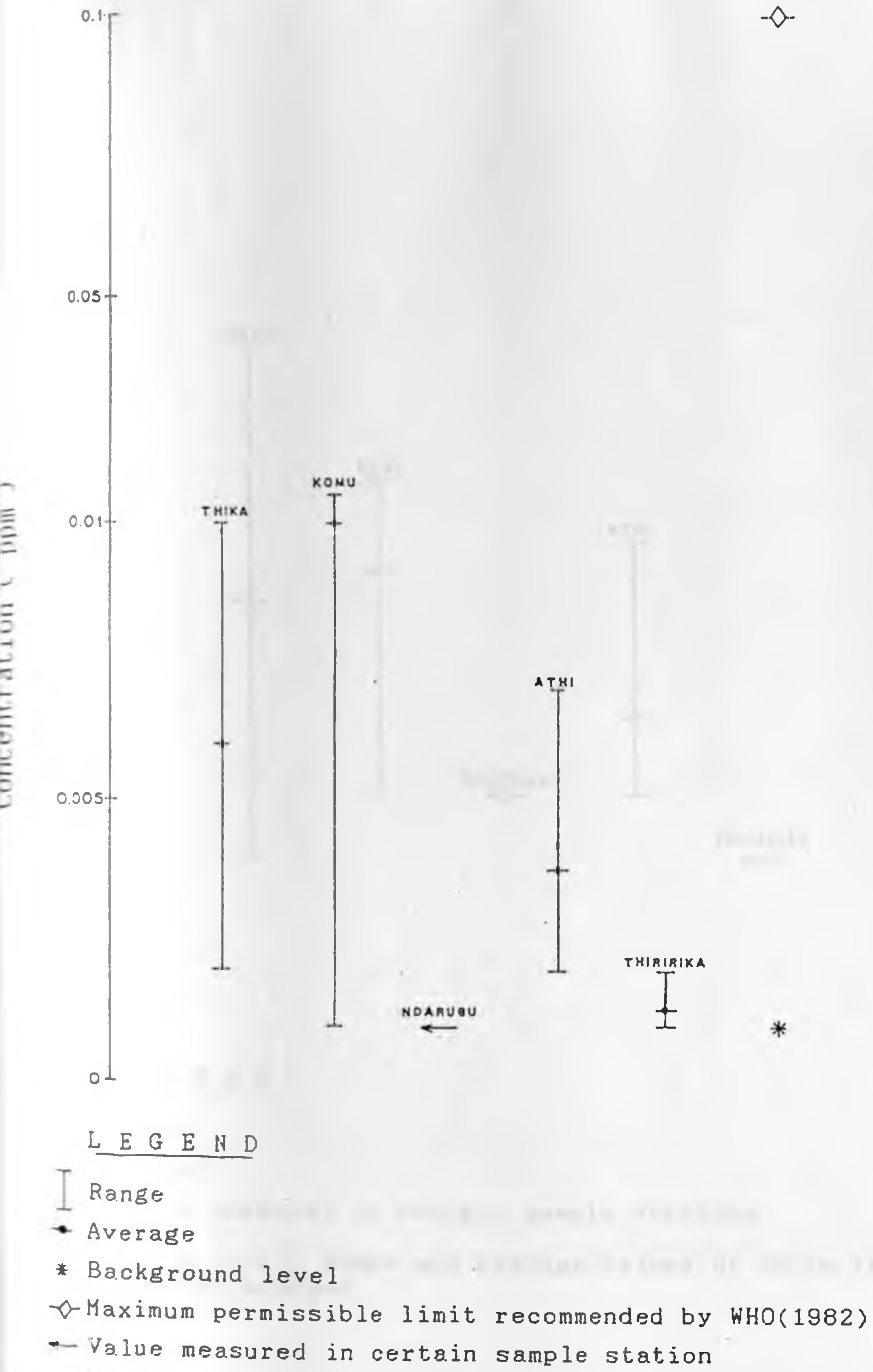


Fig. 4.12(b): Range and average values of Ni in the rivers of the area studied, the background level and maximum permissible limit recommended by WHO(1982)

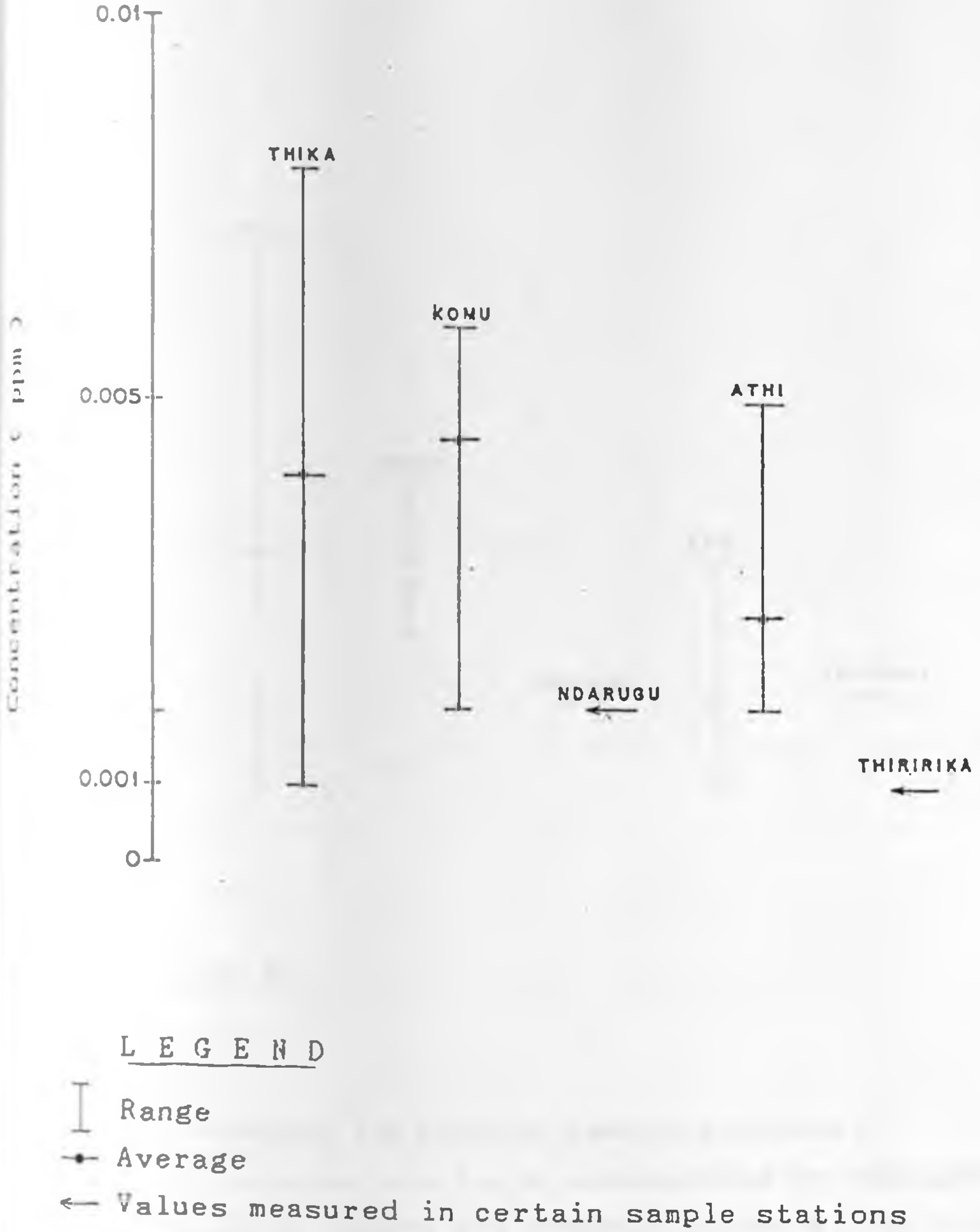
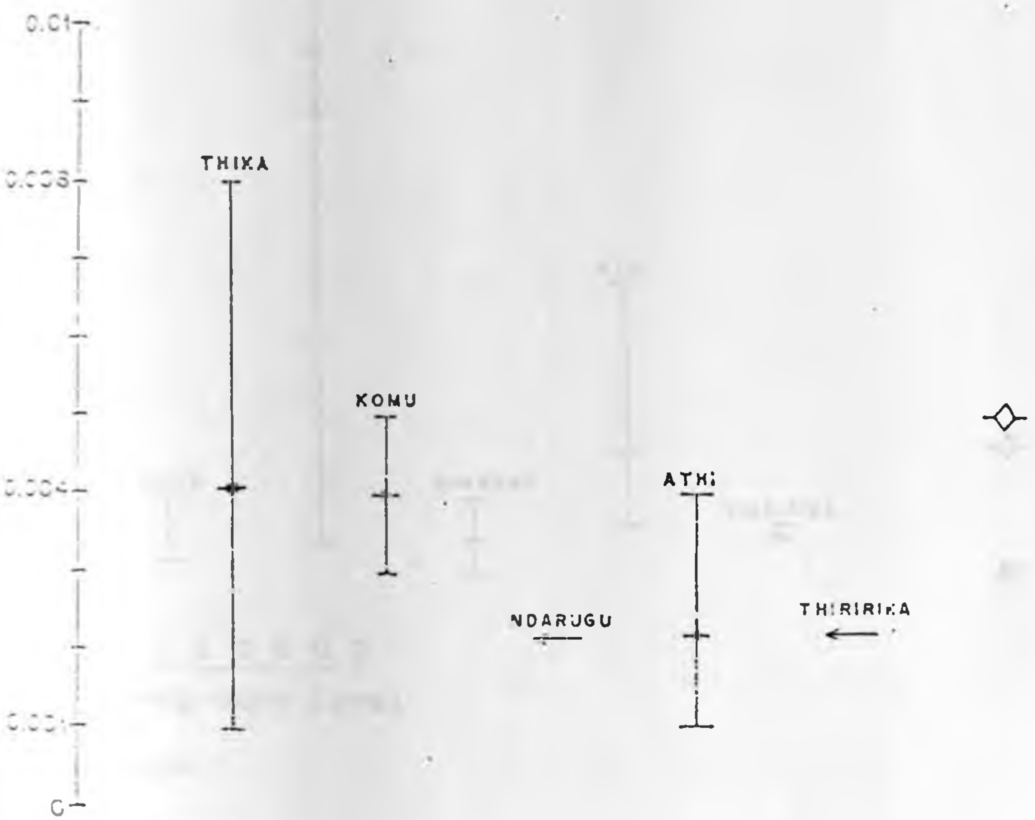


Fig. 4.12(c): Range and average values of Co in the rivers of the area studied



L E G E N D

⊥ Range

-+- Average

← Value measured in certain sample stations

-◇- Maximum permissible limit recommended by WHO(1982)

Fig. 4.12(d): Range and average values of Cd in the rivers of the area studied and the maximum permissible limit recommended by WHO(1982)

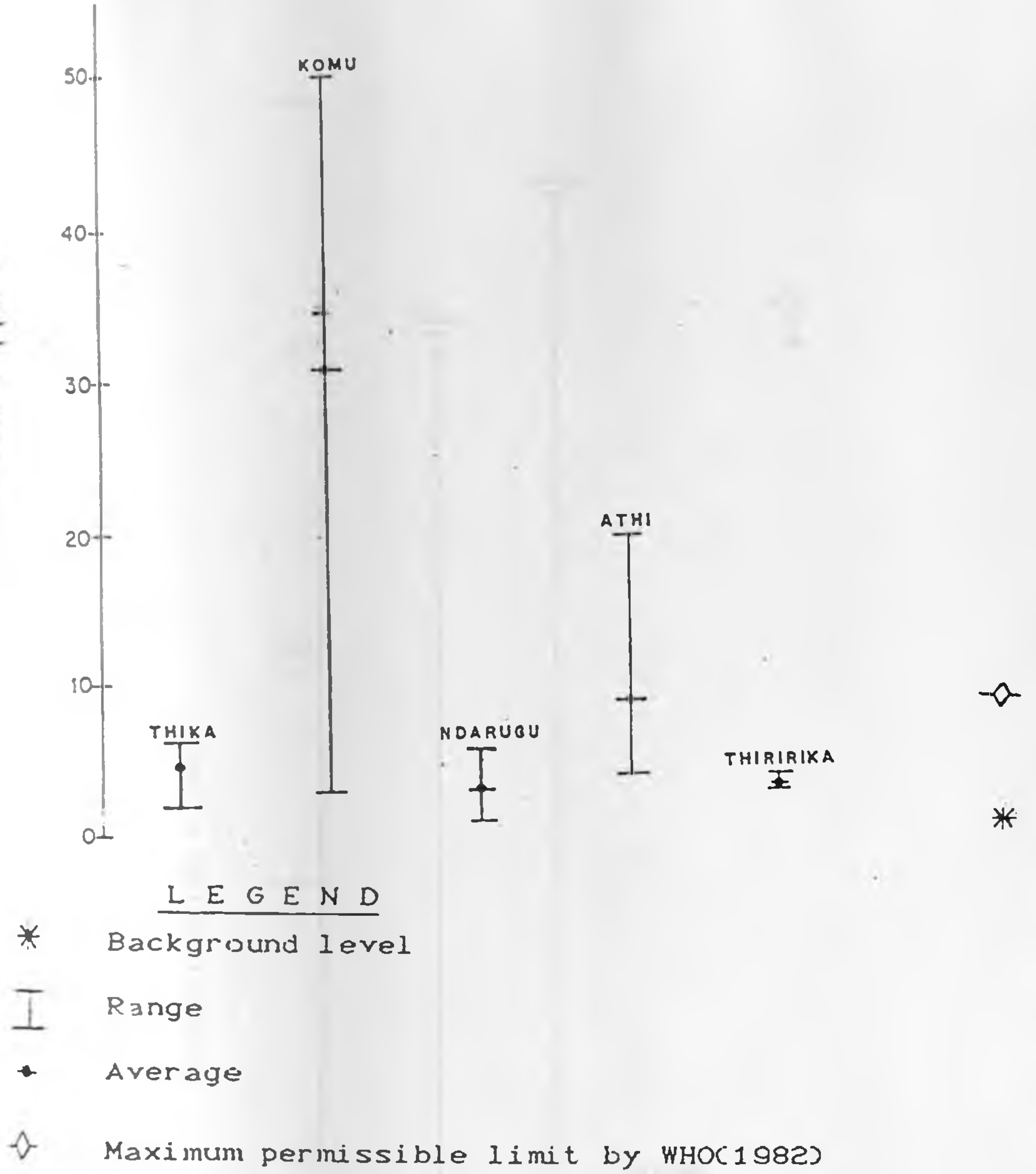


Fig. 4-12 (e): Range and average values of NO_3^- in the rivers of the area studied, the background level and the maximum permissible limit by WHO(1982)..

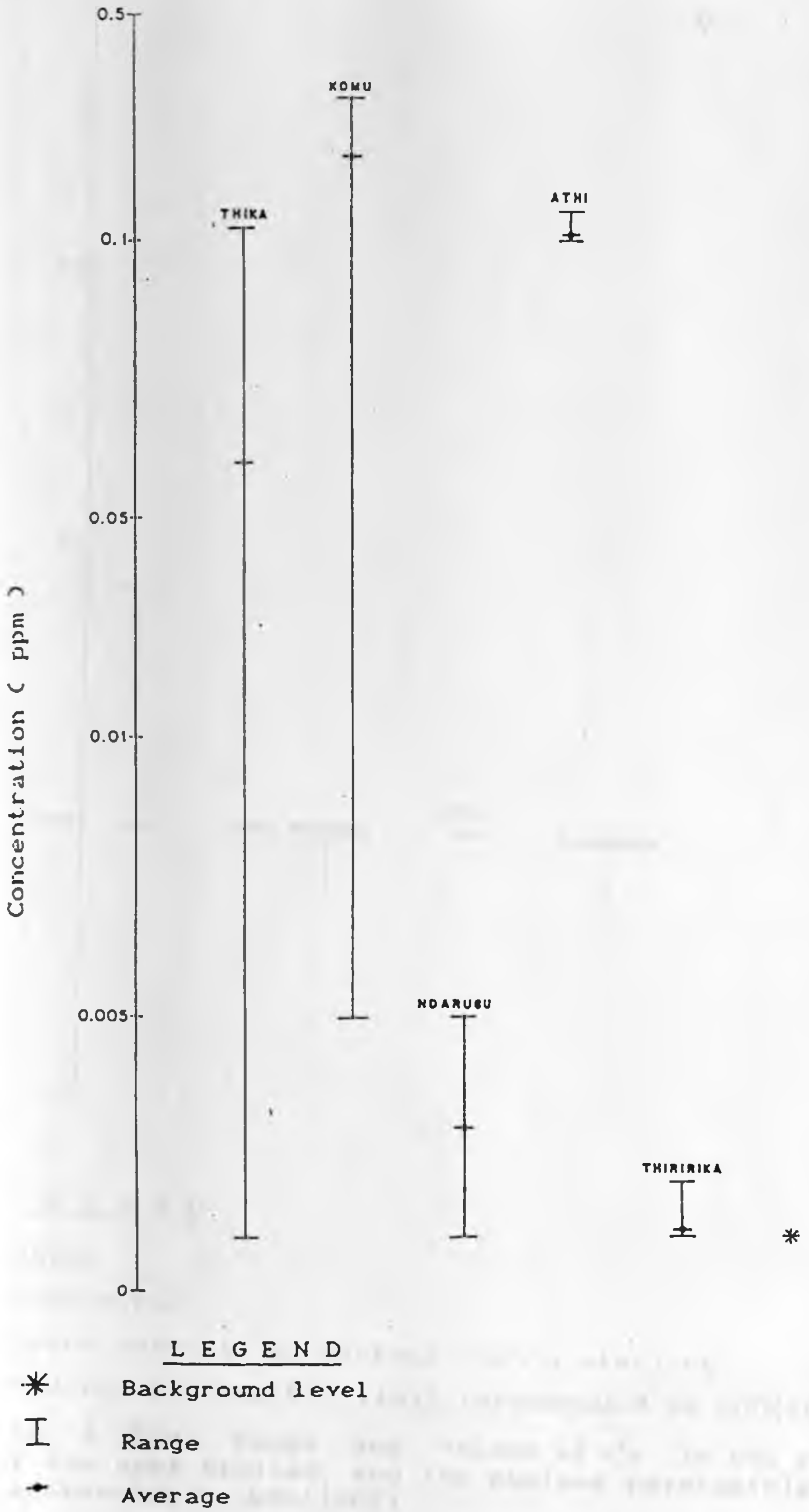


Fig. 4-12(f): Range and average values of P in the rivers of the area studied and the background level.

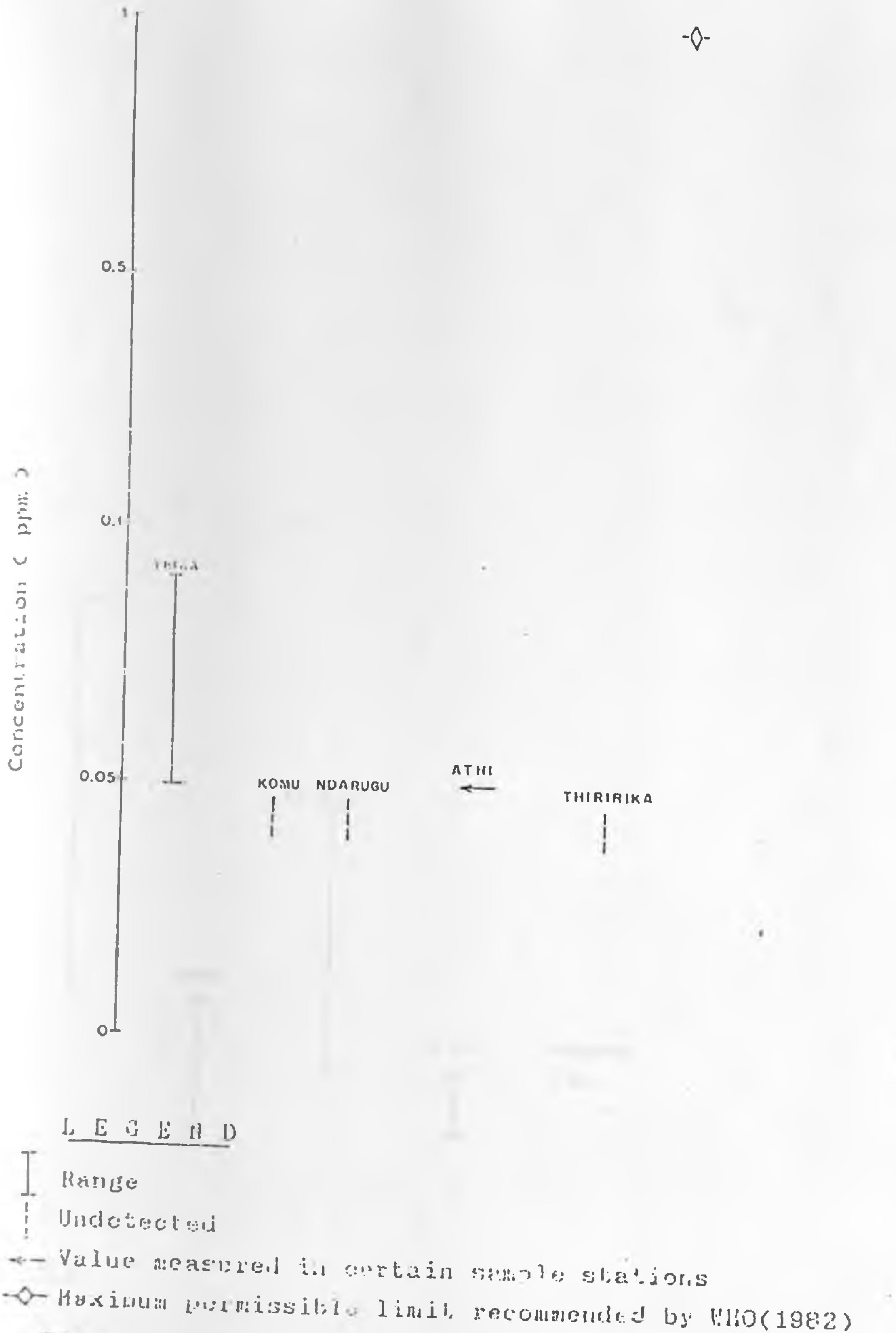


Fig. 4.12(g): Range and values of Cu in the rivers of the area studied, and the maximum permissible limit recommended by WHO(1982)

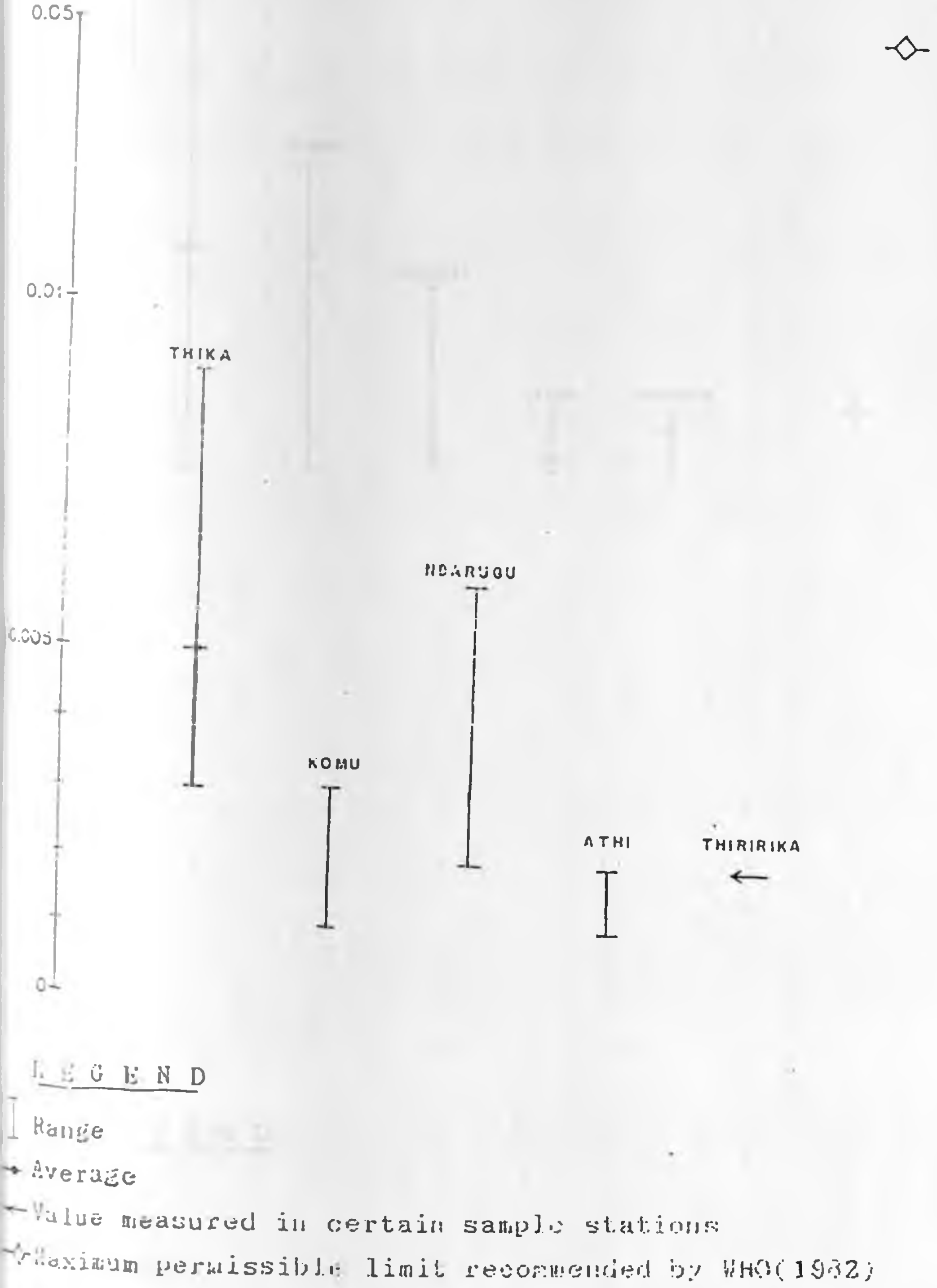
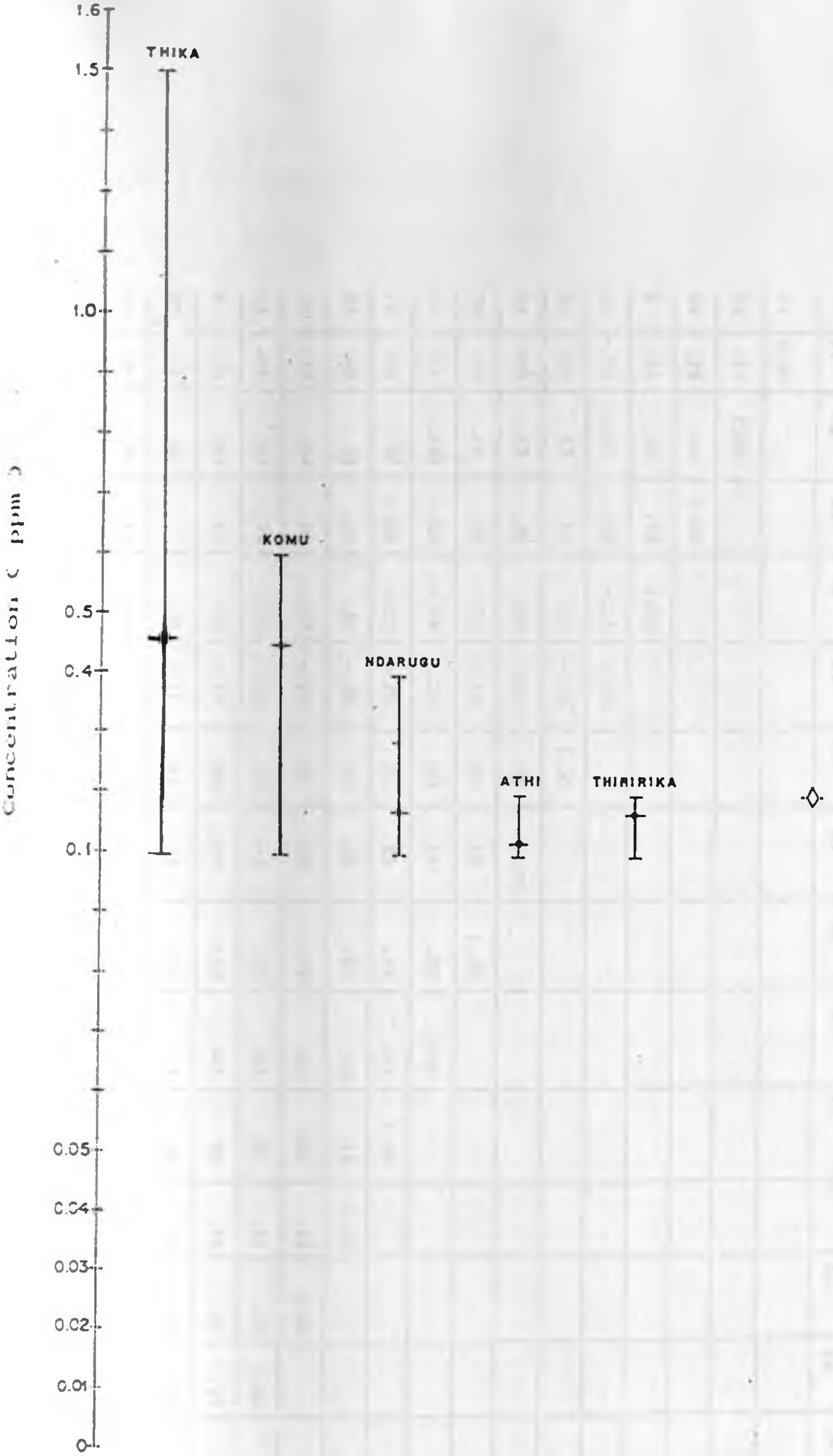


Fig. 4.12(h): Range and average values of Pb in the rivers of the area studied, and the maximum permissible limit recommended by WHO (1982)



L E G E N D

Range

Average

Maximum permissible limit by WHO(1982)

Fig. 4-12 (i): Range and average values of Al in the rivers

Table 4.6: Correlation coefficient values calculated for 15 parameters in the surface water samples.

	Ca	Mg	Na	K	Al	Mn	Fe	Zn	Cu	Pb	Ni	Co	Cd	P	NO_3^-	Ec	pH
Ca	1.00																
Mg	.85	1.00															
Na	.78	.61	1.00														
K	.68	.46	.78	1.00													
Al	-.03	-.01	.02	-.14	1.00												
Mn	.80	.63	.56	.60	-.33	1.00											
Fe	.40	.43	.38	.29	.03	.55	1.00										
Zn	.59	.44	.39	.20	-.16	.55	.45	1.00									
Cu	.21	.182	-.07	-.19	-.31	.35	.14	.80	1.00								
Pb	.20	.37	-.05	-.33	-.29	.31	.05	.48	.64	1.00							
Ni	.62	.52	.42	.31	-.06	.54	.46	.67	.40	.18	1.00						
Co	.73	.64	.51	.40	-.25	.81	.55	.77	.56	.45	.78	1.00					
Cd	.66	.57	.34	.13	-.09	.52	.42	.81	.66	.51	.81	.87	1.00				
P	.74	.67	.41	.48	-.27	.80	.44	.63	.45	.36	.74	.81	.69	1.00			
NO_3	.57	.49	.37	.20	-.11	.44	.23	.32	.13	.26	.67	.52	.58	.55	1.00		
Ec	.66	.45	.82	.77	-.11	.41	.22	.25	-.05	-.19	.15	.27	.14	.35	.13	1.00	
pH	.38	.28	.26	.39	-.14	.18	-.02	.07	-.03	-.13	.33	.10	.12	.39	.35	.41	1.00

Table 4.7: Loadings of each variable on each of the three factors for the surface water samples.

	FACTOR		
Variable	1	2	3
Ca	.875	-.281	.64
Mg	.787	-.144	.118
Na	.681	-.568	.070
K	.567	-.723	-.167
Al	-.215	-.187	.840
Mn	.834	-.050	-.152
Fe	.557	-.030	.380
Zn	.776	.390	.026
Cu	.474	.717	-.224
Pb	.37	.702	-.188
Ni	.801	.141	.243
Co	.915	.229	.046
Cd	.821	.409	.193
NO_3^-	.879	.073	-.120
P	.624	.041	.134
Ec	.513	-.669	-.232
pH	.337	-.383	.017

Table 4,8 : Concentration in ppm of major and trace elements, nitrate and phosphorus in the groundwater samples of the area studied (February, 1991).

Sample station	Ca	Mg	Na	K	Al	Mn	Fe	Zn	Cu	Pb	Ni	Co	Cd	P	NO_3^-
1	20	3	24	6.4	0.6	0.4	0.5	0	0	0	0.006	0.005	0.005	0.001	8.75
2	29	12	85.5	12	0	0.4	0.8	0	0.05	0.001	0.005	0.003	0.002	0.002	0.54
3	12	4.2	10	4.2	0	2	2.2	0	0.05	0.006	0.007	0.005	0.003	0.02	5.4
4	14	5.5	40	6.5	0.2	2	2.5	0	0	0	0.002	0.001	0.001	0.01	9.5
5	18	3.2	38	4	0.3	1.2	1.6	0.05	0	0.003	0.0025	0.002	0.003	0.01	8.5
6	26	5	58	11	0	0.07	0.06	0	0	0.001	0.001	0.001	0.001	0.001	4.6
7	90	9.6	82	42	0.1	0.9	0.8	0	0	0.002	0.003	0.002	0.002	0.002	8.5
8	35	6	31.5	7	0	0.09	0.1	0	0.002	0.006	0.001	0.002	0.002	0.001	8
9	29	0.5	44.1	2	0	0.5	0.6	0	0	0	0.001	0.005	0.005	0	1
10	102	14.5	240	180	0.01	2.4	2.8	0	0	0.001	0.002	0.001	0.001	0	1.9
11	45	8.6	31	12	0.1	1.2	2.1	0	0	0.002	0.002	0.001	0.002	0	1.5
12	27	6.2	12.5	16	0.3	1.4	1.2	0.05	0	0.004	0.006	0.004	0.004	0	2.25
13	32	7.8	28.5	8	0.1	0.4	0.4	0.05	0	0.001	0.003	0.002	0.003	0	2.75
14	23	6.2	30	5.6	0	0.1	0.09	0.15	0.05	0.001	0.001	0.001	0.003	0	2.2
15	18	4	35	6.5	0	0.4	0.5	0	0	0.001	0.002	0.001	0.001	0	2.5
16	16	2.8	18	4.8	0.1	0.1	0.2	0	0	0.002	0.001	0.001	0	0	2.5
17	12	3.5	16	3	0	0.1	0.009	0	0	0.001	0.001	0.001	0	0	2.4
18	27	5.5	46	10	0.2	0.6	0.8	0	0	0.001	0.001	0	0	0	2.5
19	28	3.8	40	12	0.1	0.2	0.3	0	0	0	0.001	0	0	0	2.5
20	30	6	46	6.4	0	2.4	2.6	0	0	0.002	0.004	0.003	0.001	0.001	2.8
21	18	2.8	28	7	0	0.8	1.1	0.05	0	0.002	0.003	0.002	0.002	0.001	3
22	40	20	39	6.4	0	0.2	0.3	0.05	0	0.004	0.005	0.004	0.001	0.002	6.8
23	27	6	22.2	8	0	0.2	0.3	0.05	0	0.006	0.005	0.004	0.003	0.004	8.2
24	22.5	7.5	28.2	4.8	0	0.2	0.1	1.3	0.05	0.001	0.004	0.004	0.005	0	3.5
25	100	38	68	6	0	0.2	0.1	0.05	0	0.001	0.004	0.002	0.003	0.001	4.75
26	16	2.5	24.6	3.1	0	0.01	0.06	0.13	0.05	0.003	0.006	0.006	0.004	0.00	3.70
27	22	3	32	6	0.1	0.1	0.2	0.13	0.05	0.003	0.006	0.006	0.005	0.00	2.5
28	30	6.8	33	6	0	0.1	0.3	0	0	0.003	0.005	0.003	0.004	0	4.5
29	19	4.2	18.9	5.4	0.4	0.3	0.3	0	0	0.003	0.005	0.0045	0.004	0.001	3.75
30	30	7	15	8.4	0	0.8	0.6	0	0	0.002	0.002	0.002	0.002	0.001	3.75
31	46	0.8	42	10	0.2	0.4	0.4	0	0	0.001	0.002	0.002	0.002	0.001	3

Table 4.9: Correlation coefficient values calculated for 15 parameters in the groundwater samples.

	Ca	Mg	Na	K	Al	Mn	Fe	Zn	Cu	Pb	Ni	Co	Cd	P	NO_3^-	Ec	pH
Ca	1.00																
Mg	.51	1.00															
Na	.72	.41	1.00														
K	.70	.44	.63	1.00													
Al	-.23	-.29	-.36	-.20	1.00												
Mn	.22	.09	.15	.37	.12	1.00											
Fe	.11	.01	.14	.33	.11	.93	1.00										
Zn	-.17	.002	-.09	-.20	-.14	-.39	-.44	1.00									
Cu	-.30	.008	-.12	-.21	-.21	-.32	-.26	.71	1.00								
Pb	-.22	.15	-.47	-.08	.07	.01	.14	-.06	.12	1.00							
Ni	-.02	.26	-.20	-.05	.08	.03	.11	.12	.28	.64	1.00						
Co	-.02	.15	-.32	-.15	.19	-.08	.01	.28	.40	.66	.86	1.00					
Cd	-.11	.15	-.34	-.10	.30	-.18	-.18	.44	.44	.45	.70	.73	1.00				
P	-.22	-.26	-.17	-.14	.31	-.16	-.02	-.02	.15	.19	.22	.36	.25	1.00			
NO_3^-	-.01	.24	-.09	-.03	.24	-.02	-.04	-.08	-.08	.33	.49	.44	.38	.30	1.00		
Ec	.82	.48	.80	.61	-.37	.28	.25	-.20	-.20	-.14	-.07	-.25	-.28	-.26	-.05	1.00	
pH	-.04	-.26	.08	-.18	-.10	-.16	-.09	-.07	-.07	-.30	-.09	-.11	-.21	-.14	-.32	-.13	1.00

Table: 4.10: Loadings of each variable on each of the four factors for the groundwater samples.

Variable	FACTOR			
	1	2	3	4
Ca	.687	.482	-.276	.194
Mg	.246	.640	-.364	.078
Na	.751	.242	-.354	.090
K	0.622	.522	-.097	.001
Al	-.345	-.011	.557	.314
Mn	.406	.373	.612	-.453
Fe	.327	.376	.656	-.502
Zn	-.421	-.103	-.680	-.257
Cu	-.497	.015	-.576	-.414
Pb	-.532	.525	.197	-.122
Ni	-.548	.694	-.031	-.135
Co	-.712	.567	-.051	-.133
Cd	-.694	.470	-.203	-.006
P	-.442	.098	.185	.533
NO_3^-	-.342	.527	.136	.515
Ec	.740	.460	-.257	.035
pH	.087	-.433	-.100	-.209

CHAPTER FIVE

5.0 INTERPRETATION AND DISCUSSION OF THE RESULTS

5.1 Surface Water Quality

The water quality parameters of colour, turbidity and suspended materials vary markedly between the sampled rivers (Appendix VII- XI).

In Thika river, the colour of water changed from brown at upstream to reddish-brown between stations T4 and T5 (the zone of large industrial activities). Between those two stations the water was highly turbid and contained large amounts of suspended material compared to the other sampling stations in the Thika river. This was due to the direct discharge of highly coloured industrial effluents into the river, e.g. Kenya Paper Mill discharges into the Thika river effluents which contain dust-like particles of paper. From station T3 going downstream, the colour of the water reverted to brown and the turbidity and suspended matter in the water decreased by 20 percent because of dilution which came about through Kabuku and Samuru tributaries as they join the Thika river at downstream. In addition, to the dilution, self purification plays an important role in decreasing the turbidity and suspended matter in the Thika river. At downstream, the river is shallow and turbulent with a rocky bed. The water is highly aerated, therefore the river purifies itself in a short time.

There was no difference in colour, turbidity and suspended materials between October, 1990 and February, 1991 at any of the sampling stations in the Thika river. However the reddish brown colour at stations T4 and T5 was prominent in February, 1991, during the period of low river flow. It can be deduced that the ratio of the volume of the effluents to the volume of the stream is greater in February, 1991 than in October, 1990. Therefore the reddish-brown colour appears well in February, 1991.

Komu river had grey colour along its entire length in both October, 1990 and February, 1991 collections. Its water was highly turbid and contained about 70 per cent of suspended material and organisms which were derived from the sewage plant. The river is shallow and slow-moving, hence the self-purification of the river is ineffective. Sludge deposits are formed on the bed of the Komu river as a result of sedimentation of the suspended solids and also by flocculation of the colloidal matter and the formation of insoluble humus as a final decomposition product of organic matter. The oxidation of these deposits can go on for very long periods. Sludge deposits owing to their high oxygen demand, adversely affect the self purification of the Komu river by depleting the dissolved oxygen in the water.

Athi river had brown colour along its entire length. The water was less turbid and contained less suspended matter with respect to Komu river. The suspended solids in Athi river were mainly derived from Komu river at their confluence at station A2 (Fig. 3.1a). There was no difference in the physical characteristics of the water between October, 1990 and February, 1991, because the flow of the river is practically constant throughout the year.

Ndarugu and Thiririka rivers exhibited brown colour in both October, 1990 and February, 1991 collections. Their turbidity and suspended matter content were lower than those of the other rivers sampled . The brown colour observed in most of the sampling stations was due to the discharge of liquid organic wastes into the river by the industries and sewage plant.

5.1.1 Temperature

Daily and seasonal temperature fluctuations were noted in the sampled rivers. In October, 1990, the surface water temperature of the area studied varied from 19°C to 22°C. About 65.5% of water samples had a temperature value of 20°C. The average value of the temperature for all surface water samples collected in October, 1990 was 20°C which is the mean annual air temperature of the area studied.

In February, 1991, during the hot and sunny period, the water temperature varied from 22°C to 27°C. The average water temperature (23°C) was higher than that of October, 1990 because the water temperature in the month of February increased with the increase of the air temperature.

5.1.2 pH and Electrical Conductivity

The pH values of the surface water samples presented in Appendix (VII-XI) show that there is no significant difference in pH between the sampled rivers. Although industrial and sewage effluents are discharged in the Thika and Komu rivers, the effect of these wastes on the pH of the water was not much because of the buffering capability of these rivers.

Slight difference in pH between October, 1990 and February, 1991 collections was observed at stations T4 and T5 in the Thika river. This change was due to the variable discharge of industrial effluents into the river.

According to Stumm and Morgan (1981), the pH of the natural water ranges from 6 to 9. The pH values of all the surface water samples are within this range and also within the pH range of 7 to 8.5 for drinking water recommended by WHO (1982). Table 4.6 shows that the pH of the surface water samples has no significant correlation with any of the other parameters determined in this study. In surface waters, the supply of water is ordinarily large in comparison with the solid material available for solution. The pH of the water, therefore may not be greatly affected by the solution of all available ions (Hem, 1959); hence the pH of the surface water will not more closely reflect the influence of the solid material that was available.

There is strong correlation between conductivity and major elements (Table 4.6). The conductivity has direct relationship with the dissolved solids in the water. The highest values of electrical conductivity were for the Komu river where high contents of major elements were also found.

5.1.3 Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

There is a variation in BOD and COD in the sampled rivers (Tables 4.3a and 4.4a). The highest BOD and COD values were for the Komu and Athi rivers. Komu river receives domestic wastes which contain large amounts of organic matter and the Athi river receives polluted water from Komu river. Large amounts of oxygen is demanded to remove organic matter from the water in the processes of decomposition by aerobic bacteria.

The average values of BOD and COD for the month of October, 1990 in the Komu river were 20.8 ppm and 53ppm respectively ; and for February, 1991 collection were 22.6ppm and 55ppm respectively. In Athi river, the average values of BOD and COD for October, 1990 collection were 7.4ppm and 23.6ppm respectively ; and for February, 1991 collection were 7.95ppm and 26ppm respectively.

The World Health Organization (1982) has not set a maximum permissible limit of BOD and COD for drinking water. But some countries have set up standards of BOD for their water. For example , the Ontario Water Resources Commission has set 4ppm as the maximum acceptable BOD of natural waters (Andrews, 1972). The USSR has set 3ppm of BOD as the maximum acceptable limit for drinking water (Chapman , 1992) . In Britain, the standards that have been adopted for river water quality are as illustrated in the following table (Andrews, 1972).

General condition of water	BOD
very clean	1ppm
clean	2ppm
moderately clean	3ppm
of doubtful cleanliness	4ppm
poor	5ppm

According to Chapman (1992), unpolluted waters typically have BOD and COD values of 2ppm and 20ppm or less respectively, whereas those receiving wastewaters may have values up to 10ppm or more for BOD and 200ppm or more for COD. The values found in Komu and Athi rivers are above the values recorded by Chapman

(1992) and the maximum acceptable value of BOD for natural waters set by the Ontario Water Resources Commission. Komu and Athi rivers receive effluents of high BOD and COD levels from the sewage plant.

5.1.4 **Major and Trace Elements**

Pearson's product moment correlation coefficient and factor analysis were employed for the interpretation of the analytical results.

5.1.4.1 **Factor 1**

Factor 1 is statistically dominant and characterised by relatively high loadings of Ca, Mg, Na, K, Mn, Fe, Zn, Ni, Co, Cd, NO_3^- and P (Table 4.7). These elements correlate well with each other, hence they stand out as separate components. They are enriched downstream at the Thika and Komu rivers where agricultural and sewage pollution is the greatest. The association of these elements in Factor 1 is considered to be related to agricultural pollution. Chemical fertilisers and sewage sludge have been applied to the soil for many years. NO_3^-, P, K, Ca and Na are major components of the chemical fertilisers used. The sewage sludge contain considerable amounts of trace elements because during the sewage treatment, trace elements are enriched in the sewage sludge (Chino, et al, 1991).

Calcium and Magnesium

The average values of Ca and Mg in the Thika river for October, 1990 collection were 12.2 ppm and 2.8 ppm respectively. Their average values in the Thika river, for February, 1991 collection were 14.1 ppm and 3.4 ppm respectively (Tables 4.3b and 4.4b). The results of analyses presented in Figures 4.9a and 4.9b show that the Ca and Mg concentration in the Thika river varies locally because of the different agricultural activities along this river. The highest concentrations of Mg and Ca were found downstream at station T2 and T1, areas of large agricultural activities. Water leached from the cultivated soil carries more Ca and Mg ions into the river.

Komu river had the highest average concentration of Ca and Mg compared to the other rivers (Tables 4.3b and 4.4b). The highest values of Ca and Mg were found between station KM1 and station KM4 (Figs. 4.9 c and 4.9 d). The sewage plant discharges effluents which contain considerable quantities of Ca and Mg into the river. Significant amounts of Ca and Mg are derived from the sewage sludge and other suspended solids deposited upstream of station KM1. From station KM4, the concentration decreased to a minimum at station KMO owing to dilution by Ndarugu river (Fig. 3.1a).

Athi river is next to Komu river in terms of the high average values of Ca and Mg (Tables 4.3 b and 4.4 b). The highest values of Ca and Mg were found at station A2 (Figs. 4.9e and 4.9f). These high values were derived from Komu river which joins to Athi river near station A2 (Fig. 3.1a).

The lowest average concentrations of Ca and Mg were found in Ndarugu river (Tables 4.3b and 4.4b). The Ca and Mg concentrations in the Ndarugu river vary very slightly in all the sampling stations (Tables 4.3a and 4.4a). The slight variation of Ca and Mg in this river suggests the lack of other inputs of Ca and Mg ions into the river.

The highest Ca and Mg concentrations in the Thiririka river were found in downstream at station TR1 (Tables 4.3a and 4.4a), the junction of the Thiririka and Ruiru rivers (Fig. 3.1a). Ruiru river has added more Ca and Mg ions into the Thiririka river.

WHO (1982) has proposed 75 ppm for Ca and 150 ppm for Mg as the maximum permissible limits for drinking water. All the surface water samples analysed in this study contained Ca and Mg concentrations below these limits.

Ca and Mg are essential for normal human growth. It has been found in several epidemiological investigations in the USA and European countries that drinking water hardness, i.e. concentrations of Ca and Mg, is inversely associated to cardiovascular mortality in particular, and adults mortality in general (Schroeder, 1960; Crawdford et al., 1968; CEC, 1976; Sonneborne et al., 1983). These investigations have pointed out that the presence of Ca and Mg in the drinking supplies might prove beneficial to humans. But excessive Ca levels in drinking water have under certain conditions also been implicated as factors relating to the formation of kidney or bladder stones in the human body. Mg at high levels has laxative effects, particularly upon those who have never ingested it excessively. High concentrations of Mg in drinking water also cause scouring diseases in livestock (McKee and Wolf, 1972).

Potassium and Sodium

Tables 4.3a and 4.4a show that there is a difference in Na and K concentrations between the sampled rivers. The highest values were found in Komu and Athi rivers. It can also be noted from the results that there is local and seasonal variations of the Na and K concentrations in the rivers.

In Thika river, the K concentration tend to fit the same general trend in both October, 1990 and February, 1991 (Figs. 4.10a and 4.10b). It increases from upstream and reaches a maximum in downstream at station T1 (8.1 ppm for October, 1990 and 12 ppm for February, 1991). The Na concentration in Thika river also follows the same trend in both October, 1990 and February, 1991 collections. It increases from upstream and reaches a maximum at station T5; it then decreases at station T3. This decrease relates to the decrease of the velocity of flow at station T3 where the river meanders.
The Na and K concentration increased again to a maximum at station T1 where water leaching from the cultivated soil carries more K and Na ions into the river.

In Komu river, the Na and K concentrations followed the same trend in both October, 1990 and February, 1991 collections. The highest values were found between stations KM1 and KM4 which are downstream from the point where the Komu river receives the sewage effluents (Figs. 4.10c and 4.10d). This high Na and K values were derived from the sewage sludge accumulated upstream of the station KM1. The concentrations decreased downstream owing to dilution through the Ndarugu river (Fig. 3.1a).

Tables 4.3a and 4.4a show that there is periodical fluctuation of Na and K concentrations in the Ndarugu river. Those Tables also show that there are no significant variations of the Na and K concentrations between the sample stations of the Ndarugu river. This indicates that there are no other inputs of Na and K ions into this river. However, the Na and K concentrations seem to decrease downstream. This decrease relates to the decrease of the velocity of the river downstream.

In Athi river, there is periodical fluctuation of the concentrations of Na and K. The concentrations of these elements in the Athi river tend to fit the same trend in October, 1990 and February, 1991 (Figs. 4.10e and 4.10f). The highest concentrations were found at station A2, near the point where Komu and Athi rivers join. Going downstream the concentrations decrease as the velocity of the river decreases.

The highest values of Na and K were found at station TR1 (Tables 4.3a and 4.4a), the junction of Thiririka and Ruiru rivers (Fig.3.1a). Ruiru river added more Na and K ions into the Thiririka river.

There is no proposed drinking water quality standards for K by WHO (1982). The maximum permissible limit of Na for drinking water is 200 ppm as recommended by WHO (1982). All the surface water samples analysed in this study contained Na values below this limit.

K is an essential nutritional element , however, if presents in excessive quantities it is a cadartic (i.e., at doses of 1 to 2g). The element at levels of 1000ppm to 2000ppm is regarded as the extreme limit that should be allowed in drinking water (McKee and Wolf, 1972). High concentrations of Na have been implicated in hypertension (Sakaki,1964; Shaper et al., 1969; WHO , 1978a).

Iron and Manganese

Tables 4.3a and 4.4a show that there is a difference in Fe and Mn concentrations between the sampled rivers. The highest average values were found in Komu and Athi rivers. The average concentrations of Fe and Mn in the Thika river were considerably higher than those in the Ndarugu and Thiririka rivers (Tables 4.3 b and 4.4 b).

The Fe and Mn concentrations in the Thika river followed the same trend in both October, 1990 and February, 1991 collections (Figs. 4.11a and 4.11b). The highest concentrations were found at Station T1. Water leached from the cultivated soil drains into the river and carries more Fe and Mn ions into the river. The decrease of Fe and Mn at station T3 (where the river meanders) was related to the decrease of the velocity of the river.

The concentrations of Fe and Mn in the Komu river follow the same trend in both October, 1990 and February, 1991 collections (Figs. 4.11c and 4.11d). The highest concentrations were found at station KM1 near the point where the river receives sewage effluents. The concentrations decrease downstream owing to dilution through Ndarugu river.

The Fe and Mn concentrations in the Ndarugu river were found to be the lowest compared to the other rivers (Tables 4.3a and 4.4a). Mn was not detected in any of the samples of this river. The highest value of Fe was found at station ND2 (Tables 4.3a and 4.4a). Water leached from the cultivated soil drains into the river and carries more Fe ions into the river. Going downstream the Fe concentrations decrease as the velocity of the river decreases.

The highest values of Fe and Mn in the Athi river were found at station A2 (Figs. 4.11e and 4.11f). The concentration decreased gradually downstream as the velocity of the river decreases.

The highest Fe and Mn concentrations in the Thiririka river were found at station TR1 (Tables 4.3a and 4.4a), the junction of Thiririka and Ruiru rivers (Fig. 3.1a).

The maximum permissible limits of Fe and Mn in the drinking water are 0.3 ppm and 0.1 ppm respectively, as proposed by WHO (1982). It can be observed from the result (Tables 4.3a and 4.4a) that the concentrations of Fe and Mn in most of the surface water samples exceeded those limits. It is also noted from the results (Figs. 4.10 - 4.11) that there is periodical fluctuation of the major element in all the sampled rivers. In February, 1991, the concentration of elements is high due to lack of rain water which dilutes the pollutants.

High Fe and Mn levels are an objectionable constituent in water supplies used for domestic and industrial purposes. They can affect the taste of beverage and stain laundered clothes and plumbing fixtures (Cohen, 1960). Fe ingestion in large quantities also results in a condition known as haemochromatosis (normal regulatory mechanism do not operate effectively) wherein tissue damage results from Fe accumulation (Hopps, 1972). It has recently been suggested that the presence of Mn in drinking water is inversely related to cardiovascular mortality (Masiron, 1973).

Trace Elements

From the results of analyses, samples taken from most stations contain trace elements. The concentrations of these trace elements are below the maximum permissible limits recommended by WHO (1982) except Cd and Al which exceed these limits for samples collected from the Thika river.

By comparison of concentrations of trace elements, nitrate and phosphorus, station ND4 along Ndarugu river had the lowest relative to the other stations. This is attributed to it's removal from industrial and agricultural centres, as compared to the other sample stations . Thus the input of pollutants in the zone of station ND4 is minimal, bearing in mind that upstream section of the Ndarugu river passes through an agricultural centre. Consequently station ND4 is taken as reference or base station with which the concentrations of trace elements in the other sample stations are normalised with. Concentrations above those of sample taken from ND4 are indicative of pollution though not necessary above the safe levels recommended by WHO (1982).

Zinc

Figure 4.12a shows that Thika river has a wide range of Zn (0.05 - 0.125 ppm) concentration compared to the other sampled rivers. The highest concentration of Zn in the Thika river was found downstream at stations T1 (0.125 ppm) and T2 (0.05 ppm), areas of large agricultural activities (refer to Fig. 4.13a in the Appendix). The concentration of Zn at these stations were well above the background level of Zn (<0.025 ppm) in the studied area. The rain and irrigation water percolating into the soil carry more ions of Zn into the river at these stations.

The concentration of Zn found at certain sample stations in the Komu river (0.05 ppm) is higher than those of the other sampled rivers except Thika river (Fig. 4.12a), and it is above the background level of Zn in the surface water samples of the area studied. The highest concentration of Zn in the Komu river was found between stations KM1 and KM4 (Fig. 4.13a). The concentration decreases downstream at station KMO owing to dilution through the Ndarugu river. The source and pathways of Zn in the Komu river is the sewage sludge deposited upstream of station KM1.

The concentration of Zn in the Athi river is above the background level of Zn in the surface water samples (Fig. 4.12a). The highest concentration of Zn in the Athi river was found at station A2 and A3. More ions were derived from Komu river as Athi and Komu rivers join together near station A2. Going downstream no traces of Zn were found because the concentrations at those sample stations were below the detection limit (0.025ppm).

No traces of Zn were found in Ndarugu and Thiririka rivers (Fig. 4.13a).

The maximum permissible limit of Zn in the drinking water is 5 ppm as recommended by WHO (1982). The Zn concentration in all the surface water samples are below this limit (Fig. 4.12a).

Zn is considered essential for normal human growth, and drinking water is considered to contribute significantly to daily requirements (WHO, 1978b). But high levels of Zn in drinking water are considered toxic to human. Symptoms of Zn toxicity in humans include vomiting, dehydration, abdominal pain and lack of muscular co-ordination (Parasad and Oberleas, 1976b).

Nickel

The average concentrations of Ni in the Thika, Komu, Athi and Thiririka rivers are well above the background level of Ni (0.001 ppm) in the surface water samples of the area studied. The highest average concentration of Ni (0.01 ppm) was found in Komu river (Fig. 4. 12b).

In Thika river, the concentration of Ni in each sample station was above the background (0.001 ppm) of Ni in the surface water samples of the area studied. The highest concentration of Ni was found downstream at station T1 and T2 (refer to Fig. 4.13b in the Appendix). More dissolved ions of Ni were derived from the cultivated soil.

The highest concentration of Ni in the Komu river was found between station KM1 and KM4 (Fig. 4.13b). The values of Ni found at these stations were above the background level of Ni in the surface water samples of the area studied. The source and pathways of Ni in the Komu river is from the sewage sludge deposited upstream of station KM1.

In the Athi river, the highest concentration of Ni was found at station A1 and A2 (Fig. 4.13b). The source and pathways of Ni in this river are presumed to be from Komu river. The concentration decreases downstream as the velocity of the river also decreases.

In Ndarugu river, the Ni concentration in each sample station is 0.001 ppm which is the value considered as the background level. This indicates that there is no other input of Ni in this river.

In Thiririka river, the concentration of Ni in upstream stations was 0.001 ppm which is the background level of Ni in the surface water samples of the area studied. The Ni concentration increases in downstream at station TR1 where Thiririka and Ruiru rivers join (Fig. 4.13b). More Ni ions were derived from Ruiru river.

The maximum permissible limit of Ni in drinking water is 0.1 ppm as proposed by WHO (1982). All the surface water samples of the area studied contained Ni values below this limit (Fig. 4.12b).

The levels of Ni found in natural water are not considered a serious health hazard . However certain nickel compounds have been shown to be carcinogenic in animal experiments (International Agency for Research on Cancer, 1976).

Cobalt

The average concentrations of Co in all sample stations of the rivers studied except certain sample stations in Ndarugu and and Thiririka rivers are above the background level (<0.001 ppm) of Co in the surface water samples of the area studied, meanining that all the rivers were polluted. The highest average concentration of Co (0.0045 ppm) was found in Komu river (Fig. 4.12c in the Appendix).

In Thika river, the concentration of Co in each sample station is above the background level of Co. The highest concentration of Co in this river was found in downstream at stations T1 and T2 (0.008 ppm) (Fig. 4.13c in the Appendix). The source of Co in this river is from the cultivated soil. Water leached from the cultivated soil carries more Co ions into the river.

The highest concentration of Co (0.006ppm) in the Komu river was found at stations KM1 and KM2. The concentration of Co at those two stations was higher than the background level of Co in the surface water samples of the area studied. The concentration decreased downstream at station KMO owing to dilution through Ndarugu river (Fig. 4.13c).

The average concentration of Co in the Athi river (0.0032 ppm) is lower than those of Komu (0.0045 ppm) and Thika rivers (0.004 ppm) and is also higher than those of Ndarugu (0.001 ppm) and Thiririka rivers (0.001 ppm) (Fig. 4.12c). The concentration in each sample station of the Athi river is above the background level of Co in the surface water samples of the area studied (Fig. 4.13c). The Co concentration decreases downstream.

No traces of Co were found in Ndarugu river except station ND2 (Fig. 4.13c). The source of Co at this station is the cultivated soil. Water leaching from the cultivated soil carries more Co ions into the river.

In Thiririka river, the Co concentration remained constant in all the sampled stations (Fig. 4.13 c).

There is no proposed permissible limit of Co in the drinking water by WHO (1982). But some countries like USSR have set 0.1ppm as the maximum acceptable limit for drinking water (Chapman, 1992). All the surface water samples analysed in this study contain Co values below 0.1ppm.

Cadmium

The average concentrations of Cd in the Thika (0.004 ppm) and Komu (0.004 ppm) rivers were higher than that in the Athi (0.002 ppm) river. The average concentration of Cd in Thika, Komu and Athi rivers are above the background level of Cd (<0.001 ppm) in the surface water samples of the area studied (Fig. 4.12d).

In Thika river, the highest concentration of Cd was found at stations T1 and T2, areas of the large agricultural activities (refer to Fig. 4.13 d in the Appendix). Leachate of Cd from the cultivated soil might have caused the high Cd concentration at these stations.

In Komu river, the highest concentration of Cd was found at station KM1 and KM2 (Fig. 4.13 d). The source of Cd in this river is from the sewage sludge deposited upstream of station KM1. The concentration decreased downstream at station KM0 due to dilution through Ndarugu river.

In Athi river, the highest concentration of Cd was found at station A2, near the point where Athi and Komu rivers join (Fig. 4.13 d). The Cd is therefore derived from Komu river. The concentration of Cd in the Athi river decreases downstream.

0.002 ppm of Cd was found in Ndarugu and Thiririka rivers. The value, 0.002 ppm of Cd in the Ndarugu river was found at station ND2 where water percolating through the soil drains into the river. The concentration decreases downstream. The value, 0.002 ppm of Cd in the Thiririka river was found at station TR1 where Thiririka and Ruiru rivers join. Ruiru river carried more Cd ions into the Thiririka river.

The maximum permissible limit of Cd in the drinking water is 0.005 ppm as proposed by WHO (1982). The values found at station T1, T2, T3 and T4 in the Thika river exceed this limit. And the values of Cd at stations KM1 and KM2 in the Komu river coincide with this limit (Fig. 4.13d).

Cd in water is considered a serious health hazard . Where the exposure has been high , as was in the case in Japan in the outbreak of Itai - Itai disease (a bone disease), irreversible renal injury occurred in those most severely exposed, especially in elderly women (Hiatt and Juff ,1975).

Nitrate

The average concentrations of nitrate in all the sampled rivers were above the background level of nitrate (1.2 ppm) in the surface water samples of the area studied. The highest average concentration (33 ppm) was found in the Komu river(Fig. 4.11e).

In Thika river, the average concentration of nitrate (4.84 ppm) is higher than those of the other sampled rivers, except Komu river. Gitathuru tributary added water of high nitrate content (10 ppm) to the Thika river (refer to Fig. 4.13e in the Appendix). But it seems that the water of this tributary has not significantly affected the nitrate level of the Thika river because of dilution. Leachate containing NO_3^- from the cultivated soil might have caused the high NO_3^- level in the Thika river. The NO_3^- concentration in each sample station of the Thika river is above the background level of NO_3^-. The NO_3^- concentration in this river increased downstream at station T1 and T2 following the large application of nitrogenous fertilisers to the soil.

In Komu river, the highest levels of NO_3^- are found at stations KM1 and KM4 (Fig. 4.13e). The source and pathways of NO_3^- in this river is from the sewage wastes which are discharged into the river. The concentration decreased considerably at station KMO due to dilution by Ndarugu river.

The average concentration of NO_3^- in the Ndarugu river (3.08 ppm) is lower than those of the other sampled rivers. The highest concentrations were found upstream, but the concentration decreased downstream stations which are far from agricultural areas. The river is shallow and fast moving thus leading to easy oxygenation by the atmosphere. The river thus purifies itself.

The NO_3^- concentration in each sample station of the Athi river was above the background level of NO_3^- in the surface water samples of the area studied. The highest concentrations were found upstream, where the Athi river joins the Komu river, which had high NO_3^- concentration. The concentration decreased downstream because of the self-purification of the river. In downstream, the river is shallow and fast moving. The water can be easily re-aerated by the atmosphere.

The concentration in each sample station of the Thiririka river was above the background level of NO_3^- in the surface water samples of the area studied. The highest value for NO_3^- in this river was found at station TR1 (Fig. 4.13e). Ruiru river has added more NO_3^- into the Thiririka river.

WHO (1982) has proposed 10 ppm of NO_3^- as the maximum permissible level of NO_3^- in the drinking water. The concentrations of NO_3^- in Thika, Ndarugu and Thiririka rivers are below this limit; but the concentrations found at stations KM2, KM3 and KM4 in the Komu river and stations A1 and A2 in the Athi river are above the permissible level. However, one should bear in mind that even quite low concentrations of NO_3^- may harm microbial life and may influence the essential processes of soil and water chemistry.

Levels of nitrate above 10 ppm can be considered dangerous, since nitrate can be reduced in the stomach to nitrite; nitrite in turn is rapidly absorbed into the blood where it oxidises the iron in haemoglobin to the ferric state, forming methaemoglobin which can be used for the transportation of the oxygen (Keeney, 1982).

Phosphorus:

The average concentrations of P in all the sampled rivers were above the background level of P in the surface water of the area studied. The highest average concentrations were found in the Komu (0.25 ppm) and Athi (0.1 ppm) rivers (Fig. 4.12f).

In Thika river, the average concentration of P (0.006ppm) was higher than those in the Ndarugu (0.003 ppm) and Thiririka (0.0001 ppm) rivers and lower than those in the Komu and Athi rivers. The highest concentration of P in the Thika river was found at station T4 and T5. Water leached from the soil caused the high level of P at those stations. The concentrations decreased downstream owing to dilution through Kabuku and Samuru tributaries (refer to Fig. 4.13f in the Appendix).

The average concentration of P in the Komu river(0.25ppm) was higher than those of the other sampled rivers. The concentration of P in each sample station of this river was above the background level of P (.001) in the surface water samples of the area studied. The highest concentrations were found between stations KM1 and KM4 (Fig. 4.13f). This is due to the discharge of the sewage effluents into the rivers. The concentration decreased to a minimum at station KMO due to dilution through Ndarugu river.

The average concentration of P (0.114ppm) in the Athi river was higher than those of the other rivers except Komu river (Fig. 4.12f). The highest value of P(0.15ppm) in this river was found at station A2, near the point where the polluted Komu river joins the Athi river. The P concentration decreased somewhat downstream, because the river becomes shallow and fast flowing. Therefore the water is easily aerated by the atmosphere which purifies itself.

The average value of P in the Ndarugu river (0.003 ppm) is higher than that of the Thiririka river (0.001 ppm) and is lower than those of the other sampled rivers. The highest concentrations were found upstream. The concentration decreased to a minimum in downstream stations, because these are far from agricultural centres. Self purification of the river which has been explained previously is the cause of the P decrease downstream.

The average value of P in the Thiririka river (0.001 ppm) was lower than those of the other rivers. The highest value was found at station TR1. Ruiru river added more P ions into the Thiririka river.

WHO (1982) has not recommended the maximum permissible limit of P in drinking water; but concentrations above 0.015 ppm can cause algal bloom and eutrophication of rivers (Klein, 1962). Figure 4.13f shows that all samples in the Komu river except sample KM and all the sample stations in the Athi river have concentrations above 0.015 ppm.

5.1.4.2 Factor 2

Factor 2 is statistically dominant and characterized by relatively high loadings for Cu (.71) and Pb (.70) (Table 4.7). There is significant correlation between Cu and Pb. Both Cu and Pb correlate well with the other trace elements except Ni. Cu and Pb have no correlation with the major elements, NO_3^- and P. The association of Pb and Cu in this factor 2 is considered to be indicative of industrial pollution, because they are enriched in the Thika river where industrial pollution is greatest.

Copper

The concentration of Cu in each sample station of the Thika river was higher than those in the other sampled rivers and was above the background level of Cu (<0.05 ppm) in the surface water samples of the area studied (Fig. 4.12g). The highest values were found at station T3, T4 and T5, the area of large industrial activities (refer to Fig. 4.13g in the Appendix). These high values resulted from the direct discharge of industrial effluents into the river. The concentration decreased downstream because of dilution through Kabuku and Samuru tributaries. No traces of Cu were found upstream of Thika river and all the sample stations of Komu, Ndarugu and Thiririka rivers.

In Athi river, only stations A2 and A3 had 0.05 ppm of Cu. The source of Cu at those stations are not yet known. The concentration decreased downstream.

No tracing of Cu were found in Komu, Ndarugu and Thiririka rivers.

WHO (1982) has proposed 1 ppm of Cu as the maximum permissible limit in the drinking water. All the surface water samples of the study area contained concentration of Cu below this limit.

Cu is a gastrointestinal tract irritant and can be highly toxic (NRC, 1977). there are reports of infant mortality and an outbreak of copper poisoning associated with contaminated drinking water (Semple et al., 1960; Walker Smith and Blomfield, 1973).

Lead

The average concentrations of Pb in the Thika river was above the background level of Pb (<0.001 ppm) in the surface water samples of the area studied (Fig. 4.12h). Thika river had the highest average concentration of Pb (0.005 ppm) compared to the other sampled rivers. The Pb concentration found in each sample station of the Thika river was above the background level of Pb in the studied rivers. The highest values (0.009 ppm) were found at stations T4 and T5, areas of large industrial activities. The source and pathways of Pb may be related to direct disposal of industrial wastes into the river. The concentration of Pb decreases downstream due to dilution by Kabuku and Samuru tributaries.

The concentration of Pb in the Komu river range from 0.001 to 0.003 ppm. The concentration at each sample station in this river was above the background level of Pb in the studied rivers. Although sewage effluents are added to the Komu river, the Pb contamination appeared to be relatively low compared to the Thika river. This is due to the adsorption of Pb ions by the large amount of organic and inorganic matter in the Komu river.

In Athi river, the concentration of Pb in all sample stations was lower was than that of the Thika, and Ndarugu rivers. The highest concentrations were found at stations A1, A2 and A3. The Pb ions were derived from Komu river since Athi river receives polluted water from Komu river at station A2 (Fig. 4.13h).

The concentration of Pb in the Ndarugu river range from 0.002 to 0.006 ppm. The highest concentration of Pb (0.006 ppm) was found at station ND2, near a coffee factory (Fig. 4.13h). The source of Pb is from the coffee factory.

In Thiririka river, 0.002 ppm of Pb was found at station TR1, the junction of the Thiririka and Ruiru rivers. Ruiru river has added more Pb ions into the Thiririka river.

The maximum permissible limit of Pb in drinking water is 0.05 ppm as recommended by WHO (1982). The values found in all the surfaces water samples were below this limit.

Pb is a cumulative general metabolic poison . Some of the symptoms of acute poisoning are tiredness , anaemia, irritability and slight abdominal discomfort (WHO , 1977).

5.1.4.3 Factor 3

Factor 3 is statistically dominant and characterized by high positive loading of Al (.84) (Table 4.7). No significant correlation exists between Al and the other elements analysed in this study (Table 4.6). Therefore Al stands out as a separate component. This factor is considered indicative of weathering residues. Toxic metals like Al are released by the decomposition of clay minerals (King et. al. 1974).

The highest average concentrations of Al were found in Thika (0.46 ppm) and Komu (0.45 ppm) rivers. The highest level of Al (2.2 ppm) was found at station KC (refer to Fig. 4.13i in the Appendix). At Thika river, the highest concentrations were found upstream. The values found in Komu river were higher than those found in Thika and the other sampled rivers.

In Ndarugu river, Al values higher than those in the Athi river were found. Al values of 0.1 to 0.2 ppm were found in Thiririka river (Fig. 4.13i).

WHO (1982) has proposed 0.2ppm of Al as the maximum permissible limit in drinking water. The Al contents in samples G2, KC, K, T8, T6, T4, ND4 and all the samples collected from Komu river are above that limit (Fig. 4.12h).

High level of Al has been associated with certain neurological disorders such as dementia (Sorenson ,1974).

5.2 Groundwater

The groundwater supply in the area studied is extracted from both shallow groundwater which flows in highly weathered rocks and deep groundwater in Tertiary volcanic and sediments consisting of basalts, phonolites, shales, sandstone, limestones and grits. The aquifers in the area studied are mainly recharged through infiltration of river waters and atmospheric precipitation. The recharge areas of the aquifers form extensive tracts of valuable agricultural land.

5.2.1 Temperature

The temperature value of all the groundwater samples varied from 20°C to 30°C. The temperature values of the shallow boreholes and springs were lower than those of the deep boreholes, and were near to the mean annual air temperature (19.5°C) of the area studied (Appendix XII). The high value of temperature in the deep boreholes was caused by the effect of pumping.

5.2.2 pH and Electrical Conductivity

The pH value of the groundwater samples ranged from 5.8 to 7.3 (Appendix XII). The pH range of the natural water is 6 to 9 (Stumm and Morgan, 1981). The pH value of most of the groundwater samples falls within this range. Only three samples had pH values below this range. Appendix XII also shows that the pH values of some of the groundwater samples were below the limit of the WHO (1982) permissible range of 7 to 8.5.

The difference in pH values of the groundwater samples depends on several factors such as the chemistry of the groundwater which is influenced by the composition of the aquifers, by human activities and chemical and biological processes occurring during infiltration. The slight acidity (pH 7) of most of the groundwater samples (Appendix XII) was due to the presence of free CO_2 in the groundwater of the Thika area (Gevaerts, 1970). Microbial respiration may increase the CO_2 level in the groundwater, leading the decrease of pH (Hem,1959) There is no significant loading of the pH on all the factors (Table 4.10). Also there is no significant correlation between the pH and any of the other elements analysed in this study (Table 4.9). The pH of the water might change during the sampling and storage because CO_2 can be lost when the water is drown from underground. This changes the pH and consequently disturbs the chemical equilibrium of the water. Therefore the pH can not exactly reflect the dissolved ions in the water (Hem, 1959).

The conductivity of the groundwater ranged from 0.18 to 1.18 $mScm^{-1}$. It is statistically dominant on factor 1(Table 4.10), which will be discussed later. There is strong positive correlation between conductivity and Ca, Na and K (Table 4.9). The highest values of electrical conductivity were found for those boreholes which contain much higher concentration of dissolved species, especially major elements (Table 4.8). It can be said that the conductivity of the groundwater increased with the increase of Ca, Na and K content in the groundwater. Significant amounts of chloride and sulphate in borehole waters of the Thika area have been measured by Gevaerts (1970). The chloride and sulphate might also increase the conductivity of the groundwater.

5.2.3 Factor 1

Factor 1 is statistically dominant and characterized by high positive loadings of Ca, Na, K and electrical conductivity (EC)

(Table 4.10). These elements correlate well with each other, therefore they stand out as a separate component. The high negative loading of trace elements on the factor 1 (Table 4.10) and the weak correlation of the trace elements and major elements (Table 4.9) indicate that the major elements and trace elements were derived from different sources. Since Ca, Na and K make up the major constituents of the rocks, their association in factor 1 can be considered indicative of geological factor. That is to say they were derived from the aquifer materials. A comparison of the surface water and groundwater content of Ca, Na and K indicates that the surface water concentrations of these elements were generally smaller than those in the groundwater. This also suggests that the sources of these elements in the groundwater were situated within the aquifer. Mg was expected to correlate well with Ca, Na and K, but the predominance of Ca, Na and K over Mg in most of the groundwater samples suggests that Ca, Na and K are much more abundant than Mg in the aquifer materials.

Table 4.8 shows that the concentration of Ca ranged from 16 to 102 ppm, Na from 10 to 240 ppm and K from 2 to 180 ppm. The highest concentrations of Ca, Na and K were found in borehole 10 which is deep . In agreement with Gevaerts (1970), the high concentration of these elements in borehole 10 was derived from the lacustrine sediments interbedded with the volcanic rocks.

The maximum permissible limit of Ca in drinking water is 75 ppm as recommended by WHO (1982). The concentration of Ca in certain boreholes of the area studied (Table 4.8) exceeded this limit. The concentration of Na in each borehole water sample except borehole 10 (240 ppm) was found to be lower than the maximum permissible level of 200 ppm for drinking water recommended by WHO (1982). No permissible limit was recommended for K in drinking water by WHO (1982).

5.2.4 Factor 2

Factor 2 is statistically dominant and characterized by high positive loading of K, Mg, Pb, Ni, Co and NO_3^-; Cd also contributes in this factor (Table 4.10). The trace elements Pb, Ni, Co and Cd correlate well with each other.

There is no correlation between these trace elements and K, Mg and NO_3^-, because of their different geochemical behaviour in the groundwater. In the pH range 5.8 -7.4 of the groundwater and in the presence of free CO_2 in this water, the trace elements are largely adsorbed from the water by the hydrolyzate and oxidate sediment and may be removed from the water by precipitation in the form of carbonates. However, the association of these elements in factor 2 suggests that they were derived from a common source which can be related to agricultural activities. K makes an important component of agricultural fertilisers. When fertilisers bearing K are used excessively, they lead to higher concentration of K in the groundwater (Matthess, 1982).

It was found that K dominates both factor 1 and factor 4 (Table 4.10). This suggests that the K in the borehole water samples was derived from aquifer material as well as from chemical fertilisers.

Many coffee and pineapple farmers opted to apply nitrogenous fertilisers to the soil. A most interesting behaviour was also observed in the NO_3^-, as it dominates on other factor (Factor

4). It can be suggested that there was another source of nitrate input to the groundwater.

The concentrations of NO_3^- in the groundwater samples ranged from 1 to 8.75 ppm. The highest concentrations were found at site 1 and the shallow boreholes at Kalimoni and Witeithie villages. The groundwater in those shallow aquifers can easily be contaminated because of the thin cover of soil or its absence in some places over the water bearing material. The water table of these aquifers is very close to the ground-surface, so that the pollutants in the thin soil can easily reach the water table.

The NO_3^- concentration in the deep boreholes was derived from the soil or the uppermost weathered rock through infiltration.

The soils and the weathered rock have already been polluted by chemical fertilisers. Below the ground surface, the effect of weathering extends in some places to a depth of 3 to 4 m as shown in Figure 4.1. The porosity of the upper weathered tuff is relatively high. Its porosity was the result of surface disturbance including human activities like quarrying, and chemical processes. In the deep boreholes both rain and run-off tend to percolate downward into the lower aquifers which are mainly composed of sediments and lavas. Although the amount of the interbedded sediments is not substantial yet the sediments increase the average porosity of the whole sequence.

The piezometric surfaces of the aquifers associated with basalts and phonolite lie below the water table of the upper unconfined aquifers (Gevaerts, 1970). The shallow water not being sealed off may well be running into the deeper aquifers and easily contaminate them.

Both the basalt and phonolite present high permeability which is largely a function of primary and secondary structures within the rock. Joints, fractures and the tabular interflow zones parallel to the flow layers are some of the features that give the phonolite and the basalt their higher permeability, therefore they can easily transmit water.

The NO_3^- concentration in the deep aquifers does not yet appear to have reached danger level. The NO_3^- concentration in each individual sample of the groundwater was below the maximum permissible limit of 10 ppm recommended by WHO (1982) (refer to Fig. 4.14d in the Appendix). However, the NO_3^- concentration might rise in the future, because of the increasingly regular cropping of plants and increasing use of nitrogenous fertilisers in the study area. Serious contamination of NO_3^- might also be possible, because of the possible downward movement of NO_3^- to the water table of the deep aquifers. This major increase in cropping plants associated with the ploughing up of the soil can be another significant factor which causes NO_3^- to leach from the soil.

Pb, Ni, Co and Cd are all seem to be largely of industrial origin. However their association with NO_3^- and K in factor 2 (Table 4.10) suggests that they behave like NO_3^- and K in terms of groundwater contamination.

The sewage treatment plant in the Thika area collects both domestic and industrial effluents. During the waste treatment, considerable amount of trace elements are enriched in the sewage sludge, hence the sludge produced contains significant amount of trace elements.

Sewage sludge and other chemical fertilisers have been spread over the ground for many years. Heavy metal contamination develop if the heavy metal content of the soil layer increases in the course of the sludge and fertiliser application. The regional geology of the area indicates that the basalt and phonolite outcrop in the east (Fig. 2.1), therefore a large amount of recharge of these aquifers must be received on the eastern side of the Athi river. Chemical fertiliser application on these recharge areas can cause contamination by trace elements in deep groundwater. Figure 4.3 c shows that there is considerable thickness of gravel which is highly permeable; heavy metals might be easily transferred by infiltration to the water table of the deep aquifers where the gravel is exposed.

Heavy metals can also be added to the deep aquifers by infiltration of polluted water of the rivers into the adjacent aquifers. Thika and Komu rivers are polluted by sewage and industrial effluents. As these streams flow over the fractured basalt and the phonolite they lose much of their contaminated water by infiltration. Therefore the aquifers associated with the basalt and phonolite can easily be contaminated. The polluted water have a tendency to move into the deep aquifers. It was found from the results that the heavy metal concentration of the groundwater was generally below those of the surface water samples. In the pH range of the groundwater samples analysed in this study (Appendix VIII), the trace elements are absorbed onto the aquifer materials especially the sediments and they also precipitate in the form of carbonates. The concentration of the heavy metals in the groundwater are also reduced by the admixture of surface water and deeper groundwaters.

Lead was found to be present in all the groundwater samples except samples 1 and 33. The quantities found averaged from a minimum of 0.001 ppm to a maximum of 0.006 ppm with a fairly even distribution in between. However, in all cases, the Pb concentration in each individual sample of the groundwater was lower than the 0.1 ppm level set by WHO (1982) as the maximum permissible level for drinking water (refer to Fig. 4.14a in the Appendix). Ni was found to be present in all the groundwater samples. The quantities found averaged from a minimum of 0.001 ppm to a maximum of 0.005 ppm with a fairly even distribution in between (refer to Fig. 4.14b in the Appendix). The Ni concentration in each individual sample of the ground water is lower than the 0.1 ppm level set by WHO (1982) as the maximum permissible limit for drinking water. Co was present in all the groundwater samples, except for boreholes 19 and 20 (refer to Fig. 4.14c in the Appendix). The

highest values of Co were found in the shallow borehole waters. The maximum permissible level of Co in the drinking water is not given in the WHO (1982) standards.

The Cd concentrations in most of the borehole water samples are below the maximum permissible level (0.005 ppm) recommended by WHO (1982); but the Cd concentration of certain samples coincide with this limit (refer to Fig. 4.14d in the Appendix).

5.2.5 Factor 3

Factor 3 is statistically dominant and characterized by high positive loading of Al, Mn and Fe, and significant negative loading of Zn and Cu (Table 4.10). Mn and Fe have no correlation with Zn and Cu. Al has no correlation with Zn, Cu, Mn and Fe because of their different geochemical behaviour and origin in the groundwater. The groundwater in the Thika area contains excess fluoride (Gevaerts, 1970). Al forms strong insoluble complexes with the fluoride ions in the water (Matthess, 1982; Hem, 1959).

Al was not detected in most of the groundwater samples. Some shallow boreholes contain Al at a level higher than the maximum permissible limit of Al (0.2 ppm) in drinking water recommended by WHO (1982) (Fig. 4.8e). This high concentration of Al in the shallow wells was derived from the extensively weathered rocks at the ground surface. The Mn concentration in the groundwater samples ranged from 0.001 to 2.4 ppm. The Fe level in the groundwater ranged from 0.06 to 2.8 ppm. Table 4.8 shows that most of the borehole water samples in the area studied contained concentrations of Fe and Mn higher than the maximum permissible levels of Fe (0.3 ppm) and Mn (0.2 ppm) recommended by WHO (1982).

Zn and Cu concentrations in certain sample stations reach upto 1.3 ppm and 0.005 ppm respectively. In most of the groundwater samples the Zn and Cu contents were below their detection limits probably because of the adsorption of Zn and Cu ions onto clay minerals.

The concentrations of Zn and Cu in each individual borehole water sample were below the maximum permissible limits of Zn (5ppm) and Cu (1ppm) in drinking water recommended by WHO (1982) (refer to Figs. 4.14f and 4.14g in the Appendix).

5.2.6 **Factor 4**

Factor 4 is statistically dominant and characterized by positive loading of NO_3^-. Phosphorus also contributes in this factor (Table 4.10). No significant correlation was found between NO_3^- and P (Table 4.9) because of their different chemical behaviour in groundwater. P moves extremely slowly through the soil and is largely adsorbed onto clay minerals. The association of NO_3^- and P in this factor can be considered indicative of pollution from domestic wastes, as they are enriched in the shallow boreholes at Kalimoni and Witeithie villages (refer to Fig. 4.14d and Fig. 4.14i in the Appendix). In these villages, the dug wells penetrate only a short distance into the rock. Groundwater in these villages is drawn by means of buckets from a depth of 0.5 to 1 m. The wells in the Witeithie village are not covered and not protected against direct storm run-off that enters through the well or domestic wastes which derive from the septic tanks which are very close to hand-dug wells.

In Kalimoni Estate, the water is supplied by almost 10 hand-dug wells of 2 to 3 m deep and a diameter of 1m. The wells are protected by wood cover. The depth to water table is less than 1m below the ground surface. It has been established that the water table is subjected every season to periodic fluctuation in the level. During the rainy seasons it rises, reflecting major discharge of the springs in the area studied whereas it falls in the dry season. In February, 1991, during the second sampling exercise high concentrations of contaminants are expected in the water due to lack of rainwater to dilute the element concentration.

Since the shallow boreholes at Witeithie and Kalimoni villages have been drilled in the courtyards of the houses, the P and NO_3^- contamination of the groundwater in the shallow aquifers can be confidently attributed to domestic wastes.

5.3 Sewage Waste and Trace Elements

Though the sewage plant receives effluents from many industries, it was noted from the results of the laboratory analysis that the trace element concentration in the sewage was lower than what would be expected (Table 4.2 c).

The algal bloom and available nutrients in the sewage may act as extremely effective agents for concentrating heavy metals in the bottom sediments. Sedimentation of the metals may also be enhanced as a result of adsorption by sewage particles and elevation of the ambient pH owing to photosynthesis which would thereby promote more efficient adsorption by particulate matter. Any carbonate precipitation caused by photosynthetic activity would also promote this process.

Above all production of H_2S and reduction of algal organic matter would together tend to immobilise trace elements and trap them into the mud as complexes.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

The analyses of both surface and groundwater samples from the study area indicate that the quality of the surface water, particularly Thika and Komu rivers, is affected by anthropogenic processes. The physical and chemical properties of the waters in the Thika, Komu and Athi rivers were modified by sewage and industrial effluents discharged into the rivers.

The BOD and COD values in each sample station of the Komu and Athi rivers are above the values of BOD (2ppm) and COD (20 ppm) for unpolluted natural waters indicated by Chapman (1992).

The pH values of all surface waters fell within the acceptable range of 7 to 8.5 for drinking water as proposed by WHO (1982). But the pH values of certain borehole waters were below the lower limit of this range.

The concentrations of major elements in the rivers of the area studied vary with season. The highest concentrations were found in February, 1991 because water leaching from the soil carries more dissolved ions into the rivers.

Factor analysis indicates a division of the surface water data into three groups and those of the groundwater into four groups, consistent with anthropogenic or pedogenic processes in the study area.

6.1 Surface Water

The first factor contained species which have contributed to pollution as a consequence of fertiliser application to soil. These include Ca, Mg, Na, K, Mn, Zn, Ni, Co, NO_3^- and P. The trace elements originate from sewage sludge which has been used as soil fertiliser for many years.

The Thika and Komu rivers were more polluted in their downstream reaches relative to the other sampled rivers, due to the large industrial and agricultural activities in the case of Thika river and the sewage plant effluents, in the case of Komu river. The concentrations of these elements preponderate on factor 1.

The second factor contained elements with high concentrations that can be traced to industrial processes. These elements include Cu and Pb. The highest concentrations of these elements were found in Thika river and is a reflection of the direct discharge of industrial effluents into the river.

The concentrations of trace elements in Komu river were lower than those in the Thika river due to the large amounts of organic and inorganic particulates from the sewage into the Komu river. Trace elements are largely adsorbed by these particulates. The concentrations of Cu and Pb observed in all the surface water samples were below the maximum permissible limits proposed by WHO (1982).

The third factor contained only Al which can be related to the decomposition of weathered rocks . The concentration of Al in most of the surface water samples was above the maximum permissible limit proposed by WHO (1982).

6.2 Groundwater

The first factor comprises elements which except for Mn can be related to local lithology. These elements include Ca, Na and K. Na content in all the groundwater samples was below the maximum permissible level of the WHO (1982) standards. But the concentration of Ca in certain borehole waters was found above the maximum permissible level proposed by WHO (1982).

The second factor contained elements which have contaminated the soil as a consequence of fertiliser application. These elements include K, Mg, Pb, Ni, Co, Cd and NO_3^-. The concentration of these elements in the shallow boreholes were higher than those in the deep boreholes, but were nevertheless below the maximum permissible levels proposed by WHO (1982).

The third factor contained elements which accumulate in weathering residues. These elements are Al, Mn, Fe, Zn and Cu. Zn and Cu concentrations in all the groundwater samples were below the maximum permissible levels proposed by WHO (1982). Al, Mn and Fe concentrations in certain borehole water samples were found above the maximum permissible limits of the WHO (1982) guidelines.

The fourth factor comprises elements which are considered to be derived from domestic wastes. These elements include NO_3^- and P. The highest concentrations were found in the shallow boreholes at Kalimoni and Witeithie villages. Their concentrations in all the groundwater samples were below the maximum permissible levels set by WHO (1982).

Though the groundwater under the area studied is mainly recharged by the surface water, the effect of the surface water on the groundwater quality seems extremely small due to the many geochemical processes such as sorption, ion exchange and dilution which take place in the aquifers.

Since no boreholes were identified near the solid waste disposal site, the effect of the solid waste disposal method on the groundwater quality is not yet understood. Therefore further investigation is needed to understand this.

6.3 RECOMMENDATIONS

As a result of the research carried out in the area of study, the following recommendations were considered necessary to avoid pollution and to adopt more effective and environment-conscious approach to the problem of waste disposal in the Thika area.

1) The industrial liquid effluents should be treated and disposed of in a series of treatment (stabilisation) pools before being allowed to discharge into the rivers. It can be recommended that a technical inspection be made within the industries with a view to reducing the amount of waste to the minimum. It can be proposed that systematic and rigorous control be exercised from the point of disposal to other downstream points, with the aim of analysing the behaviour of the effluents.

2) Trace elements and nitrate pose serious threat to both plant animal life. Sewage sludge and fertilisers are the main source of trace elements and nitrate in the Thika area. They should be used with caution especially in agriculture. It is important that the sludge and fertilisers are tested before application to farms; to determine the level of trace elements and nitrate.

This will determine the deference of applying or not applying to soil.

3) As the shallow wells of the area is mainly contaminated by toilets and infiltration of surface run - off, the following procedures are proposed to safeguard the water in the wells:
i) Toilets must be constructed with insulated walls.
ii) The wells must be covered and protected against infiltration of surface run - off into the aquifers through the well.
iii) The water in the wells must be treated with chlorine to disinfect the water.
iv) some deep wells containing potable water must be drilled to supply the population.
v) The water of all wells must be regularly monitored by the public health authorities.

4) The government should provide legal and administrative protection for the quantity and quality of the natural water resources in a set of measures and laws contained in the water law and health code, both of which should form part of the constitution, thus guaranteeing the best possible basis for the development of our population, agriculture and industry.

5) Many industries and some other institutions have misused the present Kang´oki Waste Disposal site. Therefore proper supervision and sound control of methods of waste disposal at this site by the City Council is recommended.

6) The construction of a series of test wells is recommended near the waste disposal site in order to understand the behaviour of pollutants in the groundwater.

7) Sanitary landfill is recommended as the best way of disposing solid waste of the area studied in order to reduce the spread of wastes over a wide area, and the bad smell and flies created by today's waste disposal system.

8) The wastes must not be disposed on the recharge areas where the basalts and phonolites outcrop.

9) Finally further studies on the content of bacteria as well as concentrations of other toxic elements such as Hg, As, etc, in the soil, surface and groundwaters are recommended.

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APPENDIX I

Mean monthly discharge(m^3/s) of the Thika river recorded for 10 years

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	2.125	2.252	1.953	2.314	2.156	2.422	2.634	2.515	2.196	2.474
February	0.925	0.845	0.935	0.945	0.885	1.263	1.562	1.756	1.642	1.245
March	0.563	0.932	0.647	0.853	0.648	0.958	0.845	0.527	0.615	0.539
April	2.654	2.746	3.268	2.747	2.564	3.294	3.225	2.245	2.185	2.194
May	8.564	8.435	8.846	8.862	7.984	7.759	8.642	7.953	7.593	7.775
June	10.34	9.564	10.23	10.42	10.62	10.15	9.854	10.12	9.175	9.563
July	4.576	4.643	4.784	4.573	4.832	5.342	4.341	4.569	4.184	4.382
Augost	2.768	2.863	2.759	2.542	2.783	3.129	2.195	2.634	2.559	2.284
Septemb.	2.654	2.756	2.649	2.582	2.647	3.282	2.374	2.558	2.465	2.749
October	4.965	5.198	5.537	5.446	5.552	5.683	5.558	4.285	4.338	4.275
November	6.465	6.673	7.638	6.843	6.542	7.194	6.463	6.176	6.372	6.634
December	4.435	4.563	4.573	4.284	4.462	5.183	4.825	4.579	4.495	4.748

APPENDIX II

Mean monthly discharge(m^3/s) of the Athi river recorded for 10 years

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	3.125	3.567	3.432	2.885	3.328	3.968	3.953	2.989	3.673	2.958
February	1.525	1.756	1.249	1.258	1.689	2.484	2.442	1.953	2.282	2.436
March	0.953	0.969	1.026	1.212	1.486	2.125	1.246	0.945	0.866	1.125
April	4.425	4.535	4.692	4.321	4.692	5.682	5.868	4.787	5.372	5.483
May	11.56	10.96	10.78	10.43	10.76	11.23	10.27	10.64	10.93	10.55
June	12.23	12.36	12.83	11.68	11.76	12.86	12.12	11.74	11.46	11.67
July	5.454	5.793	5.984	4.995	5.685	6.762	6.239	5.734	5.768	4.985
Augost	4.252	4.876	4.647	4.475	4.842	5.683	5.522	4.869	4.678	4.958
Septemb.	4.753	4.956	5.242	4.868	5.233	5.395	5.285	4.874	5.436	4.942
October	5.654	5.856	5.942	5.665	5.656	5.316	5.425	5.854	5.785	5.953
November	8.753	8.946	9.126	8.964	8.764	9.634	8.764	8.537	8.785	9.134
December	5.852	6.125	5.784	5.659	5.795	5.946	6.324	5.845	5.692	5.786

APPENDIX III

Mean monthly discharge(m^3/s)of the Thiririka river recorded for 10 years

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	0.968	0.953	0.865	0.893	0.946	0.863	0.896	0.964	0.945	0.894
February	0.543	0.496	0.535	0.486	0.537	0.516	0.489	0.522	0.496	0.545
March	0.455	0.465	0.512	0.476	0.432	0.463	0.485	0.476	0.495	0.574
April	1.682	1.964	1.876	2.234	1.896	1.973	1.674	2.353	2.337	1.987
May	5.254	5.455	4.968	5.227	5.473	5.543	5.284	4.869	5.483	5.479
June	5.995	6.253	6.249	5.788	5.969	5.885	5.795	5.763	6.435	6.397
July	1.736	1.684	1.534	2.143	1.968	1.876	1.749	2.118	1.895	1.659
Augost	1.432	1.296	1.385	1.456	1.569	1.686	1.495	2.276	1.985	1.996
Septemb.	1.289	1.198	0.995	1.228	1.354	0.985	1.258	1.374	1.493	1.674
October	1.945	2.225	1.789	1.689	1.789	1.989	2.176	1.438	1.789	1.885
November	2.276	2.453	1.988	2.131	2.348	2.184	2.374	2.235	2.458	2.685
December	1.898	1.784	1.234	2.223	2.142	1.543	1.845	1.689	1.994	2.168

APPENDIX IV

QUESTIONNAIRES DEVELOPED DURING THE EXAMINATION OF WASTE DISPOSAL METHOD IN THE STUDY AREA

1) What kind of sewage treatment facilities do you have?

2) What is the amount of waste that enters the sewage treatment plant?

3) How do the sewage treatment plant operate?

4) Are there any problems associated with the sewage treatment plant?

5) What methods are used to remove suspended solids and nutrients like phosphorus?

6) Are the wastes recycled and what methods are used to recycle?

7) Are there any rivers or lakes near your community that are polluted by the Sewage waste?

8) Is your community making plans for better treatment of its sewage?

9) What type and amount of waste is produced by your community?

10) What methods are used to dispose of municipal waste?

11) What are the effects of the method of waste disposal on the environment?

APPENDIX V

Physical and chemical parameters of sewage and industrial effluents of Thika area (Samples collected in october, 1990).

sample no. parameter	SW1	SW2	SW3	SW4	SW5	SW6	EF1	EF2	EF3
$T^{o}C$	22	22	22	22	22	22	25	25	25
pH	8.5	8.5	8.2	8.1	7.9	7.9	7.4	5.1	8.3
EC(mS.cm^{-1})	.58	.58	.62	.59	.55	.41	4.42	1.15	6.70
color	all grey						Yel-low	all grey	
Turbidity	ALL HIGH								
Suspended solid	ALL HIGH								
Organic matter and/or Micro-organisms	ABUNDANT FOR ALL								

Range and average values of temprature(^{0}C),pH and EC(mS.cm^{-1})

	$T^{o}C$	pH	EC
range	22	7.9-8.5	.41-.62
average	22	8.2	.56

Legend for sample abbreviations
SW1– outlet
SW2– maturation
SW3– tertiary
SW4– secondary
SW5– primary
SW6– inlet
EF1– from waste disposal site
EF2– from Kenya paper mill
EF3– from leather industry

APPENDIX VI

Physical and chemical parameters of sewage and industrial effluents of Thika area (Samples collected in February, 1991).

sample no. parameter	SW1	SW2	SW3	SW4	SW5	SW6	EF1	EF2	EF3
T °C	29	29	29	29	29	29	30	30	30
pH	7.9	7.9	8.2	8.1	7.9	7.9	7.4	5.1	8.3
EC (mS.cm^{-1})	.58	.50	.57	.55	.60	.58	4.50	1.15	6.55
Color	all grey								
Turbidity	ALL HIGH								
Suspended solid	ALL HIGH								
Organic matter and/or Micro-organisms	ABUNDANT FOR ALL								

Range and average values of tempreture(°C),PH and EC(mS.cm^{-1}).

	T°C	pH	EC
range	29	7.9-8.2	.50-.60
average	29	7.98	.56

APPENDIX VII(A)

Water quality parameters of the Thika river and its tributaries for the month of October, 1990.

Parameters	T_8	T_7	T_6	T_5	T_4	T_3	T_2	T_1	G_1	G_2	K_C	S	K
	SAMPLE STATION												
T ^{o}C	18	19	21	20	20	20	21	22	19	20	21	22	21
EC(mS.cm^{-1})	.07	.08	.09	.11	.13	.11	.13	.12	.10	.10	.14	.20	.17
pH	7.4	7.1	7.0	6.8	6.8	7.1	7.1	7.	7.0	7.1	7.0	7.1	7.1
Colour	B	B	B	RB	RB	RB	B	B	B	B	B	G	B
Turb.	M	H	L	H	H	M	M	M	H	H	H	H	H
SS	M	M	L	H	H	H	M	M	M	M	H	H	M
+ water V.	M	M	M	M	M	L	M	M	M	M	L	L	L
* org.mat. & orgs.	S	S	S	A	A	A	S	S	S	S	S	S	S

Range and average values of temperature, EC and pH for October,1990 collections.

	T (^{o}C)	EC (mS.cm^{-1})	pH
Range	18-22	.07-.20	6.8-7.4
Average	20.1	.11	7.1

B---brown
RB- reddish brown
G-- grey
M---moderate
H---high
L---low
S---scarce
A---abundant
SS-- suspended solids
Turb.-- turbidity
\+ water velocity
* organic matter and organisms

APPENDIX VII(B)

Water quality paramters of the Thika river and its tributaries for the month of February, 1991.

Paramet-ers	Sample stations												
	T_8	T_7	T_6	T_5	T_4	T_3	T_2	T_1	G_1	G_2	K_C	S	K
T °C	25	24	25	24	24	24	25	22	25	24	24	24	23
EC(mS.cm^{-1})	.15	.10	.10	.15	.13	.18	.18	.19	.09	.09	.21	.28	.22
pH	7.4	7.5	6.9	6.9	7.2	7.0	7.3	7.4	7.6	7.1	7.2	7.1	7.4
Colour	B	B	B	RB	RB	RB	B	B	B	B	B	G	B
Turb.	H	H	M	H	H	M	M	M	H	H	H	H	H
SS	M	M	M	H	H	H	M	M	M	H	H	H	H
water V.	M	M	M	M	M	L	M	M	M	M	L	L	L
org. mat. & orgs.	S	S	S	A	A	A	S	S	S	S	S	S	S

Range and average values of temperature, EC and pH for February,1991 collection.

	T (°C)	EC (mS.cm^{-1})	pH
Range	22-25	.10-.19	6.9-7.5
Average	24.1	.15	7.2

APPENDIX VIII(A)

Water quality parameters of Komu river for the month of October, 1990

Parameters	Sample station					
	KM	KM_1	KM_2	KM_3	KM_4	KM_O
T °C	20	20	20	20	20	20
EC(mS.cm^{-1})	.25	.50	.49	.49	.49	.12
pH	7.0	7.5	7.6	7.5	7.5	7.2
Colour	G	G	G	G	G	B
Turb.	H	H	H	H	H	M
SS	M	H	H	H	H	M
water V.	-	L	L	L	VL	M
org. mat. & orgs.	A	A	A	A	A	A

Range and average values of temperature, EC and pH for October ,1990 collection.

	T (°C)	EC (mS.cm^{-1})	pH
Range	20.0	.12-.50	7.2-7.6
Average	20.0	.39	7.4

APPENDIX VIII(B)

Water quality parameters of Komu river for the month of February, 199

Parameters	Sample station					
	KM	KM_1	KM_2	KM_3	KM_4	KM_O
T °C	24	22	23	25	25	24
EC(mS.cm^{-1})	.26	.40	.40	.41	.42	.26
pH	7.2	7.4	7.4	7.4	7.5	7.2
Colour	G	G	G	G	G	B
Turb.	H	H	H	H	H	M
SS	M	H	H	H	H	M
water V.	S	VL	VL	VL	VL	M
org.mat. & orgs.	A	A	A	A	A	S

Range and average values of temperature, EC and pH for February,1991 collection.

	T (°C)	EC (mS.cm^{-1})	pH
Range	22-25	7.2-7.5	.26-.42
Average	23.8	7.35	.36

APPENDIX IX(A)

Water quality parameters of Ndarugu river for the month of October, 1990.

	Sample station			
Parameters	ND_1	ND_2	ND_3	ND_4
T °C	20	21	20	21
EC(mS. cm^{-1})	.09	.10	.09	.09
pH	7.1	7.3	7.2	7.2
Colour	B	B	B	B
Turb.	M	M	L	L
SS	M	M	L	L
water V.	M	M	M	M
org. mat. & orgs.	S	S	S	S

Range and average values of temperature, EC and pH for October,1991 collection.

	T (°C)	EC (mS. cm^{-1})	pH
Range	20-21	0.09-0.10	7.1-7.3
Average	20.5	0.09	7.2

APPENDIX IX(B)

Water quality parameters of Ndarugu river for the month of February, 1991.

	Sample station			
Parameters	ND_1	ND_2	ND_3	ND_4
T °C	20	21	20	21
EC(mS.cm^{-1})	.09	.10	.09	.09
pH	7.1	7.3	7.2	7.2
Colour	B	B	B	B
Turb.	M	M	L	L
SS	M	M	L	L
water V.	M	M	M	M
org. mat. & orgs.	S	S	S	S

Range and average values of temperature, EC and pH for February,1991 collection.

	T (°C)	EC (mS.cm^{-1})	pH
Range	22-24	0.09	7.0-7.2
Average	22.8	0.09	7.1

APPENDIX X(A)

Water quality parameters of Athi river for the month of October, 1990.

Parameters	Sample station				
	A_1	A_2	A_3	A_4	A_5
T °C	21	19	20	21	20
EC(mS.cm^{-1})	.13	.21	.22	.21	.20
pH	7.1	7.1	7.0	6.9	6.9
Colour	B	B	B	B	B
Turb.	M	H	H	M	M
SS	M	H	H	M	M
water V.	H	H	M	M	M
org.mat. & orgs.	S	A	S	S	S

Range and average values of temperature, EC and pH for October,1990 collection.

	T (°C)	EC (mS.cm^{-1})	pH
Range	19-21	0.13-.22	6.9-7.1
Average	20.2	0.194	7.0

APPENDIX X(B)

Water quality parameters of Athi river for the month of February,1991.

	Sample station				
Parameters	A_1	A_2	A_3	A_4	A_5
T^oC	24	25	26	25	25
EC($mS.cm^{-1}$)	.12	.36	.37	.37	.37
pH	7.1	7.5	7.6	7.1	7.1
Colour	B	B	B	B	B
Turb.	M	H	M	M	M
SS	M	H	M	M	M
water V.	M	H	M	M	L
org.mat. & orgs.	S	A	S	S	S

Range and average values of temperature, EC and pH for February,1991 collection.

	T (^oC)	EC ($mS.cm^{-1}$)	pH
Range	24-26	0.12-.37	7.1-7.6
Average	25.0	0.32	7.3

APPENDIX XI(A)

Water quality parameters of Thiririka river for the month of Octo
1990.

Parameters	Sample station		
	TR_1	TR_2	TR_3
T °C	20	20	20
EC(mS.cm^{-1})	.12	.10	.10
pH	7.1	7.0	7.0
Colour	B	B	B
Turb.	M	M	M
SS	M	M	M
water V.	M	M	M
org. mat. & orgs.	S	S	S

Range and average values of temperature, EC and pH for October , collection.

	T (°C)	EC (mS.cm^{-1})	pH
Range	20	0.10-.12	7.0-7.1
Average	20.0	0.11	7.03

APPENDIX XI(B)

Water quality parameters of Thiririka river for the month of February, 1991.

	Sample station		
Parametres	TR$_1$	TR$_2$	TR$_3$
T °C	24	25	25
EC(mS.cm^{-1})	.12	.10	.10
pH	7.5	7.2	7.1
Colour	B	B	B
Turb.	M	M	M
SS	M	M	M
water V.	M	M	M
org.mat. & orgs.	S	S	S

Range and average values of temperature, EC and pH for February,1991 collection.

	T (°C)	EC (mS.cm^{-1})	pH
Range	24-25	0.10-.12	7.1-7.5
average	24.7	0.11	7.3

APPENDIX XII

Water quality parameters of the groundwater samples (February, 1991)

sample station	T°C	EC(mS.cm^{-1})	pH	colour	organic matter
1	20	.18	7.3		scarce
2	27	.54	7.2		"
3	20	.25	5.9		"
4	19.5	.48	7.2	grey	little
5	20	.48	5.8	grey	"
6	20.5	.38	7.1	grey	"
7	20	.80	5.8		scarce
8	30	.43	6.9		"
9	35	.32	7.9		"
10	30	1.18	6.9		"
11	27	.58	7.1		"
12	28	.29	6.4		"
13	29	.31	6.3		"
14	31	.33	6.5		"
15	28	.35	6.3		"
16	27	.26	6.9		"
17	30	.24	6.9		"
18	30	.36	7.4		"
19	31	.39	6.1		"
20	29	.61	6.9		"
21	31	.42	7.4		"
22	20	.57	6.8		"
23	27	.33	7.1		"
24	21	.31	6.9		"
25	26	.88	6.8		"
26	31	.35	7.1		"
27	26	.25	7.1		"
28	20	.38	6.9		"
29	21	.26	6.9		"
30	20	.28	7.1		"
31	24	.58	7.1		"

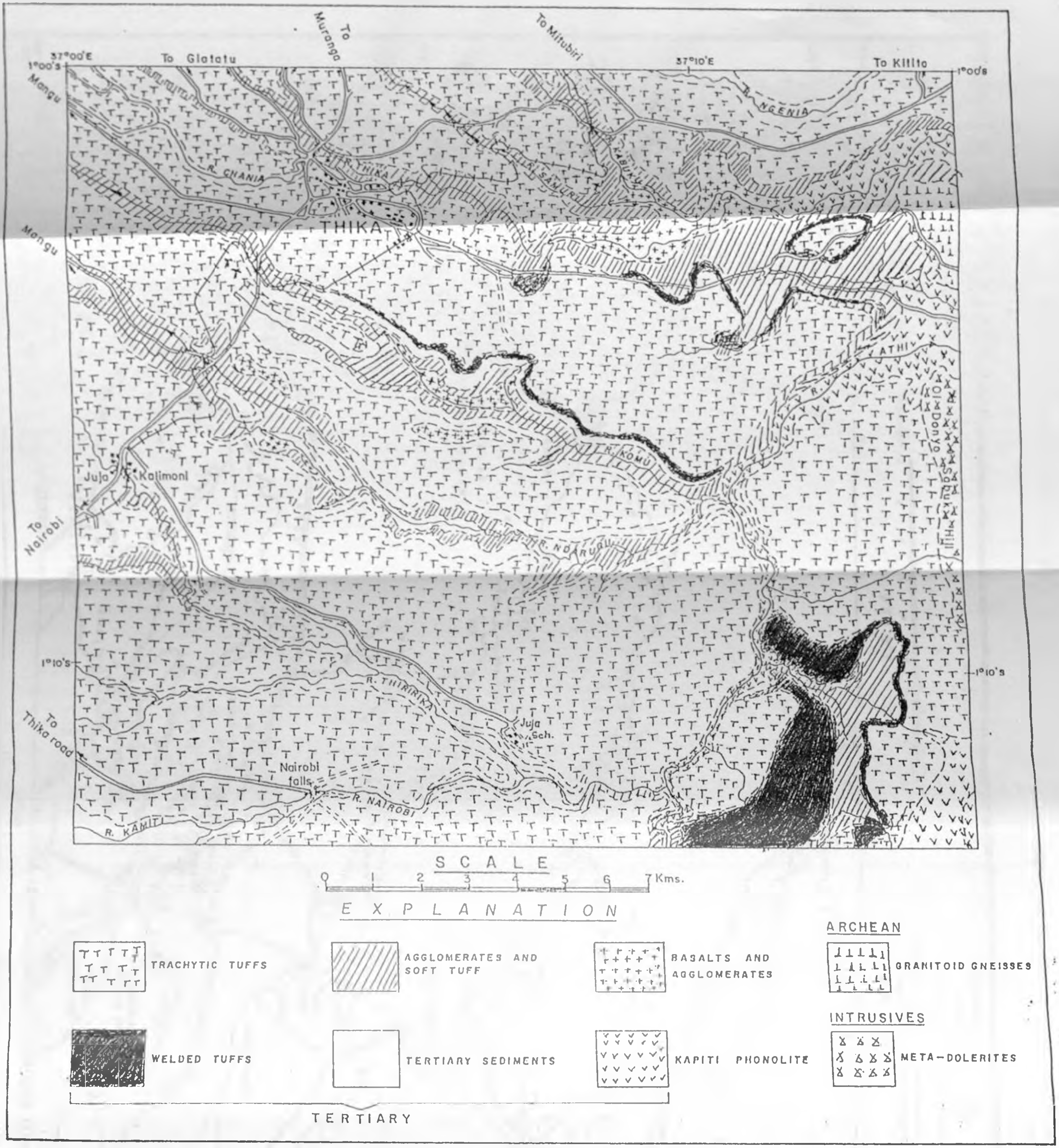


FIG. 2.1: GEOLOGICAL MAP OF THE STUDY AREA

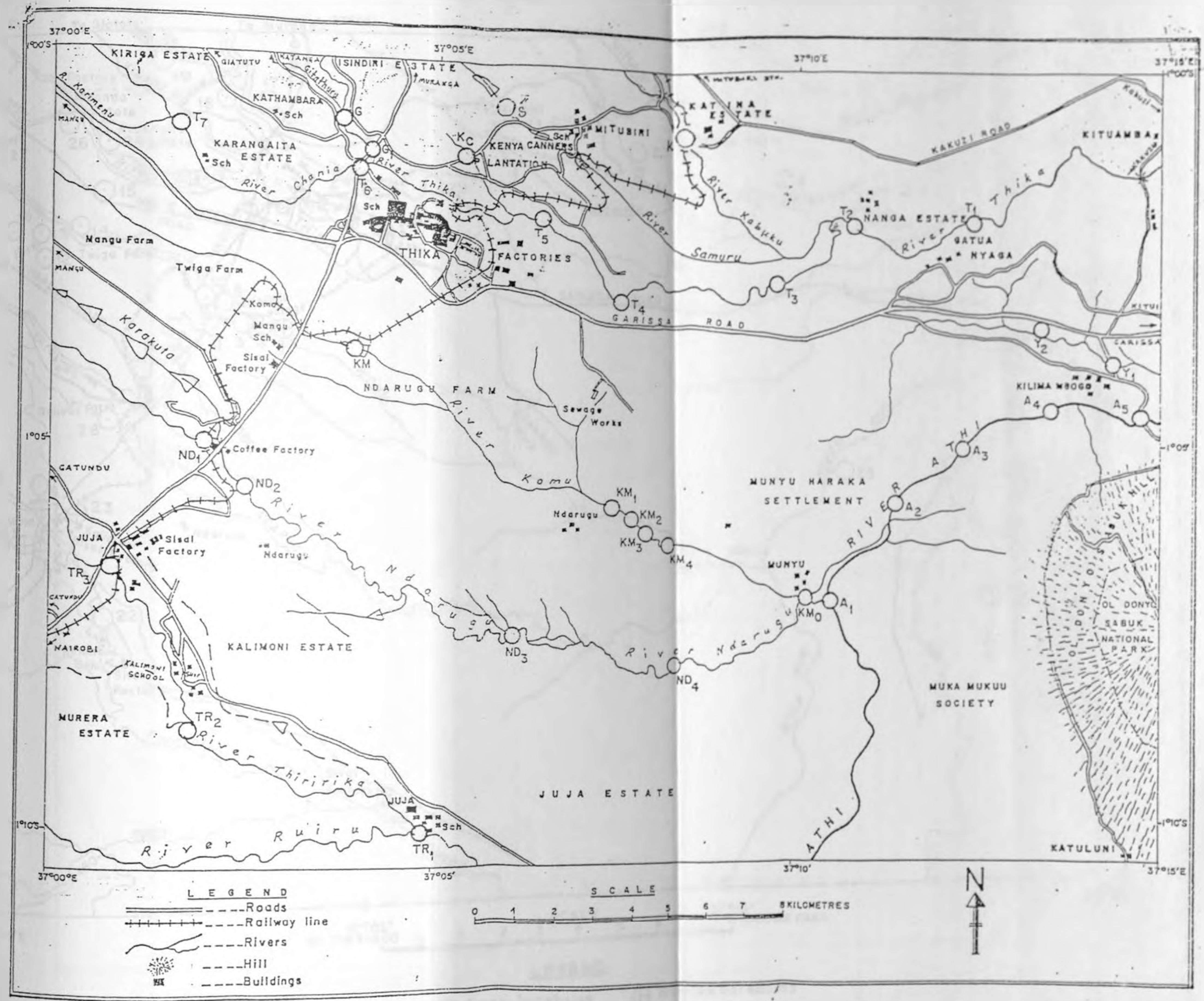


Fig. 3.1(a)
Sample stations for the surface water.

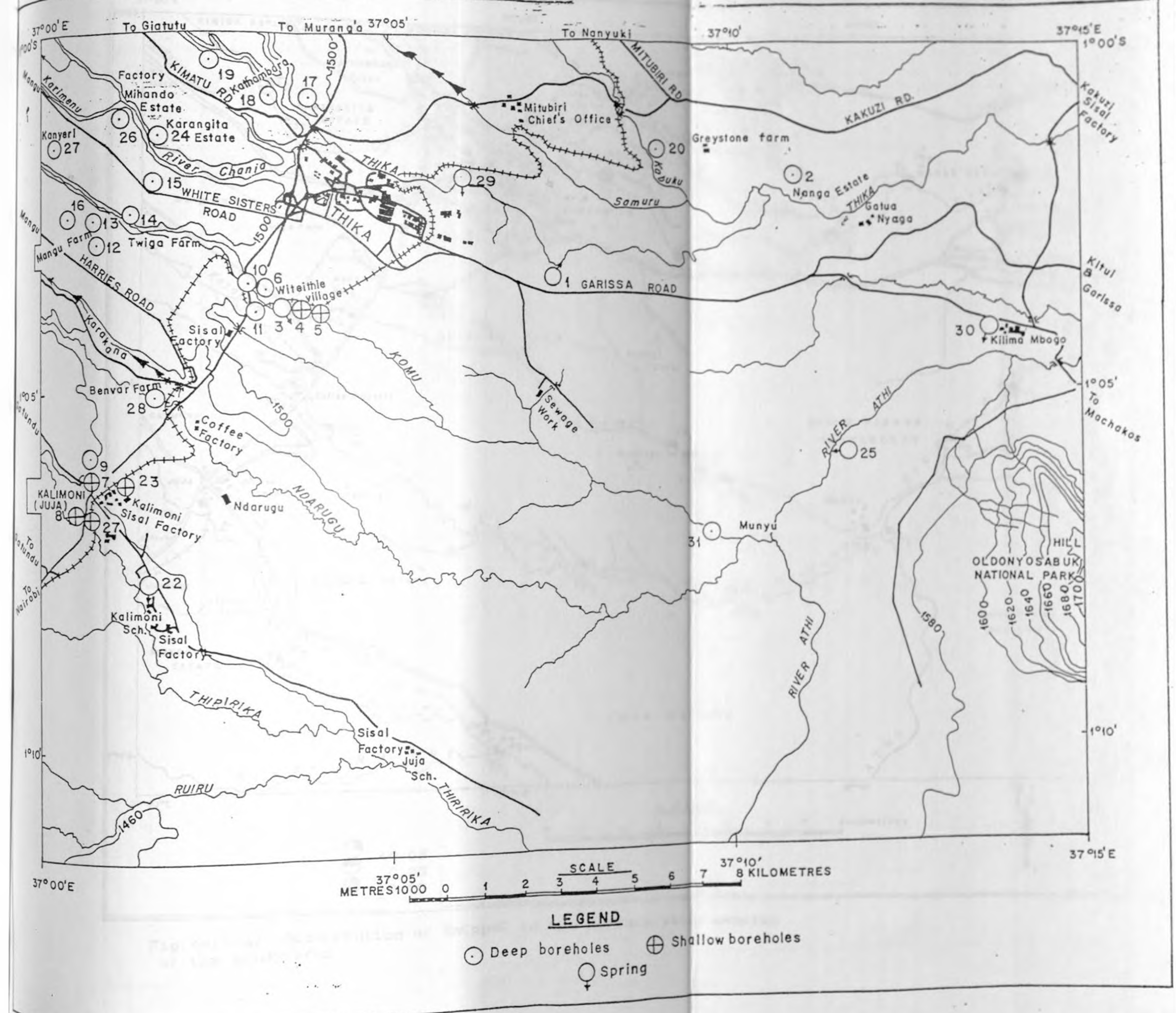


Fig. 3.1(b)
Sample stations for the ground water.

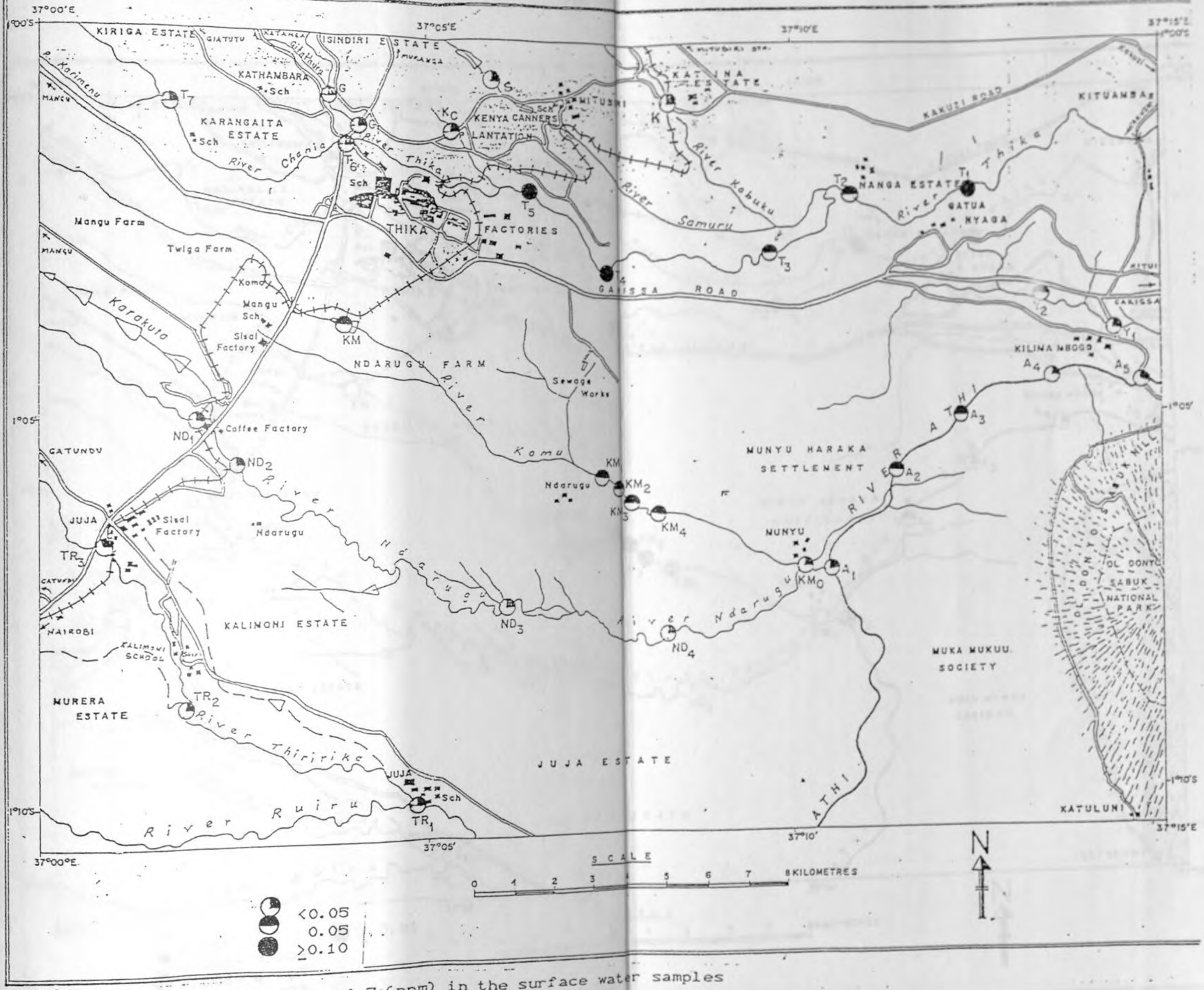


Fig. 4-13(a): Distribution of Zn(ppm) in the surface water samples of the study area

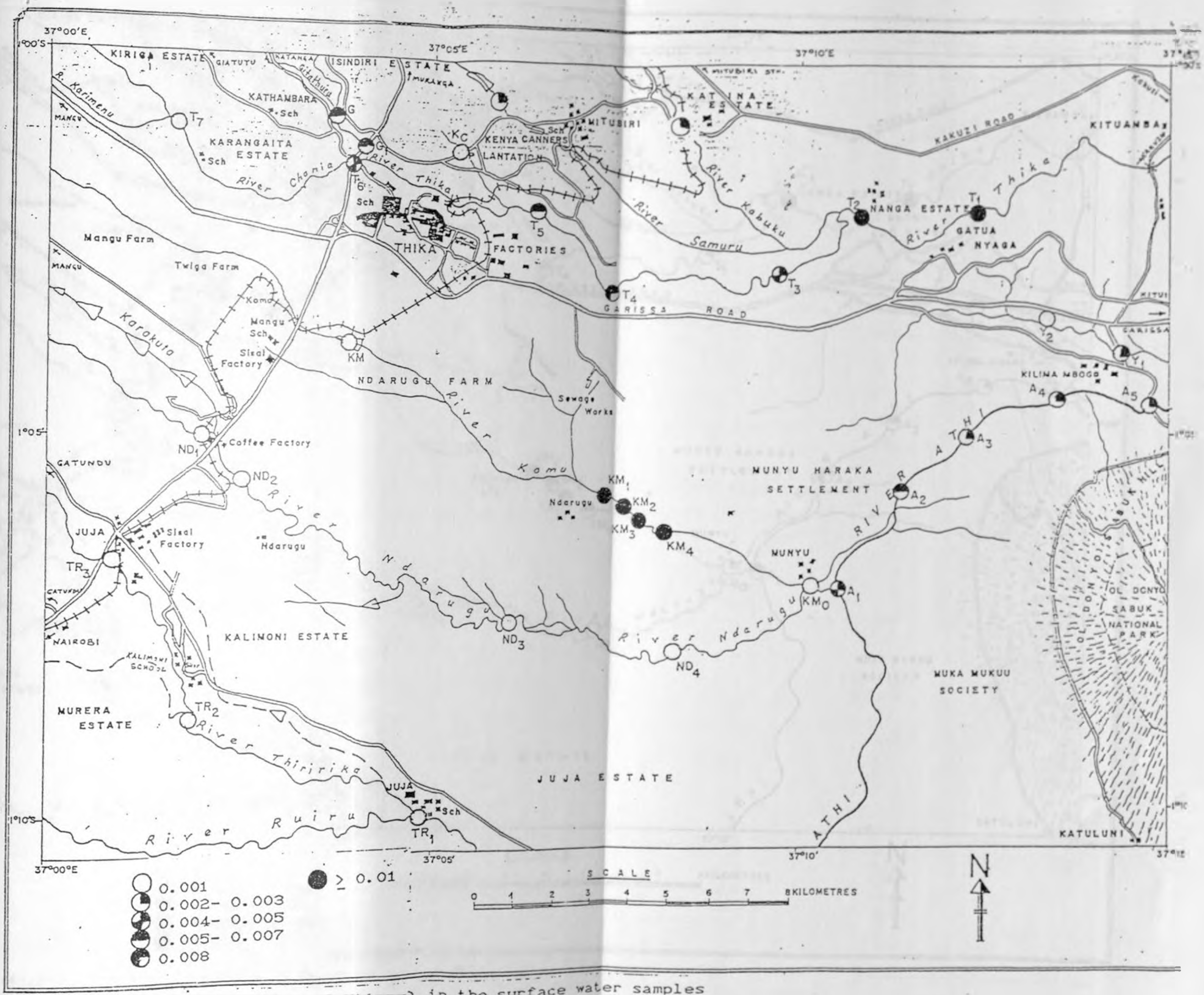


Fig. 4-13 (b): Distribution of Ni(ppm) in the surface water samples of the study area

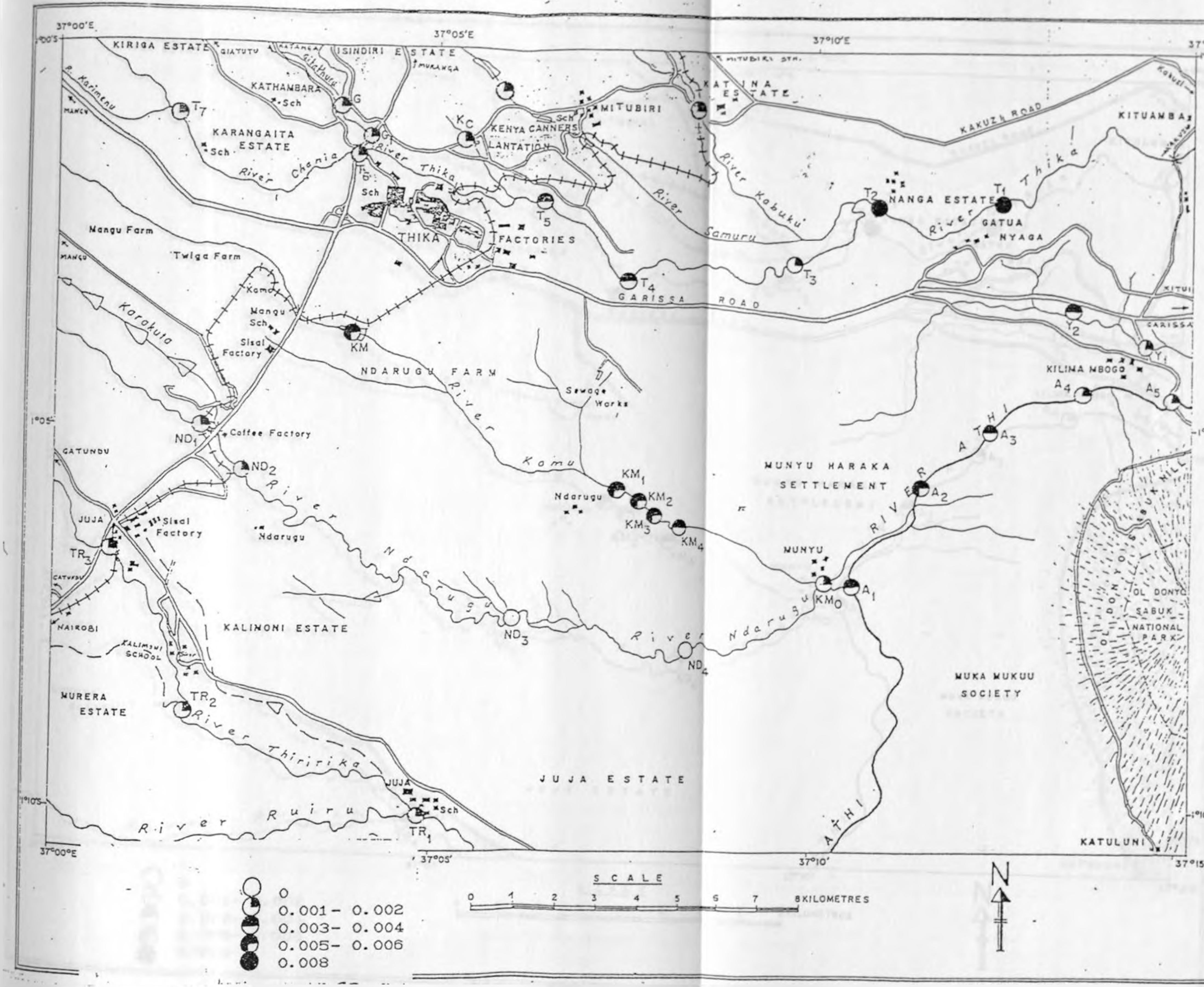


Fig. 4-13(c): Distribution of Co(ppm) in the surface water samples of the study area

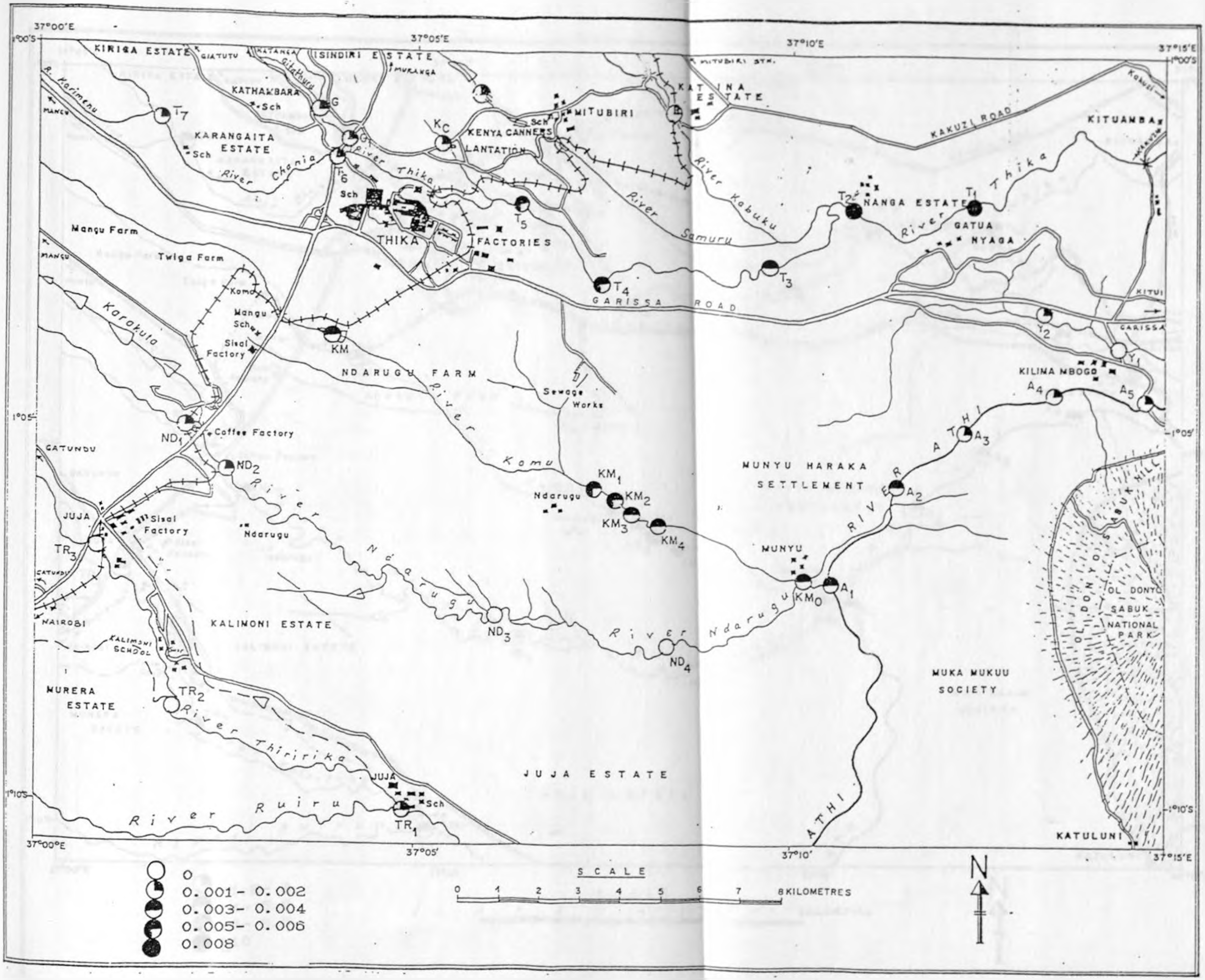


Fig. 4-13(d): Distribution of Cd(ppm) in the surface water samples of the study area

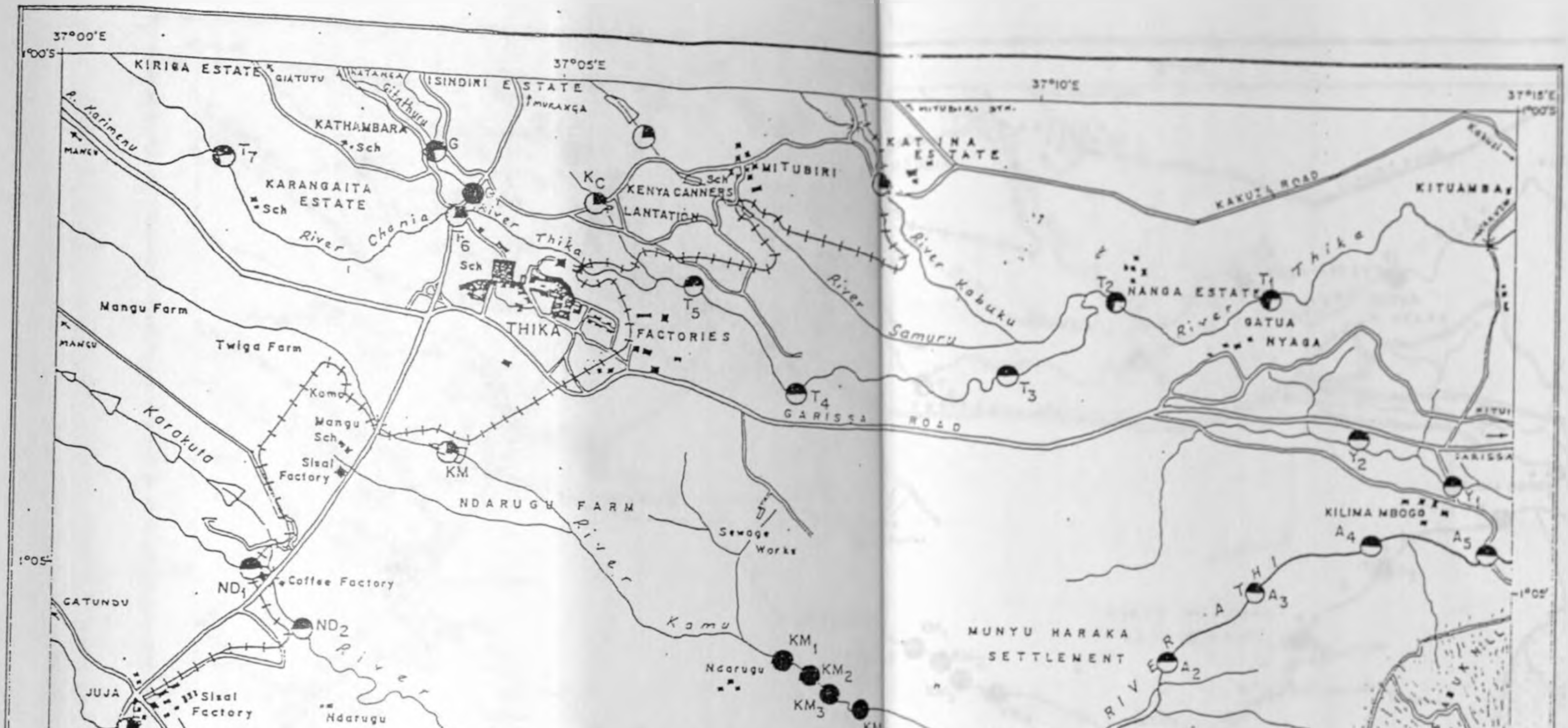


Fig. 4-13(e): Distribution of NO_3^- (ppm) in the surface water samples of the study area

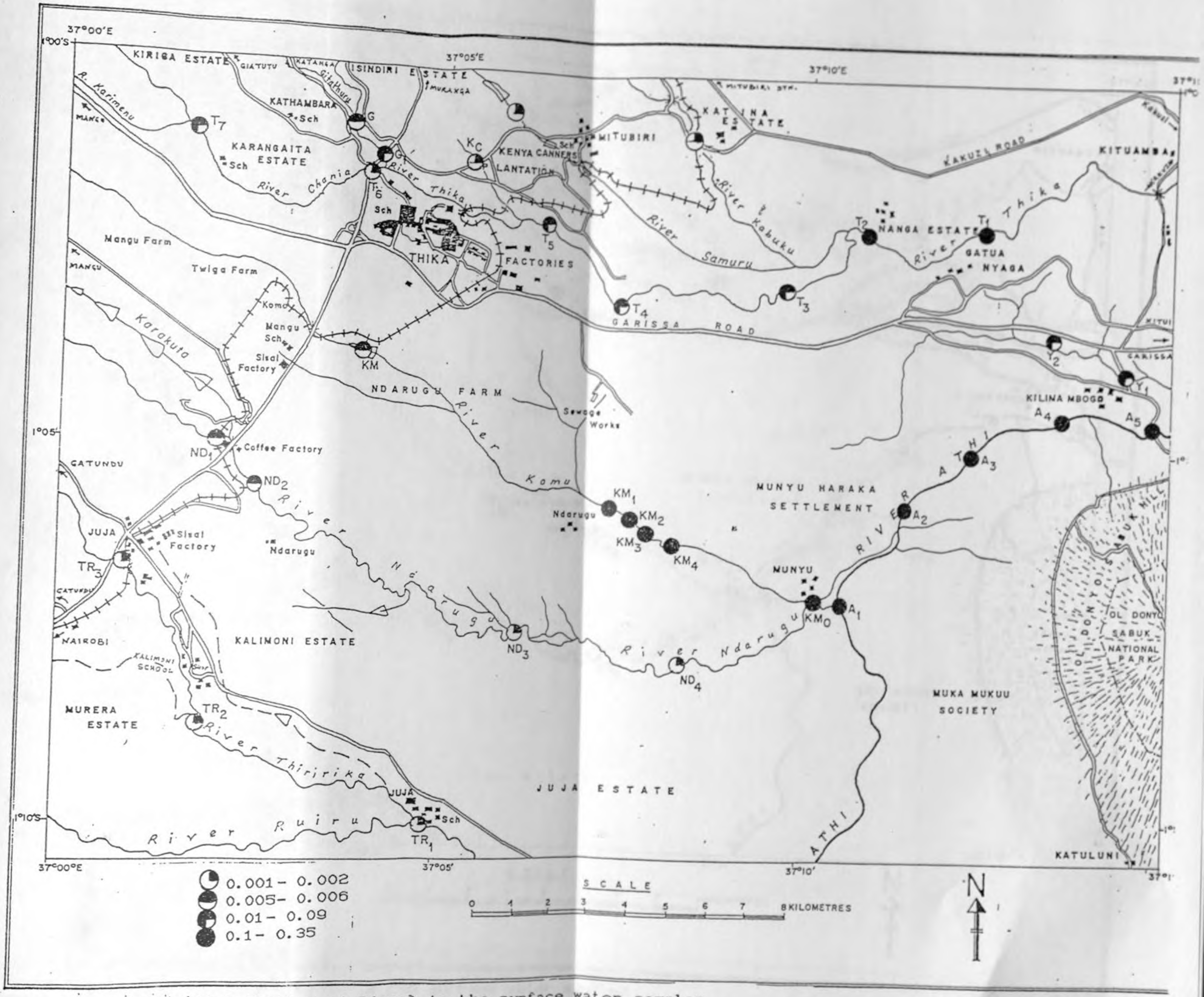


Fig. 4-13(f): Distribution of P(ppm) in the surface water samples of the study area

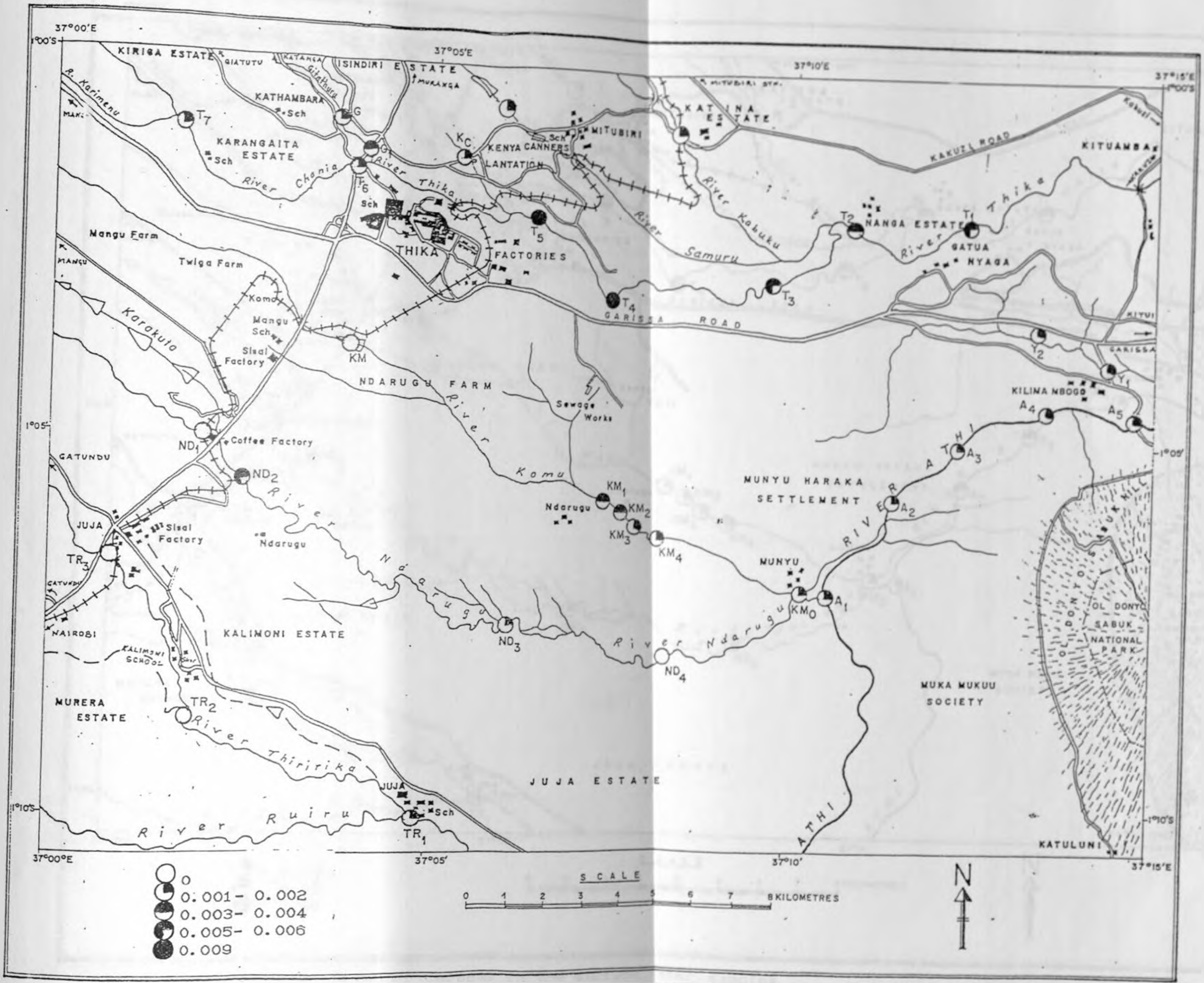


Fig. 4-13 (g): Distribution of Pb(ppm) in the surface water samples of the study area .

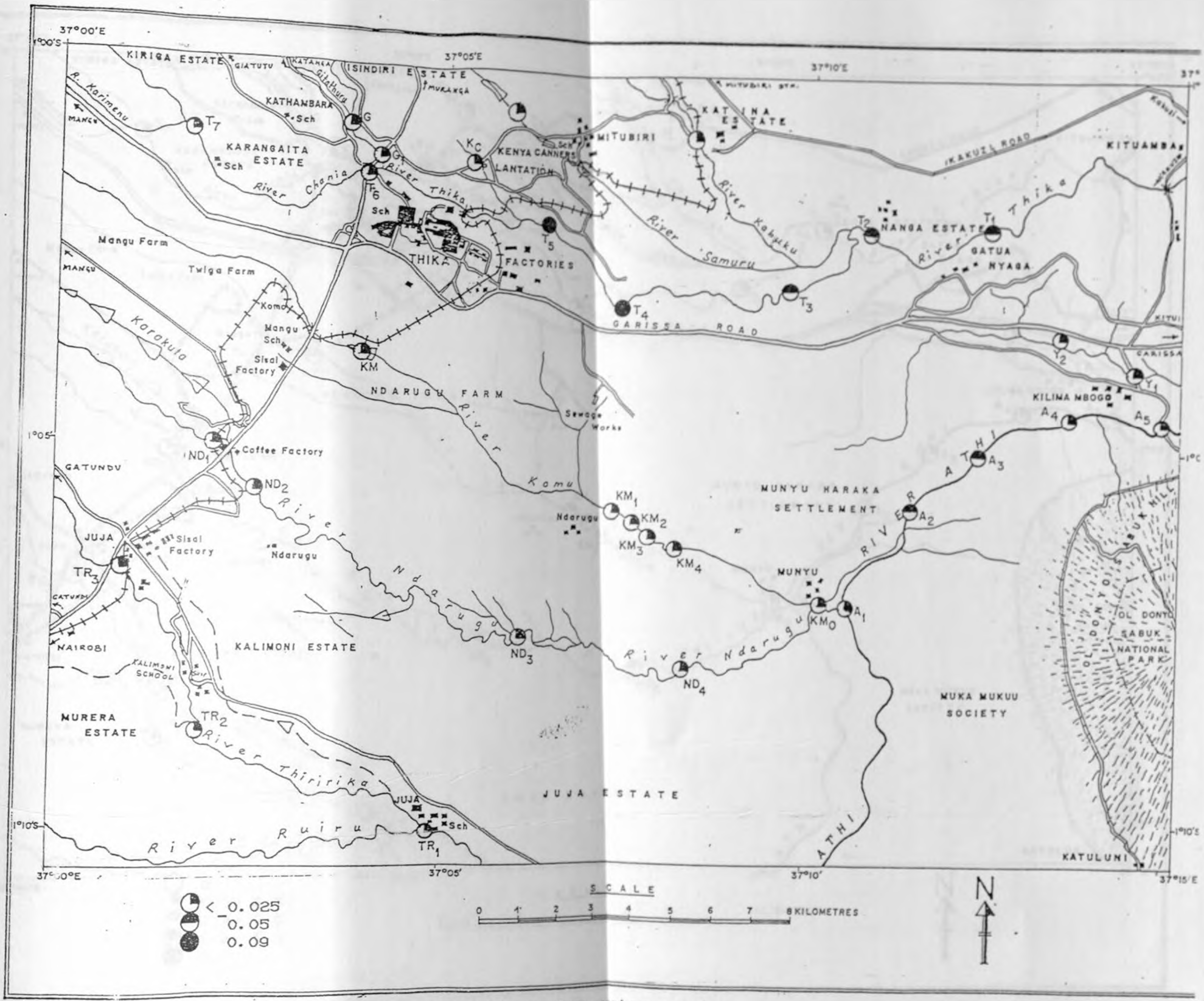


Fig. 4-13(h): Distribution of Cu(ppm) in the surface water samples of the study area

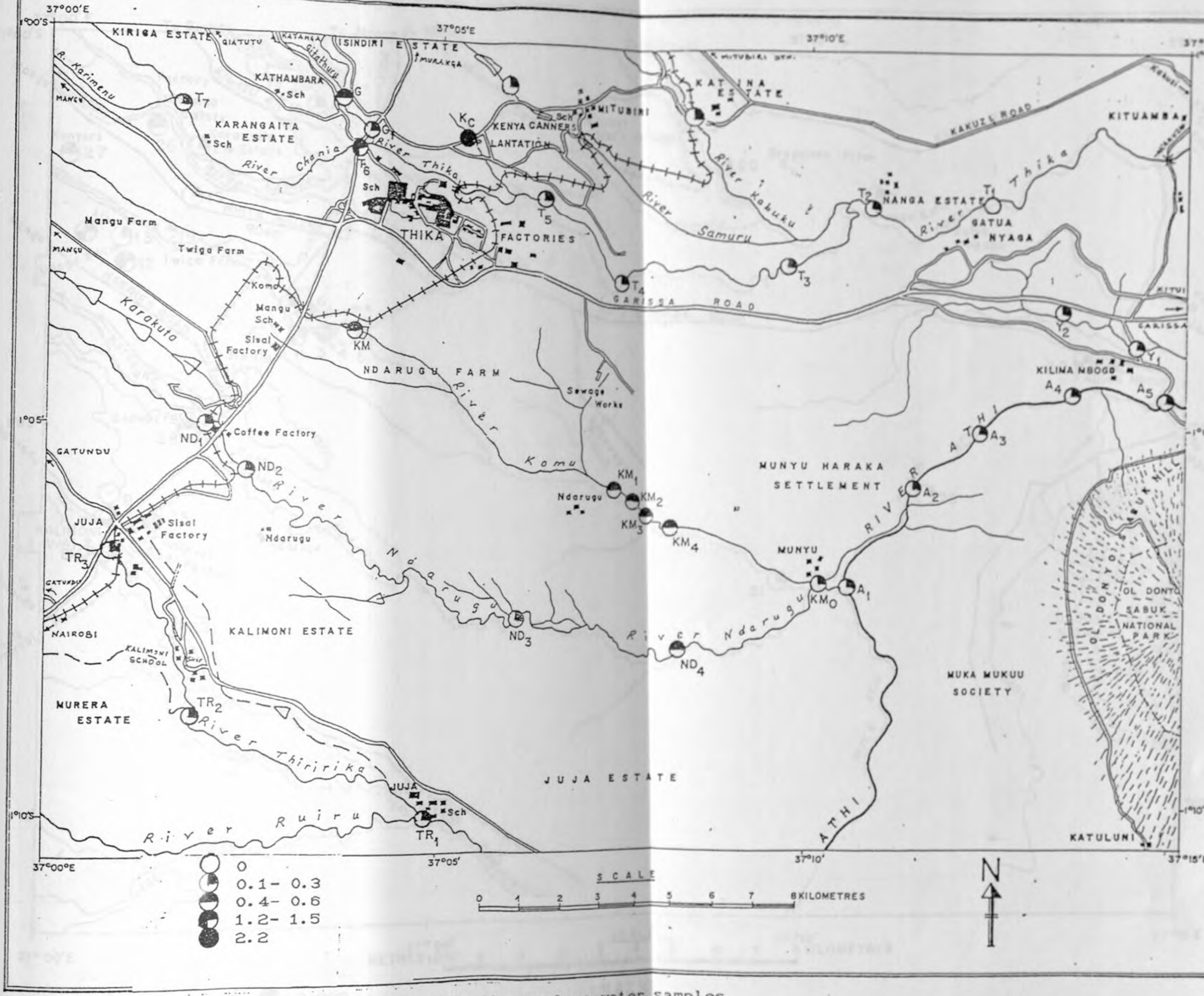
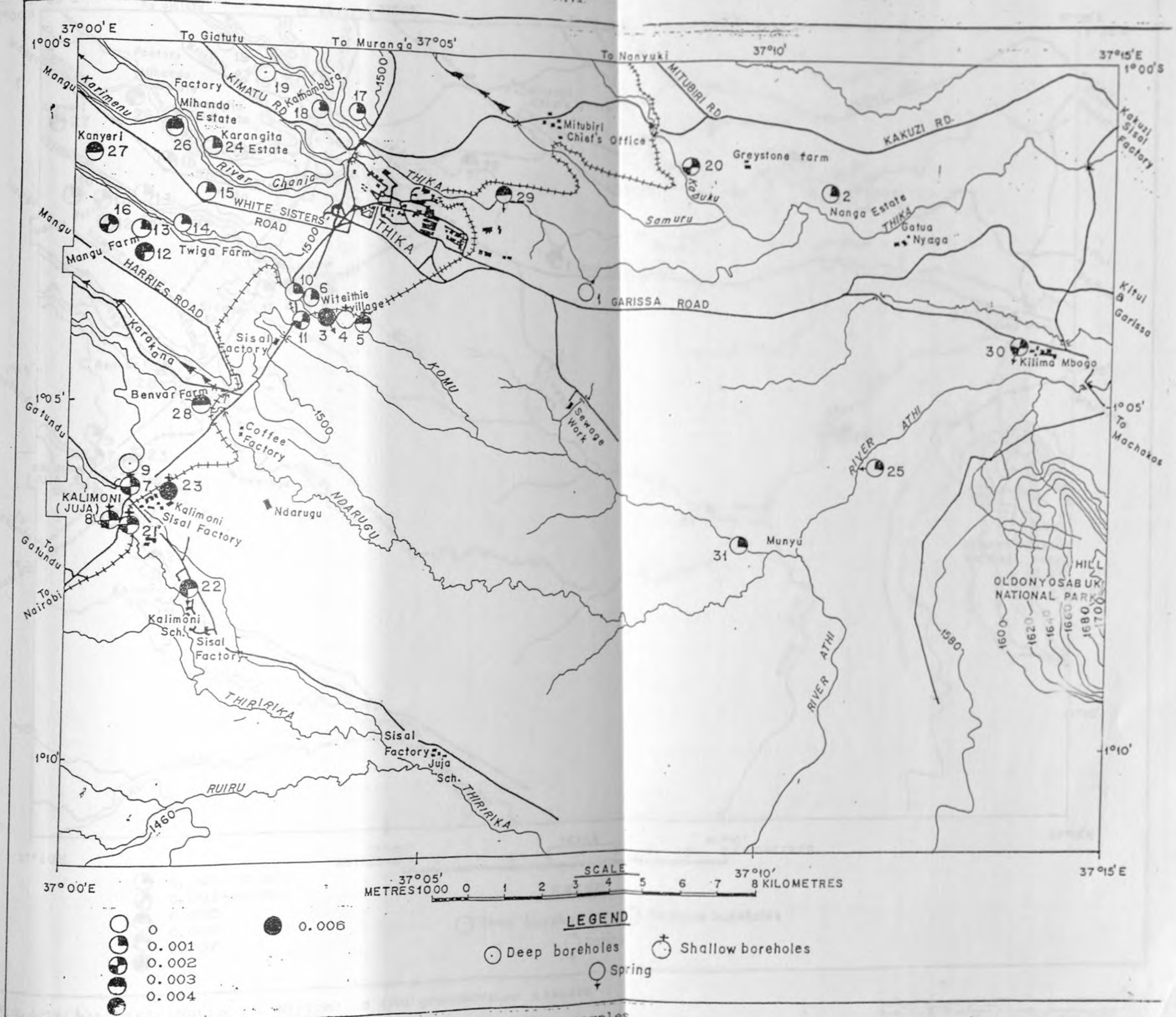


Fig. 4-13 (i): Distribution of Al(ppm) in the surface water samples of the study area



in the groundwater samples

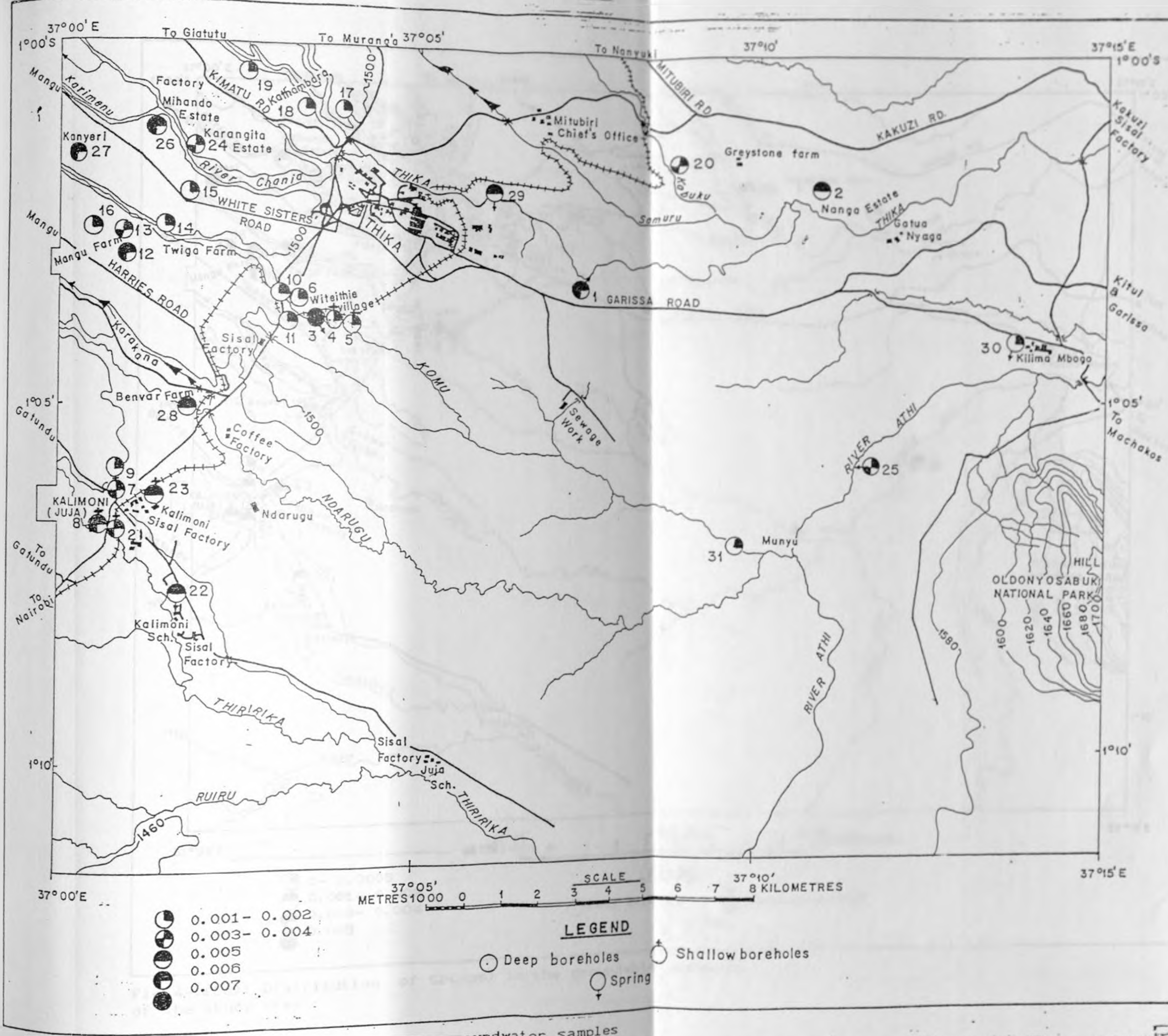


Fig. 4-14(b): Distribution of Ni(ppm) in the groundwater samples

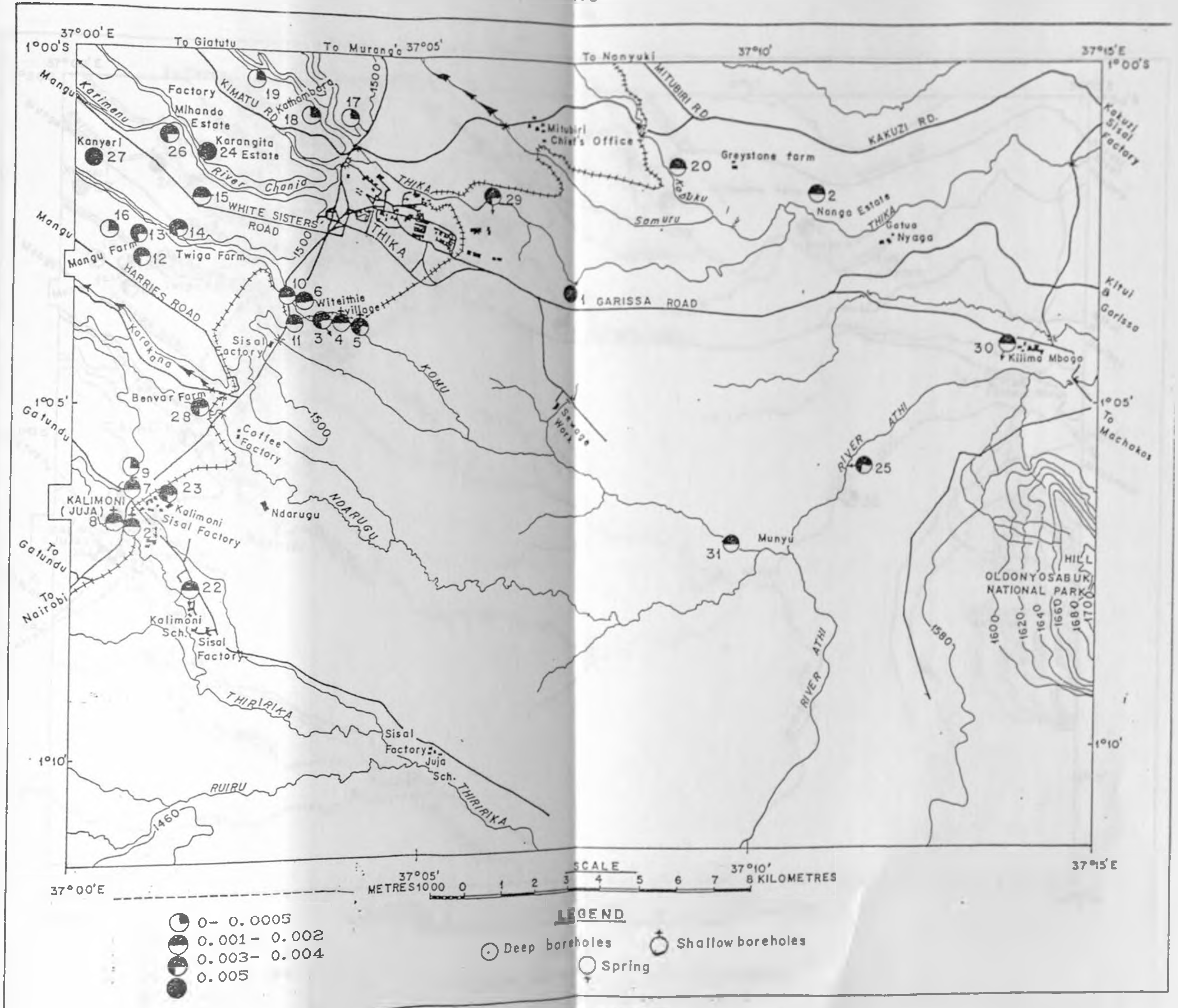


Fig. 4-14(c): Distribution of Co(ppm) in the groundwater samples of the study area

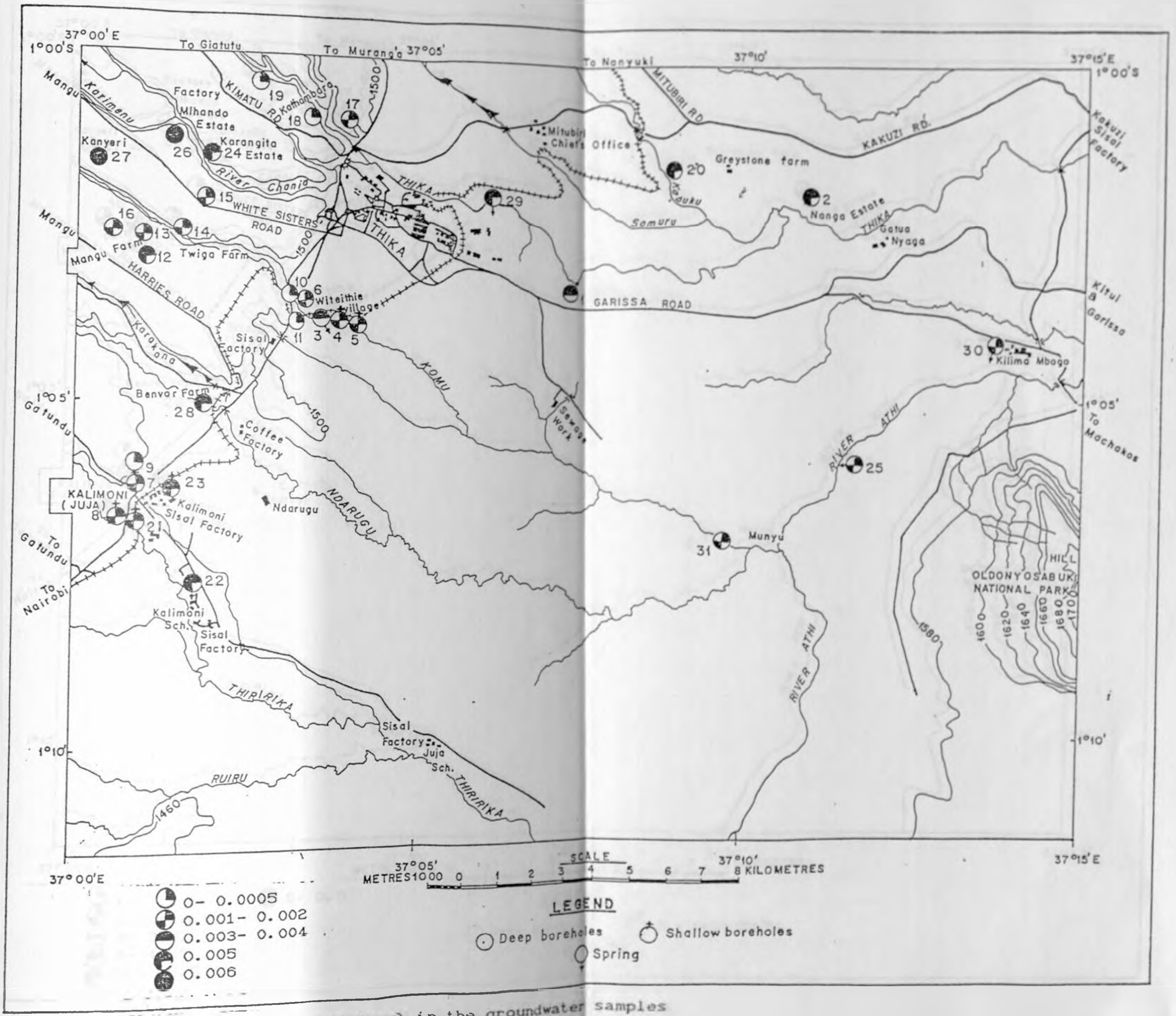


Fig. 4-14(d): Distribution of Cd(ppm) in the groundwater samples of the study area

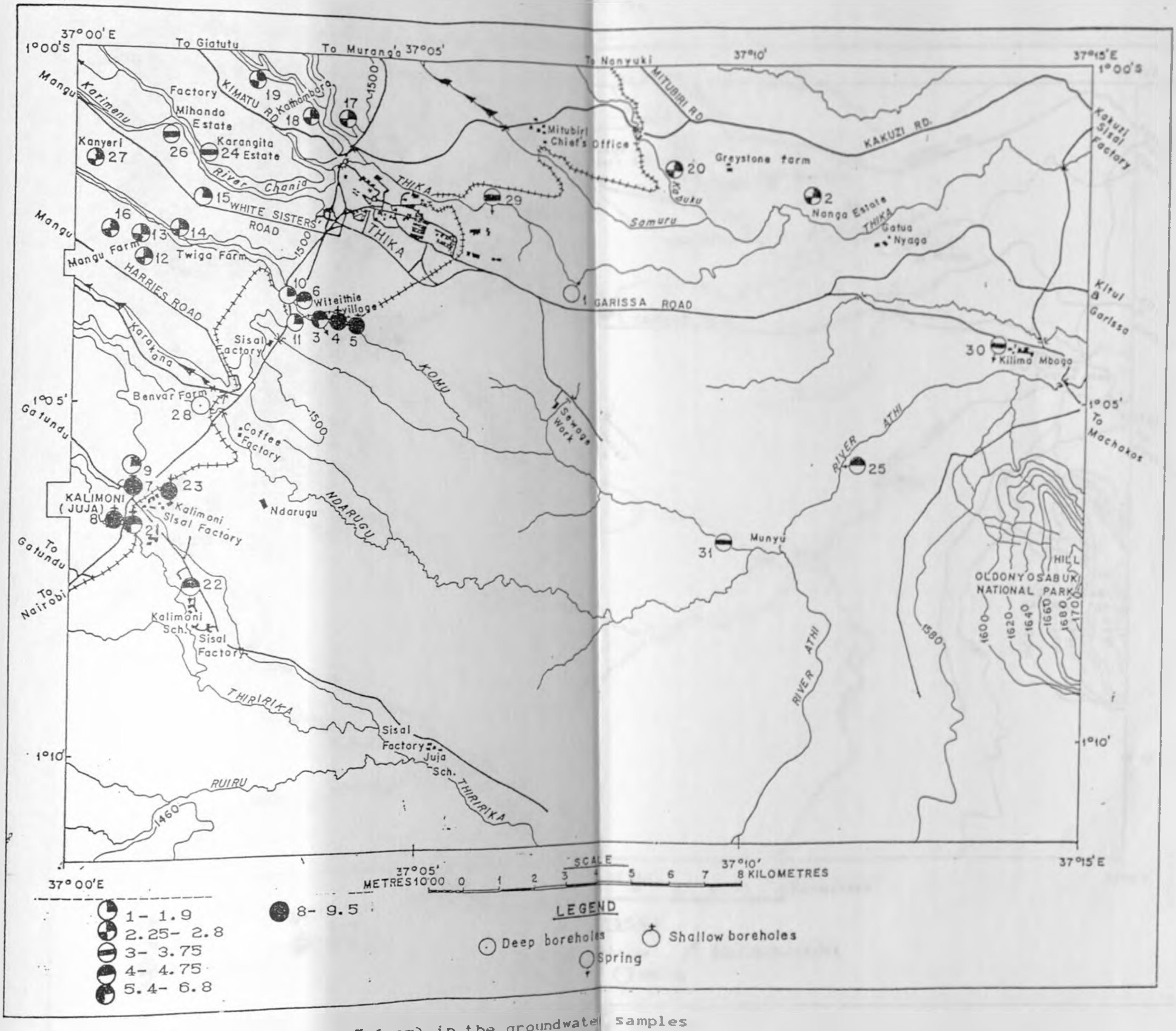


Fig. 4-14(e): Distribution of NO_3^- (ppm) in the groundwater samples of the study area

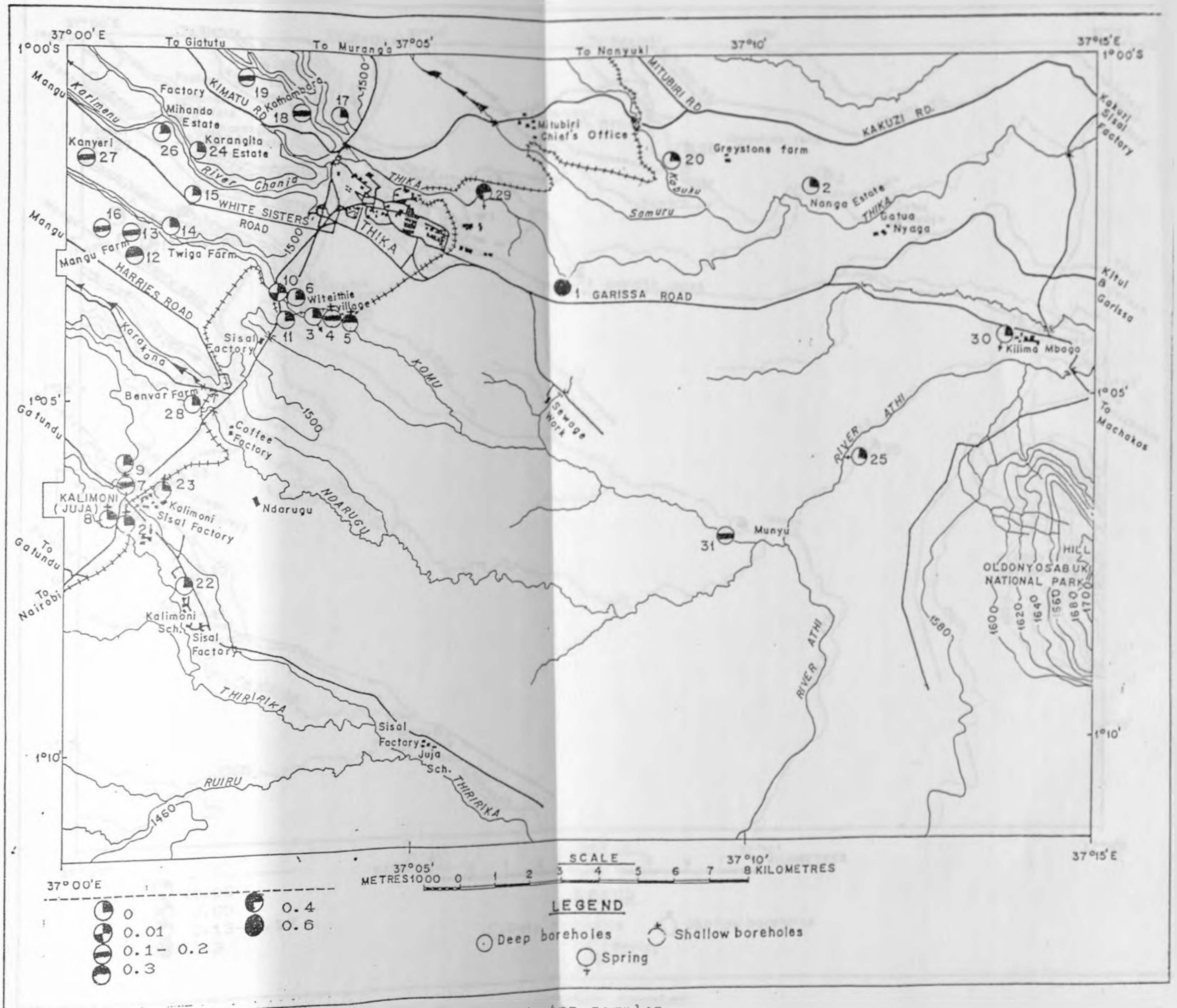


Fig. 4-14(f): Distribution of Al(ppm) in the groundwater samples of the study area

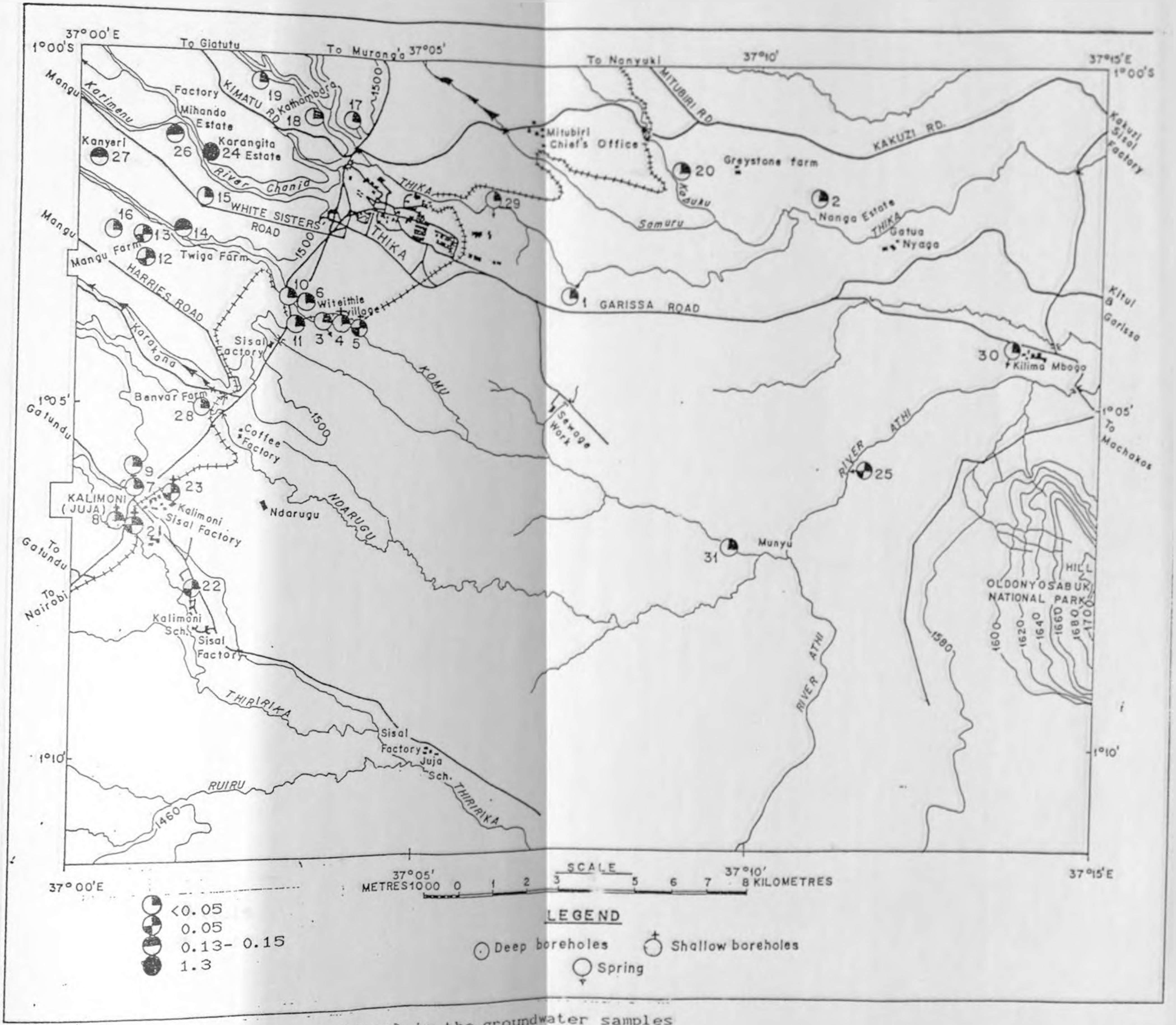


Fig. 4-14(g): Distribution of Zn(ppm) in the groundwater samples of the study area

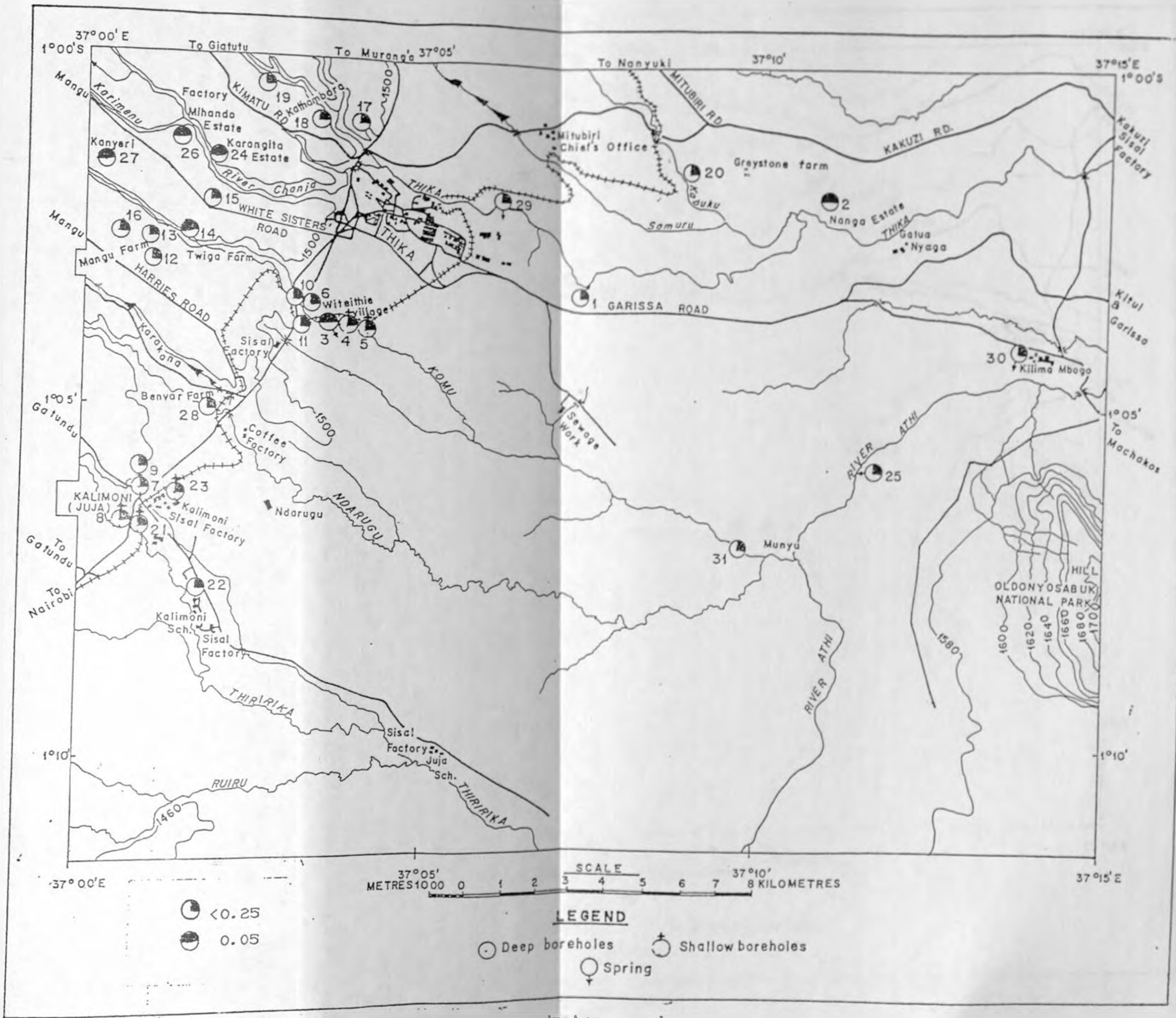


Fig. 4-14(h): Distribution of Cu(ppm) in the groundwater samples of the study area

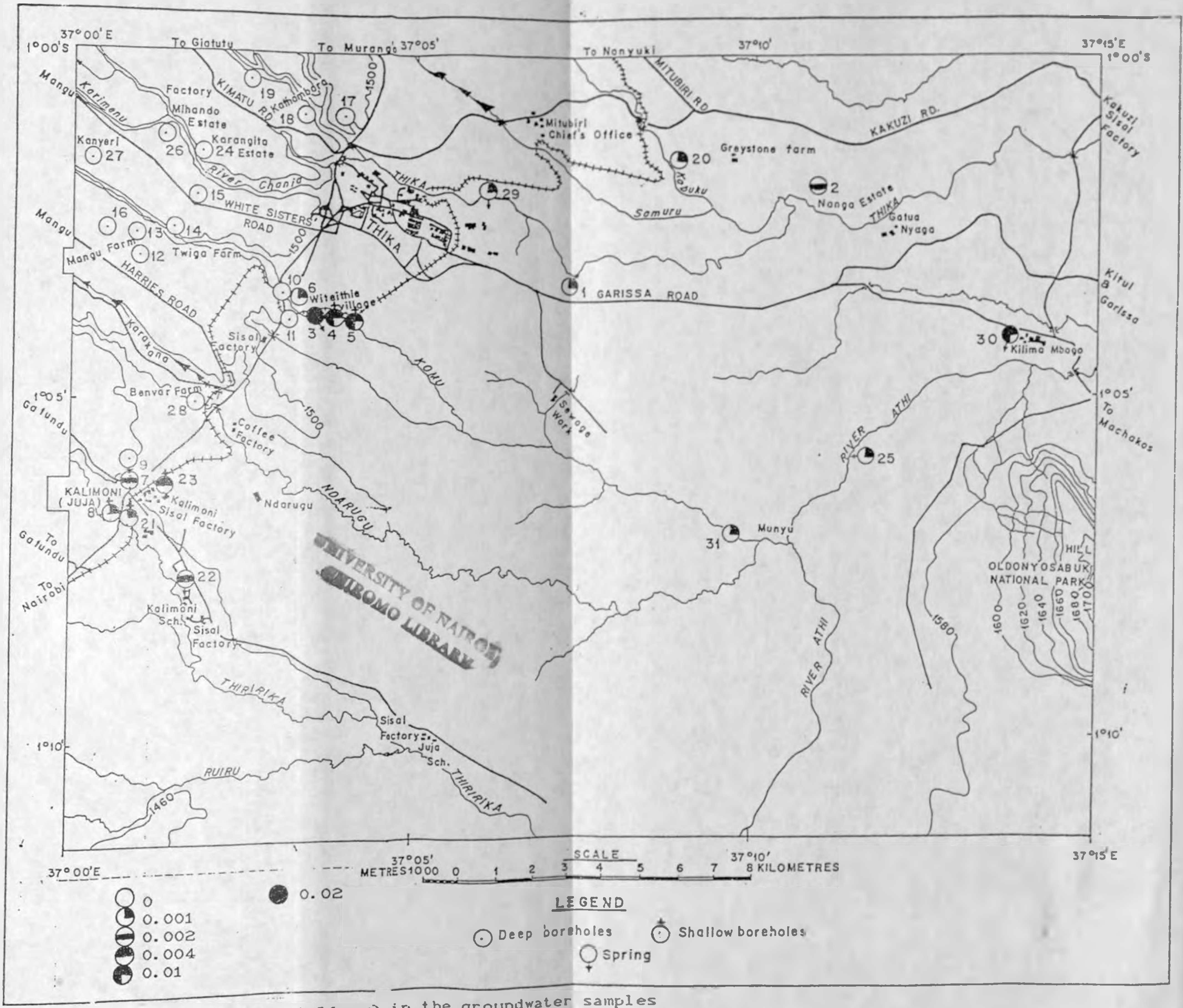


Fig. 4-14(i): Distribution of P(ppm) in the groundwater samples of the study area